TABLE OF CONTENTS

1 INTRODUCTION

Dredge fisheries face stock and environmental management pressures. Size and species selectivity and non-catch incidental mortality are important issues concerned with technical measures. Environmental issues are likely to become increasingly influential, in particular in relation to seabed degradation since many dredge fisheries take place in coastal waters, which are managed increasingly in terms of multiple resource use.

This project aims to study interactions between shellfish dredges, affected species and the marine environment. The work will be orientated towards the goals of improving selectivity, understanding and reducing incidental mortality and undesirable environmental effects. Ultimately, the intention is to develop dredge designs and management strategies that reduce environmental impacts.

This review sets the foundations of the project in context, and has four main themes:

1. A description of the ecology and population dynamics of the main resource species.

2. A catalogue of dredge designs, operating practices and fisheries, and a description of common themes concerned with dredge design, operation and resource management.

3. A review of the current state of knowledge of environmental impacts of dredge fisheries.

4. A review of relevant selectivity studies, and a discussion of how an understanding of dredge design and bivalve behaviour may aid selectivity research.

The dredge fisheries studied are those in each of the participant's regions. Emphasis is placed on scallop fisheries in Northern Europe and clam fisheries in the Adriatic and Portugal. Where information is available, the scope of the review covers all dredge fisheries in the countries of the participants in outline.

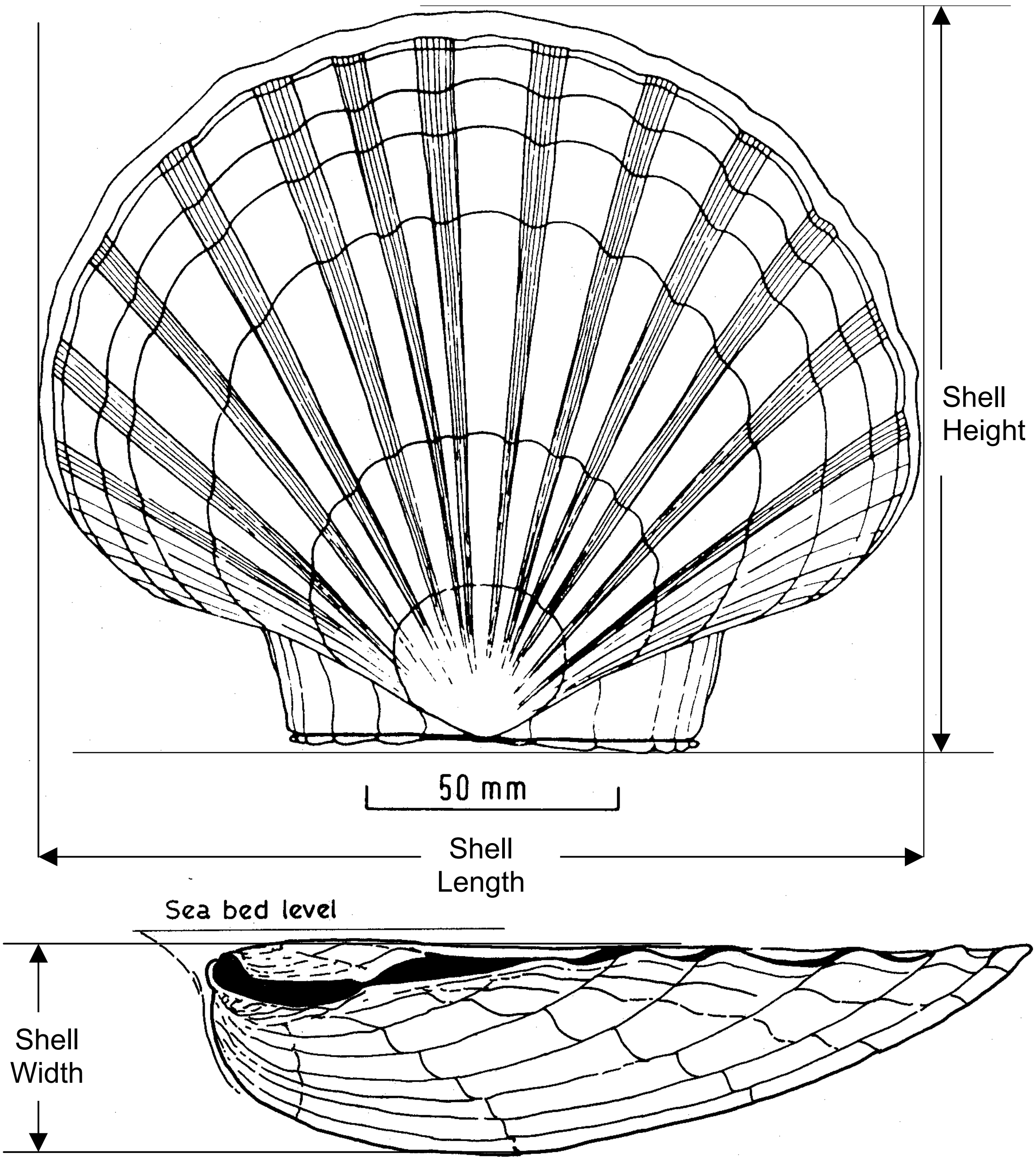


Figure 1-1 ***Pecten maximus*** **Left valve and orientation within sea-bed showing shell height, length and width dimensions (after Rolfe 1973).**

2 ECOLOGY AND POPULATION DYNAMICS

This section of the report describes known features of the ecology, lifecycle, and population dynamics of the main species studied in this project. The main effects of dredging on growth and mortality are described, where known. Where the information is available, important features of the habitat are described.

2.1 *Pecten maximus*

P. maximus is a bivalve mollusc in which the left valve is flat and the right valve is convex. The animal's normal behaviour is to recess into the substrate so that the left (upper) valve is more or less level with the substrate surface (Figure 1-1). Large scallops recess more deeply than small scallops. The animal is able to move using water-jets produced by contraction of the adductor muscle; two modes of movement have been described (Mason 1983). The animal swims using water jets ejected out around the dorsal ears of the shell, thus the animal swims with the ventral margin foremost. For 'jumping', the animal ejects water out of the ventral side of the shell, resulting in locomotion with the hinge foremost.

2.1.1 Habitat

Sea bed and hydrographic conditions: English Channel

The ecological niche of *P. maximus* is influenced greatly by depth, substrate composition and hydrodynamic energy input into the seabed due to tidal streams and wave action. In the English Channel dredge fisheries for *P. maximus* operate over identifiable grounds that occur, typically, at depths of 20-70m (>100m south-east the Isles of Scilly) (Dare et al. 1994). The grounds are characterised by low hydrodynamic bottom stress levels of 4-5 dynes per square centimetre (Figure 2-1), and substrates of mainly sand, shell and gravel, though some of the most productive grounds are on patches of sand amongst rocky and very stony substrate along the Brittany and Cornish coasts (Figure 2-1).

Sediment types and macro-benthos: Irish Sea

Bradshaw et al. (2000) describe the seabed communities found on the gravelly sediments that support the scallop fisheries around the Isle of Man. The main characteristic feature of these sediments is the presence of coarse particles, such as stones and shell at the surface. This wide range of sediment grain sizes provides a heterogeneous habitat for sessile organisms such as hydroids, bryozoans and tunicates. Larger stones and their attached epifauna also provide shelter for crabs, nudibranchs and fish, whilst areas of finer gravel are inhabited by burrowing anemones, brittlestars and starfish. It is important to emphasise the level of heterogeneity of the habitat. Changes in sediment type can be very sudden and localised, which increases the range of available niches for a wide range of animals.

2.1.2 Life cycle

Reproduction

P. maximus is a simultaneous hermaphodite, the mature gonad being divided into a proximal testis, which is whitish in colour , and a distal ovary, which is orange-red, with both parts being approximately equal in size. *P. maximus* populations in inlets of Galway Bay, on the west coast of Ireland, display a bimodal peak of spawning in April or May and a more complete spawning in July or early September (Wilson 1987). However, some low level of spawning continues throughout the summer.

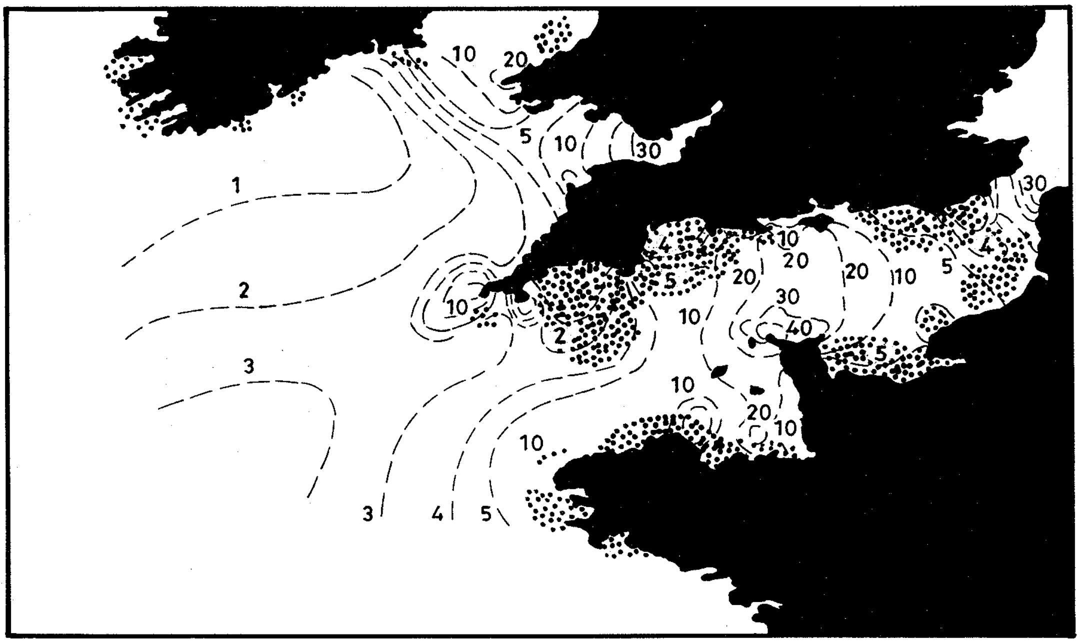


Figure 2-1. The distribution of *P. maximus* fishing grounds in relation to the mean value (dashed contours) of the magnitude of the bottom stress averaged over a tidal cycle in dynes per cm squared (Dare et al. **1994)**

In Manx waters reproduction is a seasonal event; the gonads develop mainly in the winter months, when food availability is low, utilising energy reserves built up during the spring and summer. Scallops spawn for the first time when about two years old (Mason 1958a). Thereafter, adults of most inshore populations have two main peaks of spawning each year, in spring (April-May) and again in autumn (August-September), although in some deeper water populations further offshore, there is no autumn spawning and the seasonal cycle of build-up and depletion of energy reserves proceeds 1-3 months earlier (Wanninayake 1994). Spawning itself is timed to occur when environmental conditions are generally favourable for larval growth and survival.

Spawning

At spawning, the gametes are released into the water and fertilisation occurs externally through the random contact of eggs and sperm. Although scallops are hermaphrodite, the eggs and sperm are released separately, so cross-fertilisation must be the general rule (Mason 1983). The chances of successful fertilisation will be greatly increased by the synchronous release of eggs and sperm by closely-located individuals and various mechanisms have been described which ensure that scallops on the same fishing ground tend to spawn at the same time.

The mechanisms triggering synchronised spawning are complex and involve responses to environmental factors such as the phase of the lunar cycle (Amirthalingam 1928; Tang 1941; Mason 1958b), high or rising temperature and food levels, and the presence of scallop gametes in the water (Barber and Blake 1991). Unlike the control of growth, genetic factors play a significant role in controlling the spawning cycle (Ansell et al. 1991).

Figure 2-2. Substrate composition of grounds over which *P. maximus* dredging occurs. After Dare et al. (1994).

In French waters, different spawning strategies appear in different populations. In the Normand-Breton Gulf a single spawning takes place between July and September with a more probable period between mid-July and August. Spawning appears to be stimulated by the temperature reaching 16°C. There is a large decrease in the gonadosomatic index at this time, and recruitment occurs over a very short period. In contrast, scallops in the Bay of Brest and Bay of Seine spawn over a longer period, from April to August. These are considered to be adaptations to the productivity regimes in these areas

In their natural distribution on the seabed, scallops occur in high density patches (Brand 1991) and this must aid successful fertilisation. Fishing disturbs the natural spatial distribution of scallops on the seabed and can greatly reduce the success of fertilisation by increasing the distances between adjacent scallops. There is thus very serious concern that the reproductive output of the north Irish Sea scallop populations may be declining to such low levels that recruitment might not be maintained.

Under hatchery conditions, there is between 10 and 30 minutes between the release of eggs and sperm. Larvae develop in the plankton for 3–4 weeks depending on the temperature and attach usually to bryozoans and hydroids at metamorphosis. The newly settled spat retains the ability to secrete, break and reform bysuss thread, which like mussels, enable the juvenile scallop to attach to substrates until it reaches approximately 15mm in size. Up until this stage, the juvenile scallop remains attached to rhodophytes (red algae) (Mason 1957; Le Pennec 1974)), phaeophytes (brown algae) (Elmhirst 1945; Mason 1958a; Minchin 1981)), encrusting organisms, hydroids (Round et al. 1961; Eggleston 1962a; Dare and Bannister 1987; Minchin 1992a), bryozoans (Eggleston 1962a; Brand et al. 1980)), tubiculous annelids (Eggleston 1962a) and shell gravels (Le Pennec 1974).

2.1.3 Spawning and settlement of *P. maximus* in Mulroy Bay.

Mulroy Bay is a marine lough system on the north coast of Ireland connected to the open sea by a series of long narrow channels. The tidal range within the lough is diminished as a result. The lough is well sheltered from excessive exposure and no oceanic swells are able to penetrate to the two main parts of the lough. The seawater enters through the narrows into the Broadwater, and the Moross channel enables seawater to penetrate into a further sea lough, the North Water, which is approximately 1km by 3km in extent (Minchin 1981). The bathymetry of the North Water is not fully known. Admiralty charts refer to depths of 51 metres, but as the soundings are spread far apart, much of the topographical detail has been lost.

Surveys of Mulroy Bay by the Fisheries Research Centre in Ireland revealed that large numbers of adult scallops were present around the perimeter of the North Water (Minchin 1981). These adult scallops were thought to be capable of producing large numbers of larvae, which at the time of settlement might be trapped onto collectors to provide spat for cultivation or for reseeding scallop beds

Analysis of annual growth rings of adult scallops showed that settlement had occurred every year since 1967. In 1983, the Fisheries Research Centre undertook a similar study and although the scallop settlement intensity had decreased since 1979, production of spat for over-wintering had increased to over a million. Settlement from year-to-year in Mulroy Bay is very variable (Burnell and Slater 1989; Slater 1995), and the absence of spat settlement between 1983 and 1985 has been attributed to TBT contamination (Minchin et al. 1987).

In 1997 and 1998, spat settled out of the plankton at a shell height of 190 - 220µm from late July to 9th August. The greatest density was 1390 spat per metre of 12mm diameter blue polypropylene rope. Mean growth rates of spat from August to mid October ranged from 196.9µm day^{-1} falling to 17.5µm day^{-1} from mid October to December.

In recent years, scallop divers have severely depleted the brood-stock in the North and Broadwater. Spawning is often not synchronised which means that the number of larvae does not reach a critical density for commercial settlement. Induced spawning may help this situation. Scallops held in lantern nets in deep water bays have been induced to spawn by raising them into warmer waters near the sea surface in June and July (Minchin 1992b). In 1997, North West Shellfish Co., Ireland, transferred 150,000 – 200,000 ear-hung scallops from the Broadwater to the North Water in Mulroy Bay in mid-June. Scallops removed from the Broadwater were exposed to air during the transfer period to the North Water and this resulted in a mass spawning in mid-June. The physical shock of exposure to air during the transfer period is thought to have caused a mass spawning that resulted in the mass settlement of scallop spat observed in July. It is hoped to improve future spat settlement in the bay by inducing spawning and hence improving fertilisation rates.

Spat distribution

Very little is known about spat behaviour and distribution since they are difficult to locate once they detach the byssus. *Pecten maximus* generally lose the byssus soon after metamorphosis and few larger than 15 mm shell length are found attached (Eggleston 1962b; Mason 1969; Minchin 1978; Franklin et al. 1980; Mason 1983; Minchin 1992a). Recessing in soft substrates begins quite early; spat as small as 6-10 mm shell length have been seen to recess (Minchin 1992a). Baird and Gibson (1956) suggested that, on detachment, juvenile scallops moved to ‘feeder beds’ offshore but they provided little evidence to support this hypothesis. Minchin (1992a) made observations on young scallops in Irish waters by SCUBA, and restricted these observations to scallops that had not laid down their first annular ring. The main study areas are indicated in Figure 2-3. Spat were found from June to November, and from close to the surface to depths of 43m. No spat were observed during dives carried out between December and May, a time of the year when visibility is poor. Spat were found to have localised concentrations and were normally seen attached to algae in shallow water at Lough Hyne, Dunmanus and Bantry Bays during August.

From late August to November, spat were found free. Spat attached to a wide range of organisms and materials, without any apparent preference. However, surfaces were generally free of silt and included algae, invertebrate tests and inorganic materials. These attachment sites probably represent those selected at metamorphosis. In general, in shallow and sheltered bays, settlement took place near adult populations.

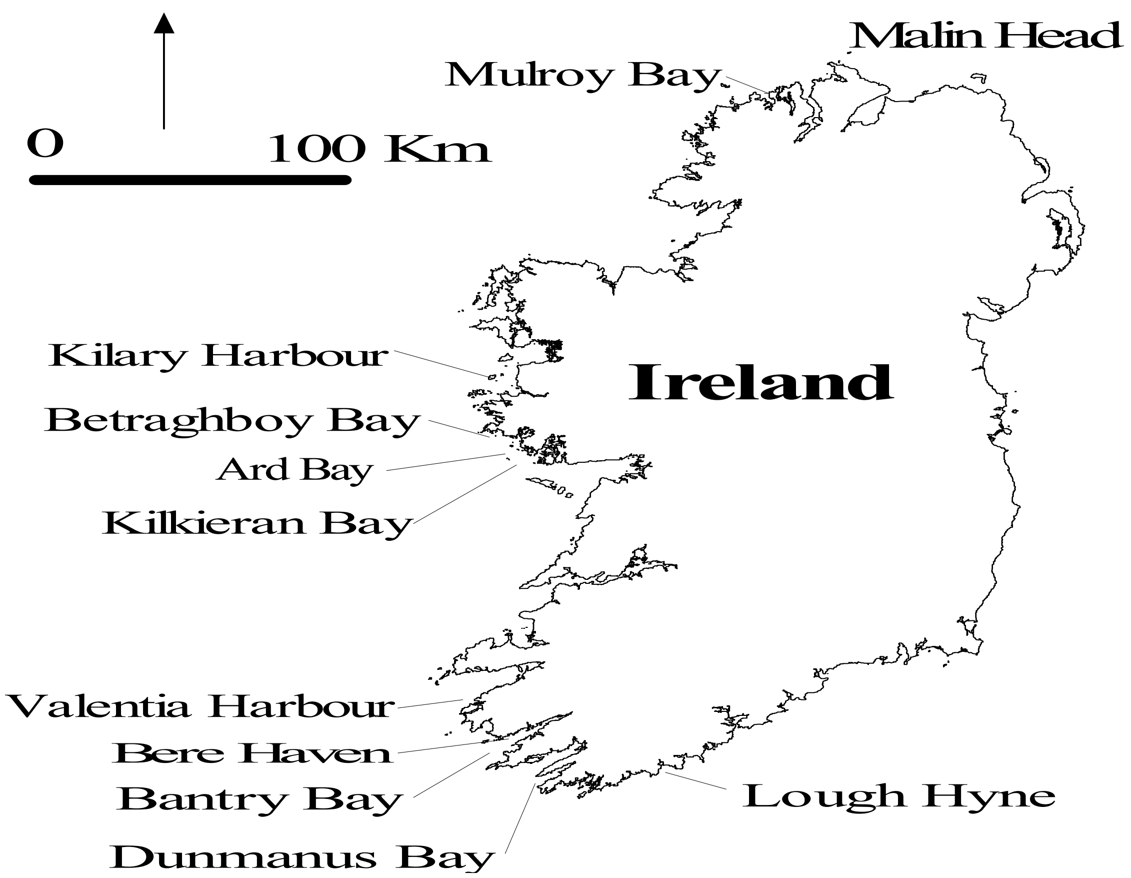


Figure 2-3 Distribution of study areas for juvenile scallops (*P.maximus*) around the Irish Coast (adapted from Minchin (1992a))

Detachment could take place amongst individuals of 1mm but in sheltered bays most individuals remained attached until 4–13mm. Following detachment, scallops recessed into the sediment, and were capable of doing so when at a size of between 6–10mm. Spat were subject to dispersal by water turbulence, and swimming was induced by starfish. Evidence was presented to suggest that predation from crabs and starfish occurred during summer and autumn. Growth is rapid in the first two seasons and gonad development usually begins after the second growth ring has been laid down. Minchin (1992a) suggested that scallop spat disperse from settlement areas to scallop fishing areas as shown in Figure 2-4.

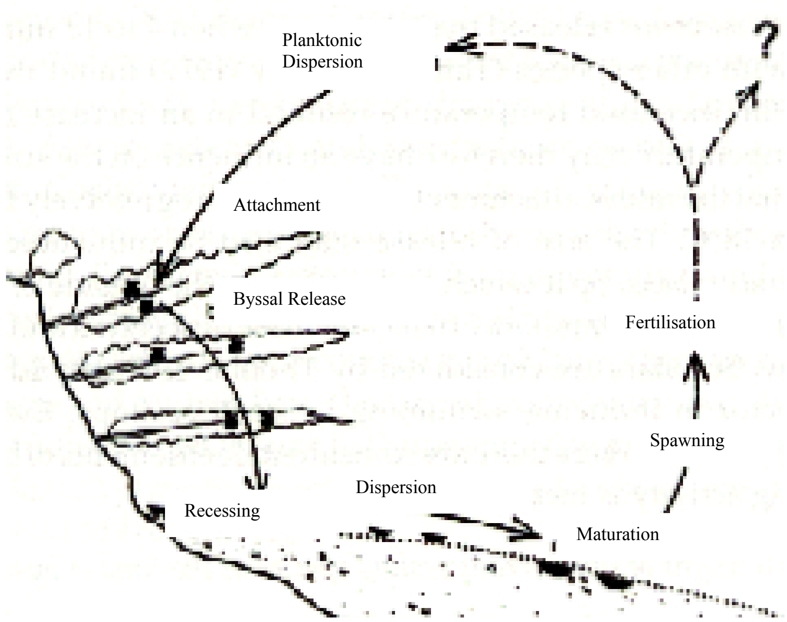


Figure 2-4 Diagrammatic representation of the distribution of different scallop (*P.maximus*) stages (from Minchin 1992a)

Maerl beds

It has been suggested that, in some areas, maerl beds may be of importance as settlement and nursery areas for scallops (Hall-Spencer 1998). Maerl beds consist of areas of living calcareous red algae (predominantly *Lithothamnion coralliodes* and *Phymatolithon calcareum*), which contain a diverse fauna and flora, and are usually situated in productive areas at the mouths of sea lochs. These areas contain large numbers of hydroids, bryozoans and other encrusting organisms, living on the maerl, which could be used for attachment by settling scallops. Large numbers of juvenile scallops of about 10mm have been found on maerl beds.

2.1.4 Growth

Irish Sea

In the north Irish Sea the normal life-span of *P. maximus,* in the absence of fishing, is probably some 15-20 years (Mason 1957). Growth is strongly seasonal and most north Irish Sea populations can be easily aged by counting the rings laid down on the shell (Mason 1957; Allison et al. 1994). The growth pattern of scallops, in terms of both shell length and meat yield, generally conforms to the von Bertalanffy growth formula (Murphy 1986; Allison 1993). The growth rates of scallops on different fishing grounds around the Isle of Man have been compared from growth curves of mean length or weight-for-age (Mason 1957; Gruffydd 1974b), from the parameters of the von Bertalanffy growth formula (Murphy 1986; Allison 1993). or from growth performance indices derived from these parameters (Allison 1993). Growth rates of scallops are generally highest on the inshore grounds off the west and north-east coasts of the Isle of Man, such as the Targets, Bradda Inshore, The Chickens and Ramsey Bay, with the exception of the Peel Head ground. Growth is lowest on grounds farther offshore to the south and east of the Island, particularly South East Douglas and the H/I Sector. (See Figure 4-13 for locations of grounds.) The differences in growth rate on different grounds have important consequences in the management of the fishery, for growth affects the age at which scallops reach the minimum legal landing size, which can vary from 3-7 years on different grounds

English Channel

Individual growth can be studied by back-calculation of winter rings formed on scallop shells (Franklin and Pickett 1980). The growth rate is high during the first two years after settlement; individual sizes approach an asymptotic level of 110 to 120mm in the Western Channel and Atlantic waters (130 to 140mm in the Eastern Channel).

2.1.5 Recruitment

English Channel

Settlement and subsequent recruitment into fished scallop aggregations is believed to be affected by larval transport, mediated by residual currents. Figure 2-5 suggests recruitment links between the exploited scallop aggregations (Dare et al. 1994). Modelling suggests minimal larval exchange in the western Channel, between the French and English coastal populations, and low larval flow from west to east. It suggests, also, that all east Channel fished aggregations probably depend on down stream drift from exploited populations in the Bay of Seine, and that east Channel stock larvae drift into the southern North Sea. This implies that conservation of the Bay of Seine stock could be an important for recruitment into the East Channel fishery.

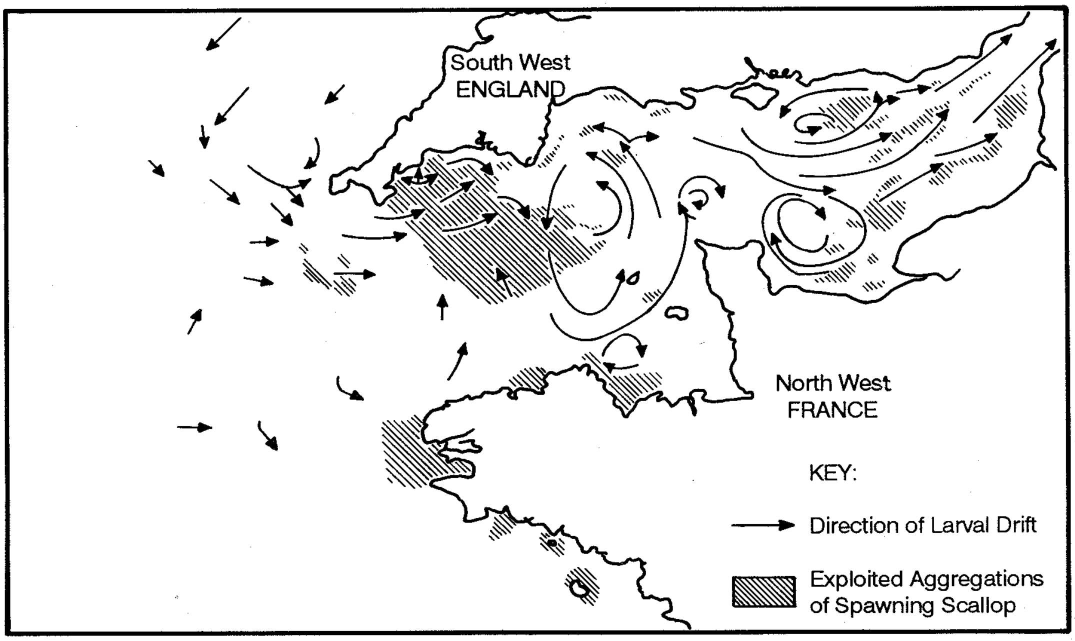


Figure 2-5 Synoptic map showing the average annual pattern of scallop larval transport in the English Channel and Celtic sea predicted by NORSWAP hydrographic model simulations of particle dispersal. Exploited aggregations of scallops are denoted by diagonal shading (from Dare, *et al.*, 1994).

Irish Sea

Recruitment to the scallop populations around the Isle of Man has been remarkably consistent from year to year. Although good and bad year-classes can be detected in the population age structures, recruitment does not appear to have failed completely in any area over more than 60 years of exploitation. This is very unusual, compared with other *P. maximus* fisheries around the British Isles, where particular year-classes can be totally absent (e.g.Franklin et al. 1980) or dominate the fishery for several years (e.g.Franklin and Conner 1980). In the Irish Sea there is generally greater variability on individual grounds offshore but, even here, recruitment is remarkably constant (Gruffydd 1974a), compared with many other scallop species worldwide (Dickie 1955; Hancock 1973; Caddy 1979). Some consistent differences have been noted in the strength of particular year-classes on grounds to the east and to the west of the Isle of Man (Murphy 1986). This suggests that hydrographic factors affecting the dispersal and survival of the planktonic larvae are important determinants of good recruitment, but variations in early post-settlement survival are also likely to be important. Both of these stages of the life-history require further study.

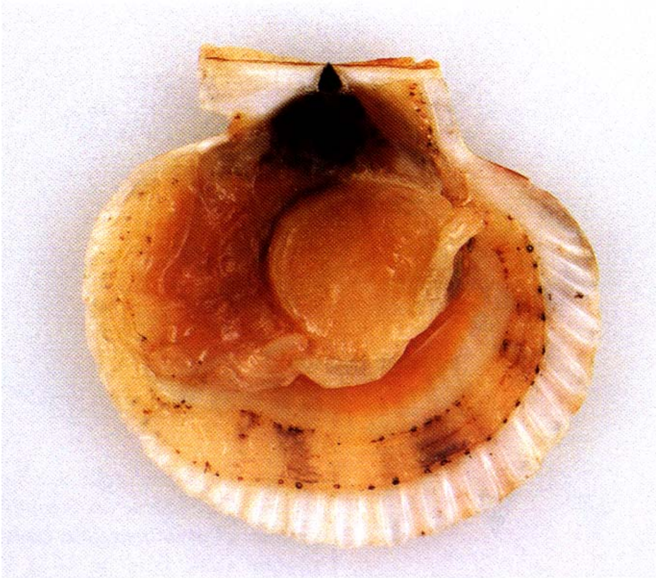
The source of larvae recruiting to individual scallop beds in the Irish Sea is presently unknown, thus limiting determination of stock recruitment relationships. Detailed hydrographic investigations of current circulation in the north Irish Sea have produced contradictory results. The earlier descriptions of the circulation patterns indicated a net northward flow, passing to the east and west of the Isle of Man (Ramster and Hill 1969). This flow pattern suggested that recruitment of scallops on either side of the Isle of Man is from the extensive grounds to the immediate south of the Isle of Man (Murphy 1986; Duggan 1987), or occasionally from even further south (Macleod et al. 1985), depending on the assumed rate of transport and length of larval life. This interpretation is now open to doubt, for more recent computer models of circulation (Backhaus 1985; Backhaus and Hainbucher 1987; Darby and Durance 1989) have indicated slow southward flow through the north Irish Sea in June and July, when scallop larvae are in the plankton. In addition, tidally-induced frontal systems are set up in the summer months, separating an area of temperature-stratified water to the west of the Isle of Man from the transitional and mixed water masses elsewhere (Ramster and Hill 1969; Pingree and Griffiths 1978), and these may act as barriers to larval dispersal. This is supported by the different patterns of recruitment noted on the west and east sides of the Isle of Man (Murphy 1986) and by studies that found genetic differences between queen populations from grounds on the two sides of the Island, implying some degree of genetic isolation, if not total reproductive isolation (Lewis and Thorpe 1994). More recently, work on scallop population genetics using DNA techniques has found differences between the scallop populations from different Manx fishing grounds, which indicate some degree of genetic isolation in open water populations (Heipel et al. 1998; Heipel et al. 1999).

2.1.6 Exploitation and mortality rates: North Irish Sea

The age structure of scallop populations in the North Irish Sea has been strongly affected by fishing (Brand et al. 1991; Brand 2000). When the fishery started the populations on all grounds were dominated by old scallops. For the Bradda Inshore ground, for example, about 50% of the population were 9 years of age or older in 1937 (Tang 1941). However, high levels of exploitation have meant that for the last 20-30 years the fishery on this ground has been based mainly on the recruiting age group (4 years old on this ground (Brand 2000)). A similar pattern of change in age structure has occurred on all of the other fishing grounds around the Isle of Man. Present age structures reflect the duration and intensity of exploitation of each ground. On the heavily exploited inshore and nearshore grounds all populations are heavily dominated by 3-6 year old scallops, with older scallops present in any quantity on only a few of the less heavily fished offshore grounds, such as South East Douglas and 20' S. Port St Mary.

Various techniques have been used to estimate the instantaneous rates of total mortality for different Manx fishing grounds and to apportion this into its two components: natural mortality and fishing mortality. The most detailed estimates for different time periods have come from two major tagging experiments (Brand and Murphy 1985; Murphy 1986; Allison et al. 1989; Brand and Murphy 1992; Allison 1993) and from analyses of CPUE and population age structure data (Murphy 1986; Wilson 1994)

The annual exploitation rates calculated from the two tagging experiments for inshore grounds such as Bradda Inshore and The Chickens are very high, with values of up to 55%. For some of the offshore grounds exploitation rates were only 1-5% in 1982/3 but had risen to 5-20% in 1987/8. Small-scale tagging experiments carried out in 1952 (Mason and Colman 1955) and again in 1965-6 (Gruffydd 1972) suggest that fishing mortality on the Bradda Inshore ground in the 1960s was at least as high as it is today. Fishing mortality is now high on all the inshore fishing grounds around the Isle of Man, and is increasing on the offshore grounds.



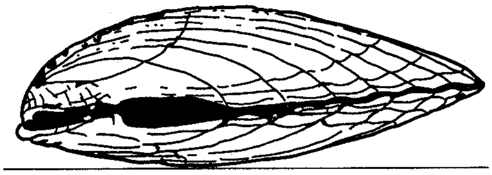


Figure 2-6 Above: *Aequipecten opercularis* with lower valve removed (Quéro and Vayne 1998). Below: Orientation of queen scallop on seabed (afterRolfe 1973)

2.2 *Aequipecten opercularis*: North Irish Sea

In many respects, the queen scallop, *Aequipecten opercularis,* is very similar to the scallop, *Pecten maximus*, for the two species have similar geographical and depth ranges, are found on similar bottom substrates and have very similar mechanisms of feeding, reproduction and larval life histories. However, a number of aspects of the ecology and behaviour of queens differ considerably. Queen scallops lie on the seabed surface with the more curved shell uppermost (Figure 2-6). They are more active swimmers than the scallop, swimming several metres into the water column(Chapman et al. 1979).

Age and growth

Like the scallop, the queen may be aged by annual growth rings but the visibility of these rings varies considerably from ground to ground and they are seldom clear (Allison 1993). Ageing is therefore much more difficult than for the scallop. Queens have a maximum life-span that does not exceed 8-10 years and is generally much less (Ansell et al. 1991). In the north Irish Sea, queens reach a commercial acceptable size at an age of 14-18 months; beyond 4-5 years old the natural mortality rate is high and individuals more than 6 years old are rare on all grounds (Brand et al. 1991). This means that only a maximum of three or four year-classes are usually well-represented in the population at any time so it is difficult to interpret annual variations in recruitment or exploitation from queen population age structures. With the very fast growth rate, changes in age structure of the catches from a fishing ground take place within the summer fishing season as the recruiting cohort grows large enough to be vulnerable to capture in the latter part of the season (Allison 1993).

The queen grows to a maximum shell height of about 90mm. The initial growth rate is fast and queens generally reach 55mm shell height and become commercially acceptable during their second growing season (at age 1+). Growth of shell and meat appears to be very variable, both spatially and temporally. Growth rates on Manx fishing grounds were highest on the Targets and Point of Ayre grounds and lowest, but with high asymptotic lengths (the final size achieved), on some of the offshore grounds to the south of the Island (Allison 1993). The areas of good queen growth are often the same as areas of good scallop growth. For both species, good growth depends on the availability and abundance of food, which ultimately depends on seasonal productivity cycles. These are greatly influenced by local hydrographic conditions, such as the tidally-induced frontal systems that are set up in the summer months.

Recruitment

Variability in the growth rates and settlement seasons of queens means that individual cohorts are not generally identifiable and population size-frequency distributions are generally unimodal. Thus variability in recruitment levels is difficult to determine. However, studies indicate that spatial and temporal variability in year-class strength has been considerably greater for queen populations than for scallop populations (Aravindakshan 1955; Allison 1993). Despite this, queen populations have displayed a relative stability over the north Irish Sea as a whole. Thus the main fishing grounds have remained spatially persistent since the fishery began in 1969, although the areas of good recruitment within each ground may vary considerably from year to year (Brand et al. 1991).

2.2.3 *Reproduction*

The reproductive life history of the queen is very similar to that of the scallop, though there are a number of important differences. The queen reaches sexual maturity rather earlier at 1-2 years old (Aravindakshan 1955) and generally shows more peaks of spawning each year. On most inshore grounds there are three more-or-less distinct peaks of spawning each year, in February-March, June-July and September-October (Aravindakshan 1955; Paul 1978; Duggan 1987), but no autumn spawning occurs on the deeper water Port St. Mary ground (Wanninayake 1994).

Exploitation and mortality rates

Due to the problems of collecting and analysing catch and effort data for the queen fishery, discussed above, little detailed study of queen population dynamics has so far been undertaken. However, tagging experiments to determine exploitation and mortality rates on the East Douglas ground, showed instantaneous rates of total (Z), fishing (F) and natural (M) mortality to be 0.41, 0.21 and 0.20 per month respectively (Allison and Brand 1995). The calculated value of M is very high but includes incidental fishing mortality resulting from gear damage. The analysis of age-frequency distributions of queens from an adjacent, largely unfished, area indicated natural mortality levels of only 0.036 per month (0.43 per year). If natural mortality on the East Douglas ground in the absence of fishing is assumed to be the same as the adjacent unfished area, then incidental fishing mortality would account for most of the calculated natural mortality in the tagging study. Incidental mortality may therefore approach fishing mortality. Very high levels of incidental mortality, have been found in some other scallop fisheries (Naidu 1988; McLoughlin et al. 1991) and highlight the need to assess the full impact of gear damage on both target stocks and the environment.

2.3 *Chlamys varia*

Figure 2-7: *Chlamys varia* (fromQuéro and Vayne 1998)

Chlamys varia is a small scallop, rarely exceeding 60 mm shell height. It has protruding auricles, the anterior of which is much larger than the posterior, and there is a prominent byssal notch in the right anterior auricle. The shell colour is very variable, ranging through off-white, yellow, orange, pink, red, brown, purple, dark green and grey to almost black, often with prominent irregular patterns in many colours. Both valves have 25-35 prominent radiating ribs, each bearing spatulate spines that are particularly well developed near the strongly crenulated margin. There are also numerous concentric growth striae, with annual growth lines sometimes clear.

Habitat

Chlamys varia has a wide distribution from Denmark, along the western coasts of the British Isles, France and the Iberian Peninsula, throughout most of the Mediterranean and into the Black Sea, and as far south as Senegal on the coast of West Africa (Tebble 1966). Light (1988) considers that *Chlamys nivea* is a geographical sub-species of *C. varia*, confined to the west coast of Scotland. *C. varia* occurs at depths ranging from low in the intertidal zone to some 80 m, usually on shelly or sandy-gravel sediments where it byssally-attaches to shells, stones and boulders (Le Pennec and Diss-Mengus 1985) or rock faces (Rodhouse and Burnell 1979). It is frequently associated with dense banks of the horse mussel, *Modiolus modiolus* (Roberts 1975) and the oyster, *Ostrea edulis* (Forester 1979; Burnell 1991). The main commercial exploitation of *C. varia* is along the French Atlantic coast, in recent years particularly the eastern part of the Bay of Brest. Unlike *Pecten maximus* and *Aequipecten opercularis*, adult *Chlamys varia* are usually byssally attached throughout life (Mahéo 1968; Soemodihardjo 1974), but they can detach the byssus and utilize similar escape responses to the other scallops, although they are not such powerful swimmers (Millward and Whyte 1992).

Reproduction

The reproduction of *C. varia* differs considerably from *P. maximus* and *A. opercularis* because *C. varia* is a successive protrandric hermaphrodite (Lubet 1959; Reddiah 1962). There is usually an imbalance in the sex ratio, with males predominating among small scallops and females among the larger animals. At any one time an individual may function as either a male or a female, but can change sex after spawning. For most areas there appear to be two main periods of spawning each year, but the timing can differ between areas, and between years. For Bay of Brest and other French populations there is a partial spawning in May-June and a complete spawning in September-October, but other intermittent spawnings can occur between May and September (Lubet 1959; Shafee and Lucas 1980). In the northern Irish Sea, around the Isle of Man, the first spawning takes place about a month later than in French waters, while the second appears to be at about the same time or slightly later, extending into November (Reddiah 1962). On the west coast of Ireland the first peak of spawning occurs in late May or early June, at a similar time to the French populations, but the second is earlier, in early August, although an additional minor spawning occurs in September in some years (Burnell 1983; Burnell 1991). Burnell noted that the major spawnings coincide with peaks in chlorophyll *a* and appear to be triggered by temperature fluctuations of 1-2ºC around 15ºC that occur at spring tides.

2.3.3 *Growth*

The most detailed studies of growth have been carried out on a population of *C. varia* from Lanvéoc, Bay of Brest, France (Shafee 1980). Studies of growth are complicated by the presence of clear biannual recruitment, and the growth curves of spring and autumn spawned cohorts remain different throughout life (Conan and Shafee 1978). Annual and seasonal growth in shell height can be predicted using linear day degree models (Shafee 1980). Empirical models using temperature, food availability and gonad index as independent variables showed that temperature and food together were decisive factors determining growth rates. There were also clear seasonal variations in the growth of body tissues, but this was not closely correlated with changes in shell height. Data from various studies were integrated to assess seasonal variation in the overall energy budget (Shafee and Lucas 1982), and to calculate reproductive effort (Shafee and Lucas 1980; Lucas 1982).

Growth has also been studied for populations on the west coast of Ireland (Rodhouse and Burnell 1979; Beaumont et al. 1985).. The life span of *C. varia* in this area is estimated to be 9-10 years. Growth characteristics, as shown by the parameters of the von Bertalanffy growth equation, were markedly different for *C. varia* in Lough Ine and Inner Roskeeda Bay. Seasonal growth at these sites was best described by a model incorporating temperature (as day degrees >9ºC) and standing crop of phytoplankton (as chlorophyll *a*).

2.4 *Chamelea gallina* in the Northern Adriatic

C. gallina is an infaunal filter feeding bivalve that lives in the surface layer of the sediment, which offers shelter and protection. The shell has two equal triangular valves; the upper portion, called the umbo, is sharp whereas the lower portion is large and rounded. The anterior margin near the umbo is small and turned forward. The shell colour is off-white with brown streaks (Riedl 1991). The exhalant and inhalant siphons are joined together, short and yellow-violet spotted.

2.4.1 Habitat

C. gallina is a fairly common species in the Mediterranean. Due to the geomorphological characteristics of Italian coastal areas, *C. gallina* beds are more widespread in the Adriatic Sea, and locally present in the middle and southern Tyrrhenian Jonic Seas. It is also possible to find this clam in the Black Sea, Caspian Sea and along the Norwegian, Icelandic and Morocco coasts. However, in Norway, Iceland and Morocco it is difficult to distinguish from *C. striatula* (an Atlantic species), so the reports referring to *C. gallina* are not reliable. The presence of *C. gallina* is reported occasionally along the Atlantic French coast and fairly often along the Spanish coasts (Stella and Rodinò 1986; Backeljiau et al. 1994).

2.4.2 The Northern Adriatic

The Northern Adriatic Sea features low and sandy coasts with a number of river estuaries; this habitat has little variation in ecological parameters and contains environments that favour the settlement of clams. In this area *Chamelea gallina* and *Owenia fusiformis* live together, particularly in the zone outside the Venice Lagoon, and has mean biomass values for the two species of 149.3 and 356.4 g/m^2, respectively (Ceccherelli 1985). The biomass per unit area in this habitat is the highest in the Mediterranean (Froglia 1975; Mizzan 1992). The environmental conditions are described below in relation to the hydrography and productivity of the area.

Oceanography of the basin

The Northern Adriatic is about 70 m deep in the southern third, decreasing progressively to less than 30 m in the northernmost area. The seabed has a moderate gradient, about 1/4000, with no noticeable irregularities; and several rivers drain freshwater from the Alps and Appennines. Of these, the river Po is the most important, with an average discharge of 1500 m^3/s from a basin of about 70000 km^2. This influences the bottom morphology of the Northern Adriatic on a geological time scale, and the density structure, the dynamics and biogeochemical processes taking place in the water column and near the seabed on a short time scale. In the northern basin, there is a general cyclonic circulation (Figure 2-9), with a northward flow along the eastern side and a southward one along the western coast (Orlic et al. 1992; Russo and Artegiani 1996).

Two main hydrological patterns can be recognised: mixed water column and stratified water column (Fonda Umani et al. 1992; Socal and Franco 1995).

Figure 2-8 Photographs of *Chamelea gallina*

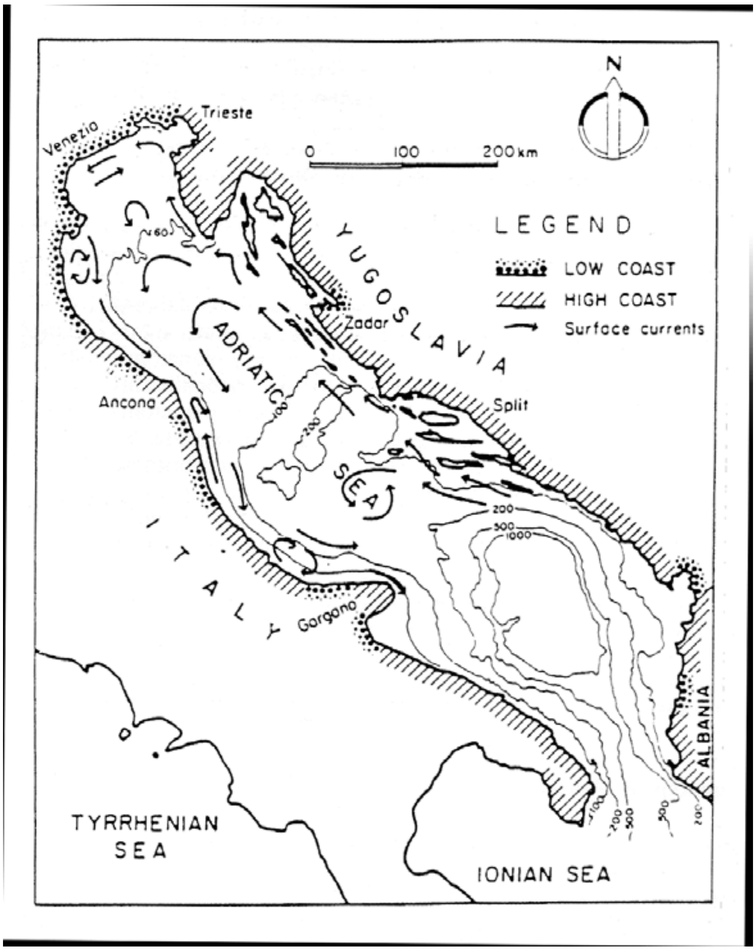


Figure 2-9 . Bathymetric chart and surface currents of the Adriatic Sea ((Brambati 1992)

Mixed water column

Mixed water column conditions (winter vertical instability, Figure 2-10) occur in autumn, with the progressive loss of heat from the surface into the atmosphere, the total heat budget becomes negative. Hence a sinking of the thermocline occurs, leading to convective instability of the water column. Vertical discontinuities disappear, replaced by a horizontal one, displaced from land to open sea. In deep winter, a frontal system separates the western coastal waters from those offshore: in this narrow coastal belt, the riverine

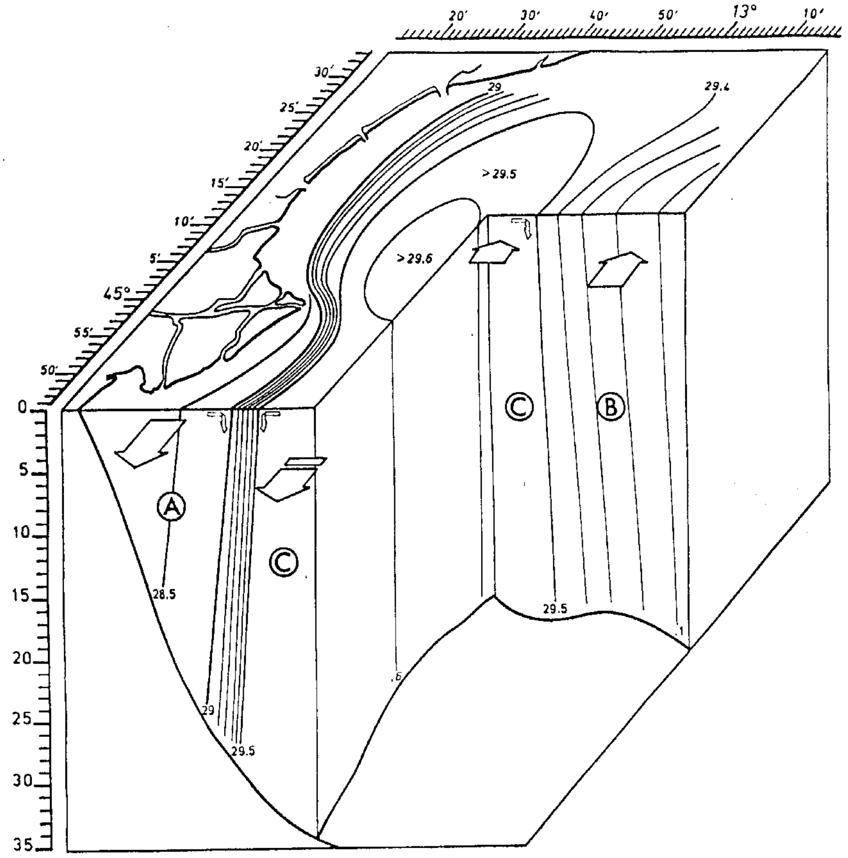


Figure 2-10. Distribution of density anomaly (kg m^{-3}) in the Northern Adriatic Sea in winter unstable conditions (Franco, 1986). The main water-masses are indicated: A = diluted; B = intermediate; C = high-salinity water masses. Arrows indicate the direction of the main currentasses coming from the south.

flows southward. The central area of the basin is almost completely replaced by high saline water masses coming from the south. Under these conditions of vertical instability, high-density waters are generated, flowing towards the central basin, especially during strong N-E winds (Bora).

Stratified water column

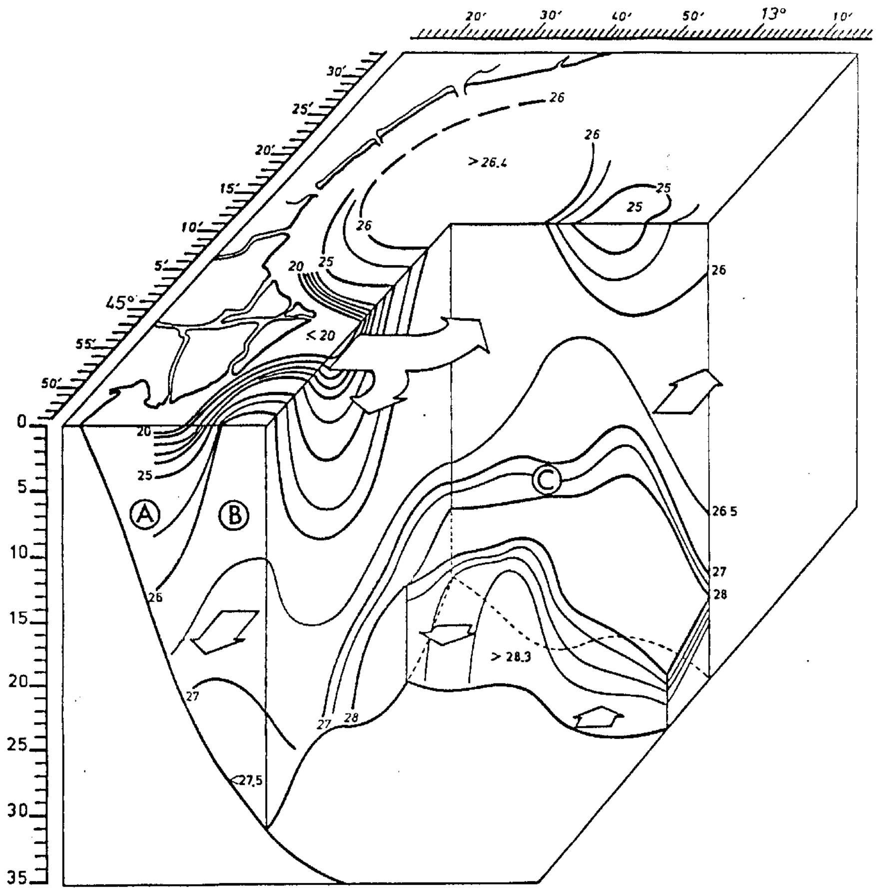


Figure 2-11 Distribution of density anomaly (kg m^{-3}) in the Northern Adriatic Sea in summer stratified conditions.

The stratified water column (summer vertical stability, Figure 2-11) occurs in spring when heat storage in the surface layer leads to the generation of a thermocline, which becomes more marked as the season proceeds. Vertical thermal discontinuities lead to a density gradient between surface and bottom. The Po river injects its plume into this stratified structure: depending on its discharge, the surface layer of the basin is more or less occupied by diluted waters from spring to late-summer.

Physical and chemical variables

The distribution of the physical and chemical variables, as well as the biology, is strictly related to the density field of the water column (Fonda Umani et al. 1992; Franco and Michelato 1992; Socal and Franco 1995).

In winter, a front separates the coastal system, with high nutrient concentrations coming from the land runoff, from the offshore system. Offshore vertical mixing causes a homogeneous distribution of dissolved and suspended matter; nutrient concentrations are low.

In summer, the Po river plume, rich in dissolved nutrients, sustains very frequent phytoplankton blooms: this is an efficient way to transfer nutrients from the dissolved to the particulate phase, along a West-East gradient. Out of the plume, in intermediate waters, nutrient content is generally low due to the phytoplankton uptake. Near the bottom, dissolved nutrients increase because of regenerative processes performed by heterotrophic bacteria; the reduced form of ammonia prevails here. When vertical stratification persists, the oxygen content of the bottom layer can be progressively impoverished; sometimes a complete depletion of dissolved oxygen can be detected in early autumn, with dramatic effects on benthos communities.

In this basin, spatial and temporal variations of autotroph abundance, biomass and production are very large. This demonstrates that the northern Adriatic shows both oligotrophic features, due to the saline and nutrient poor waters coming from the eastern Mediterranean, as well as high trophic conditions in the fertilised western area (Socal and Franco 1995; Fonda Umani 1996).

In the zone displaced under the direct influence of the Po river, chlorophyll-*a* concentrations reach values up to 10 - 20 $\mu g\ dm^{-3}$, approximately ten times as high as in the open north Adriatic waters. Similar trends are evident for primary production, with maxima over 30 $\mu gC\ dm^{-3}\ h^{-1}$ in the western part and below 10 $\mu gC\ dm^{-3}\ h^{-1}$ in the eastern area. Minimal values of < 1 $\mu gC\ dm^{-3}\ h^{-1}$ have been detected in both regions.

For these reasons, the Northern Adriatic has been recognised to be a region of high marine production at several trophic levels, from phytoplankton to fish.

Sea bed characteristics of **C.** *gallina habitat*

The ecological niche of *C. gallina* is restricted by chemical-physical seawater parameters, granulometry, oxygenation and electric potential of sediments (Stella and Rodinò 1986; Backeljiau et al. 1994). In the Northern Adriatic, the habitat of *C. gallina* is a coastal band of 10-12m depth, extending between 0.5 - 5Km from shoreline. It is limited offshore by more muddy sediments (Barillari et al. 1978). The total surface area is estimated to be about 65-70Km^2 in the studied area.

The optimum habitat for clams is represented by the littoral sand**,** terrigenous sediments, grey to very light-brown, with scarce biogenic remains and with over 95% (in weight) of particles with a diameter between 2.000 – 0.063mm. Going from the shoreline to about 5m deep, the fine sand becomes the prevalent sediment with a median size range from 0.250 to 0.125mm. Progressively, down to 5m depth, the median size decreases to about 0.080mm (very fine sand). An example of grain size frequency distribution of fine and very fine sand is reported in Figure 2-12.

The species requires good oxygenation[1]. The presence of *C. gallina* decreases in sediments with a lower percentage content of sand and higher percentages of silt and clay. The turbulence of seawater is very important as it provides for good oxygenation and the oxidation of organic substances (Barillari et al. 1978)

[1] Sediments in which the electric potential referred to a mercurous chloride electrode is always positive and typically greater than +50 Mm (Eh greater than 300 mV).

The terrigenous fraction is mainly represented by carbonates (> 80%), with dolomite constantly prevailing over calcite. The littoral sands present a porosity up to 46 ± 2%; a mean permeability coefficient of $1.5 \times 10^{-3} > K > 5.0 \times 10^{-4}$ cm/s, a mean pocket penetrometer resistance of 0.8 ± 0.5 kg/cm^2, and a specific gravity of grains of $2.60 < G < 2.71$ g/cm^3 (Brambati *et al.* 1983; Brambati *et al.*, 1988).

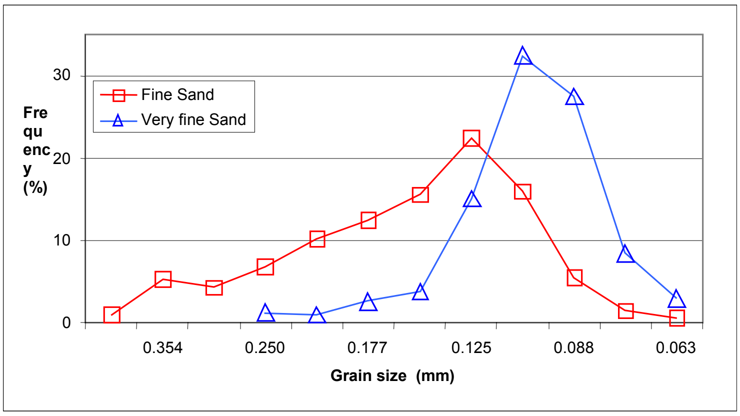


Figure 2-12. Grain size distribution of fine and very fine sand.

Macrobenthic populations of the Northern Adriatic

The Adriatic surface area represents about 1/20 of the Mediterranean Sea, whereas its total production is proportionally five times higher (1,000,000 tons per year in the Mediterranean, 250,000 in the Adriatic). Eutrophication, mainly involving the coasts of the northern and central Adriatic, affects all links in food chains and allows a high production of fish. In particular, the widespread soft substrata and the abundance of particulate matter and phytoplankton favour planktonophagous, sestonophagous and detritivorous organisms (Bombace 1992). However, algal blooms and extended hypoxia and anoxia, frequently occurring in the last 20 years, may result in serious damage to demersal resources, influencing both pre-recruitment and subsequent stages, as well as to sedentary and benthic species, mostly bivalves (Orel et al. 1989; Aleffi et al. 1998).

2.4.3 Life cycle

In contrast to some scallops, where organs producing both male and female gametes are found in each specimen, clams contain only one type of gamete. After an initial stage, in which gonads have *bi-potential*, there is differentiation of the reproductive tissue. Both males and females reach their first sexual maturity between 16-18mm shell length, at an age of one year. Gametogenesis is uninterrupted and the reproductive cycle starts again shortly after spawning. It is possible to identify 5 stages in the reproductive cycle of this species:

- STAGE 0: quiescence period. During this period, no sexual follicles can be seen. The follicles contain only a few unripe germinal cells.

- STAGES 1 – 2: slow gametogenesis. Between February and March follicles are numerous, evident and full of germinal cells. A rise in climatic temperature up to 14 - 15°C leads to the formation of spermatic cords and the release of ovocytes in the follicular lumen.

- STAGE 3: gonadal maturity.

- STAGE 4: reproductive peak of the species.

Table 2-1 Maturity stages of *C.gallina* in the Adriatic

Jan	Feb	Mar	Ap	May	June	July	Aug	Sept	Oct	Nov	Dec
2	2	2	3	3	4	4	0	0	0	1	1

Reproduction

Table 2-1 shows monthly changes in gonadal stages over a year. Spawning starts at the end of April and continues until August – September. Ripe and empty follicles can occur in an animal simultaneously, indicating that not all gametes are released at one time. The sex of clams can be determined throughout the year because ripe elements persist in the follicles (Froglia 1975; Marano et al. 1980; Nojima and Russo 1989). Fertilisation takes place externally and brings about the formation of planktonic larvae.

Growth

Benthic life starts after about 1 month with the settlement of larvae. The change between pelagic and benthic life is a delicate stage, as in this period the clam has a thin and fragile shell that can be easily damaged. *C. gallina* has a slow growth, taking about 1 year to achieve a size of 16–18mm and about 2 years to reach a commercial size of 25mm. It grows to a size of 40–50mm in about 5–6 years. A decrease in growth is evident in winter, and growth stops when the temperature falls below 10°C.

Studies regarding the growth of *C. gallina* (in the Gulf of Naples) have reported the nearly simultaneous occurrence of growth stripes or rings along the shell margin, described as "annual rings". The formation of growth rings, a frequent phenomenon in molluscs, occurs in winter at the beginning of the reproductive cycle and coincides with the first stage of gametogenesis. Data collected in the same studies indicate a similarly structured population in the Adriatic and in the Tyrrhenian Sea, although clams from the Adriatic are flatter (perhaps a sediment effect). Also the time needed for clams to reach commercial size (25mm) is different; while Adriatic clams take about 2 years, Tyrrhenian clams generally take a year longer (Nojima and Russo 1989).

Population dynamics in the North Adriatic Sea

C. gallina forms large populations and has a wide distribution. This is perhaps explained by the wide distribution of larvae that are carried long distances by the sea currents.

C. gallina fishing has been one of the most important Adriatic activities in the past. Between 1979 and 1985, with the use of hydraulic dredges, annual landings were estimated at about 100,000 tons (Froglia 1989; Del Piero et al. 1998). In the past 10 years, this activity has entered a critical period due to difficulties related to the management of resources and ecological problems (mortality events in 1991, 1993, 1996, 1998). The Ministry of Agriculture (Ministero per le Politiche Agricole) has promoted a programme for mollusc management in the District to try to resolve these problems and for a better management of the natural resource. The main objectives included the evaluation of commercial biomass and the analysis of population dynamics data (i.e. clam size distribution, extent of the clam beds, and fishing effort) (Ministero delle Risorse Agricole

Alimentari e Forestali 1998; Ministero per le Politiche Agricole 1998; Pellizzato et al. 1998; Prioli et al. 1998).

Heavy fishing causes a lowering of the median age in natural populations. Today, clams over 3 years of age are rare. It is evident that the fishery depends on a single age class, as *C. gallina* takes about 2 years to achieve the minimum commercial size, so poor recruitment in one year may compromise the fishery for at least the next 2 years. This is a critical period for the clam fishery in the Adriatic, due to the low density of commercial sized clams in all Districts and a new law that is transforming this fishing sector. The main causes of the present situation are: excessive fishing effort, a general insecurity among fishermen regarding the future of their activities, and calamitous events in the natural populations of clams (i.e. 4 mortality events in 9 years). The situation of the clam populations in different 'Fishery Districts' is discussed below.

Table 2-2 Density and biomass of *C.gallina* in the Monfalcone district

Year	Surface area used for fishing Km^2	Average density g/m^2 (≥ 10mm)	Biomass t (≥ 10mm)	Biomass t (≥ 25mm)
1984	44	46.00	2024	744
1985	34	34.94	1188	944
1986	35	44.89	1571	994
1987	28	49.57	1388	1000
1990	36	33.35	1212	470
1991	37	19.99	700	307
1992	45	13.09	592	253
1994	27	16.40	436	175
1995	40	9.21	370	157
1997	40	7.18	170	73

The coastal area of the Monfalcone District is about 50 km long and reaches a maximum depth of 6 metres. Here, the settlement of *C. gallina* occurs in two periods (Del Piero 1998):

1. late spring or summer period: this is the most important period in which clams grow quickly until winter, when they slow down until next spring,

2. autumn period: settlement is numerically scarce and growth is slower.

The size differences between these two semi-cohorts tend to disappear after 2years. Table 2-2 shows data referring to average density and biomass of *C. gallina* in the Monfalcone District (1984 – 1997).

From 1990, there is a general decrease in density, although the *Cymodocea* grasslands reappeared particularly in the coastal aresa off Grado and Primero, which stabilise the substratum and are potential nursery areas for many species, including *C. gallina*. The most productive zone moved 1 metre in the direction of the open sea between 1990 and 1992, passing from a depth of 3 – 5m to 4 – 6m. In front of Grado, there are higher yields (231.44 g/m^2), owing mainly to the fact that the fishery is not allowed here because of the presence of the outflow from a depuration plant.

In 1990, the median length of clams was greater near the coast (up until 3m depth) and decreased rapidly in fishing areas. In 1997, the most representative size class was that between 1 6 and 20mm (66%), whereas 25 % were clams of commercial size and 9% measured 7 – 11mm.

In this District, the fishery is in a critical period due to the decrease of resources and management changes (e.g. the establishment of "Consorzi") that provide for self-management fishery (Orel and Del Piero 1988; Del Piero 1998). A total closure of the Monfalcone District for a certain period and restocking of resources would be desirable. It is important to establish an appropriate level of fleet capacity congruent with the carrying capacity of this area.

Table 2-3: Density and biomass of *C.gallina* in the Venice district Zone A. From Punta Tagliamento to Porto Falconera. This was traditionally a rich zone and widely exploited. Clams live at a greater depth than in the Monfalcone District (Del Piero 1998)

Year	Surface area used for fishing Km^2	Average density g/m^2 (≥ 10mm)	Biomass t (≥ 10mm)	Biomass t (≥ 25mm)
1990	35	46.03	1622	504
1991	29	45.74	1324	382
1992	28	18.00	508	321
1994	25	97.65	2461	808

Table 2-4: Density and biomass of *C.gallina* in the Venice district Zone B. From Caorle to Malamocco. This was a scarce resource until 1994 (Del Piero and Fornaroli 1998)

Year	Surface area used for fishing Km^2	Average density g/m^2 (≥ 10mm)	Biomass t (≥ 10mm)	Biomass t (≥ 25mm)
1990	75	10.29		775
1991	57	14.42		829
1992	65	7.93		515
1994	69	30.78		642
1995	80	40.27		1590

Table 2-5: Density and biomass of *C.gallina* in the Venice district Zone A + B.

Year	Surface area used for fishing Km^2	Average density g/m^2 (≥ 10mm)	Biomass t (≥ 10mm)	Biomass t (≥ 25mm)
1997	89	6.5	678	153

These tables show an oscillation of biomass values with a peak in 1995 and a drastic reduction in 1997. In autumn 1996, especially in the northern part of the District, widespread mortality destroyed the first attempt at self-management of the "Consorzi".

In 1997, the size distribution showed a majority of clams with sizes down to 25mm (70 % between 7 and 11mm; 28 % between 16 and 20mm), in fact only 2% are clams of commercial size. The depth at which the greatest number of clams with sizes over 25mm could be found wass between 4 and 6m. Studies in February 1998 confirmed these results. Today, this District is characterised by a scarcity of commercial clams, with only a few exceptions (Porto S. Margherita, Jesolo, Lido di Venezia). The estimated density is inadequate to support an intensive fishing fleet. The year 1997 represents the starting point for a direct management programme of the operators. Generally, the fishing closure periods decided by the harbour authorities find good agreement among fishermen. Now, with the formation of a technical support service for fishermen, temporary no-fishing periods, monitoring plans, and restocking of overexploited zones are considered to be very important components for the future management of the resource (Del Piero 1998; Del Piero and Fornaroli 1998).

Chioggia District

The Chioggia District is characterised by the presence of numerous mouths of rivers (the Brenta, Adige and Po), and by an extremely variable seabed. Due to the combination of these factors, it is not easy to define the distribution of *C. gallina* along this coast.

Research is required in order to acquire more information about the situation in this area, which is characterised by intensive fishing effort. The data collected in 1986 confirmed the presence of clams along the entire coastal region of Sottomarina, while their distribution in the Po Delta was more variable. In fact, river outflows influence seabed conditions and establish, alternately, sandy and silty zones that are unsuitable for the settlement and survival of clams.

In 1986, clams of >25mm were abundant also at depths of up to 18m. In 1987, the fishing area was restricted and commercial size clams were rare; the mean biomass value for this District was 1.98g/m^2, for a surface area used for fishing of 71Km^2. The total amount of landing products was about 140 tons (Prioli et al. 1998).

Size distribution shows a predominance of the 7 – 11mm size class (85%), followed by the 16 – 20 size class (10%), while the fraction of clams >25mm is low (5%). Studies in February 1998 confirmed these results and suggested low growth of the clam population. Altogether, a great decrease in clams of >25mm is evident, while the presence of juveniles is variable throughout this area.

2.4.4 Status of clam resources: North Adriatic

Chamelea gallina

Between 1984 and 1997, the Minister of the Agricultural, Food and Forest Resource, financed many studies including surveys on the status of the mollusc resources along the Italian coasts mostly involved in this fishing activity. These surveys provided an insight into the amount of the resources, the biology of the target species, the dynamics regulating population development, and resource fluctuations during past years. This survey activity involved many research teams that conducted their surveys along the Italian coasts with professional vessels equipped with prescribed and modified gear, with the aim of acquiring all possible information.

The surveyed area extended from Trieste to Barletta (Figure 4-31) on the Adriatic coasts and from Tuscany to Campania on the Tyrrhenian coasts. The results obtained during individual research surveys for all the periods are reported in Table 2-6and Table 2-7) (Ministero delle Politiche Agricole 1998).

Table 2-6. Abundance of *Chamelea gallina* of commercial size (tons) and surfaces of the seabed with clams (Km^2), estimated by the research units, designed to evaluate the status of the clam beds along the Adriatic coasts (modified fromMinistero delle Politiche Agricole 1998).

District		1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Monfalcone	Tons	744	944	994	1000			470	307	253		175	157		51
	Km^2	*44*	*34*	*35*	*28*			*36*	*37*	*45*		*27*	*40*		*40*
Venezia	Tons							1279	1211	836		1450	1590		239
	Km^2							*110*	*86*	*93*		*94*	*80*		*89*
Chioggia	Tons			1330	416				271	1055		509	559		
	Km^2			*87*	*90*				*94*	*99*		*106*	*106*		
Ravenna	Tons	212	509	195	75	118	379	295	93	270	418	1043	182		230
	Km^2	*89*	*89*	*60*	*108*	*105*	*75*	*72*	*64*	*78*	*76*	*82*	*64*		*99*
Rimini	Tons	1245	1734	586	211	712	596	418	147	450	1125	1369	2536		
	Km^2	*80*	*127*	*71*	*92*	*91*	*75*	*65*	*63*	*80*	*52*	*78*	*66*		
Pesaro	Tons	1981	2907	1259	908	868	1301	673	251	1074	1625	352	1477	1300	440
	Km^2	*97*	*107*	*70*	*113*	*70*	*99*	*105*	*122*	*109*	*92*	*89*	*86*		*113*
Ancona	Tons	3036	9040	3913	4269				475	1102	1110	1980	5845	6822	3967
	Km^2	*267*	*274*	*271*	*300*				*240*	*251*	*194*	*202*	*219*	*256*	*260*
S. Benedetto	Tons	6310	8945	1386	3045				639	1689	1445	300	1472	2805	1194
	Km^2	*165*	*167*	*193*	*216*				*151*	*167*	*148*	*89*	*133*	*140*	*155*
Pescara	Tons	10086	3326	1970	4198				442			1024	19283		
	Km^2	*389*	*294*	*262*	*263*				*187*			*161*	*150*		
Termoli	Tons	1100	1884	136	142				36			170	1642		
	Km^2	*30*	*30*	*30*	*30*				*30*			*46*	*28*		
Manfredonia	Tons	463	3669	659	740			57	73	455		450	2287		
	Km^2	*90*	*118*	*158*	*109*			*85*	*87*	*112*		*149*	*122*		
Molfetta	Tons	475	691	159	446			4	3	35		12	44		
	Km^2	*14*	*14*	*16*	*16*			*5*	*11*	*12*		*6*	*6*		

Note – Data from: Agri.te.co. 1998; Ambrogi 1997; Ceccarelli et al. 1988 Costa *et al.*, 1987; D'Amico and Bonaduce 1988; Del Piero, 1998; Del Piero & Fornaroli, 1998; Del Piero *et al.*, 1998 Fiorentini and Froglia 1988; (Froglia et al. 1998a; Froglia et al. 1998b); Marani et al. 1998; Marano et al. 1998a; Marano et al. 1998b; Mariani et al. 1998; Orel & Del Piero, 1988; Paolini et al. 1998a; Paolini et al. 1998b Pellizzato *et al.*, 1998; Piccinetti 1988; Prioli *et al.*, 1998; Vaccarella et al. 1988; Vaccarella and Paparella 1998; Vaccarella et al. 1998.

Table 2-7. Abundance of *Chamelea gallina* of commercial size (tons) and surfaces of the seabed with clams (Km^2), estimated by the research units, designed to evaluate the status of the clam beds along the Tyrrenian coasts (mean value for the area 1985 - 1987) (from: Ministero delle Risorse Agricole Alimentari e Forestali 1996).

Areas	Cinquala - Tonfano	Macchia di S. Rossore - Macchia di S. Rossore	T.re di Palodoro - T.re di Caldara	Anzio – Sud di Nettuno	Scauri - Sud di Mondragone
Abundance (tons)	2.781	1.361	24.130	9.562	9.474
Surface (Km^2)	*3.3*	*3.3*	*12.6*	*1.9*	*5.2*

The abundance estimations reveal an extremely variable situation with particularly marked variations (up to one order of magnitude) within the period 1984 - 1997. These abundance variations may be attributed to a series of phenomena, such as: normal recruitment fluctuations, high fishing pressures, natural mortality due to environmental factors (situations of anoxia and undefined factors of environmental and pathological stress), like the critical situation that occurred during the summer and autumn months in 1991, 1993, 1996 and 1998. Considering the natural spatial and temporal variability of recruitment, it is difficult to establish the possible mean clam production in every District (Ministero delle Politiche Agricole 1998). However, clam production along the Tyrrhenian coasts is far lower than along the Adriatic coasts, due to the different characteristics of the two seas (type of bottoms, currents and productivity of the water) (Costa et al. 1987).

2.5 Portuguese clam species:

Spisula solida, Ensis siliqua, Chamelea gallina, Donax trunculus, Callista chione

2.5.1 Species

Figure 2-13 shows the shells of the five species studied in this project in Portuguese waters.

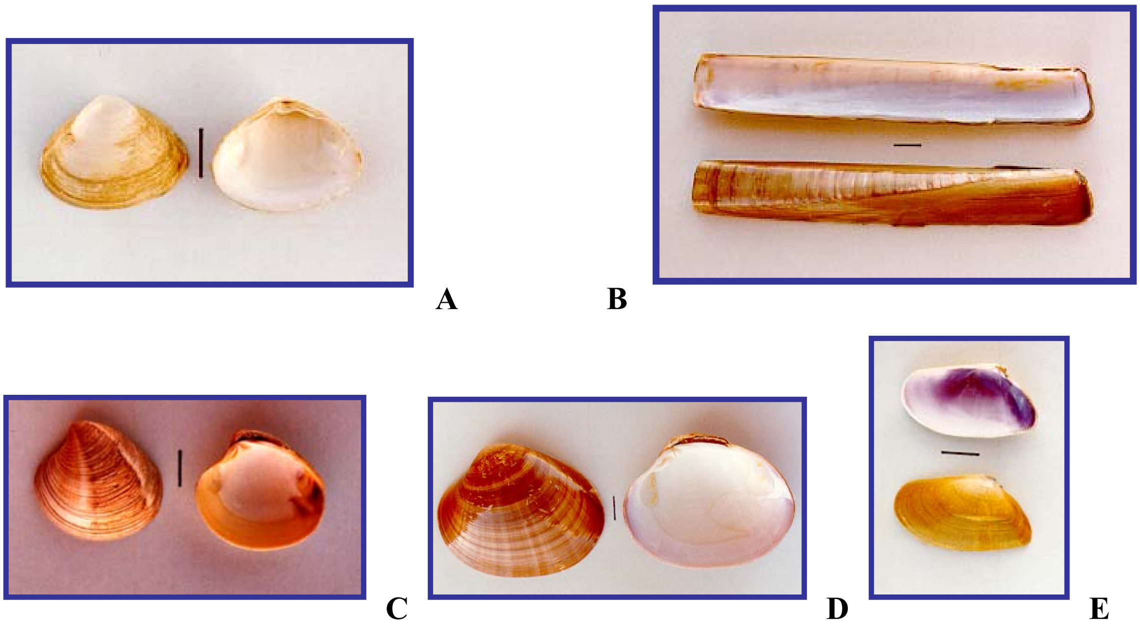
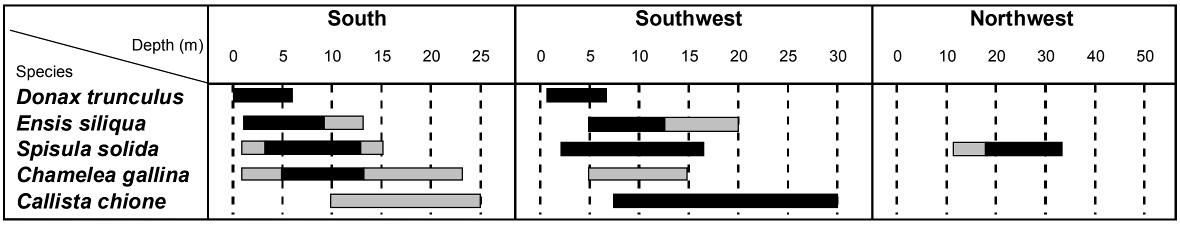


Figure 2-13 - Portuguese bivalve commercial species. A – *Spisula solida*; B- *Ensis siliqua*; C- *Chamelea gallina*; D- *Callista chione*; E- *Donax trunculus*. Scale bar = 1cm.

2.5.2 Habitat

These species are subtidal, inhabiting sand sediments. The bathymetric distribution of the species is shown in Table 2-8.

Table 2-8 – The Bathymetric distribution of the commercial bivalve species along the Portuguese coast. (■ abundant; ■ - scarce)



Spisula solida

The distribution of this species on the seabed is constrained tightly by its requirement for a substrate of fine sand in which to burrow. In the South and Southwest coast of Portugal *Spisula solida* can be found at depths between 3 and 13m, where it often forms the dominant species of shallow water benthic communities (Gaspar 1996). On the Northwest coast the depth range is greater than on the remaining part of the Portuguese coast, reaching the bathymetry of 32m.

Ensis siliqua

Ensis siliqua inhabits fine sands and is most abundant between depths of 3 and 12m. When resting, this species burrows close to the surface, with the siphon sticking out of the sediment. In response to any perturbation, they burrow deeper into the sediment in a defensive response. *In situ* observations using a probe showed that they can burrow as deep as 60 cm below the surface (Gaspar et al. 1998).

Chamelea gallina

Chamelea gallina is preferentially distributed in clean sand bottoms, in waters ranging from 3 to 24m depth, although it can occur on muddy and sand-muddy sediments; this species buries into the sediment to depths of 5cm (Gaspar 1996)

Donax trunculus

Donax trunculus is an Atlantic-Mediterranean warm-temperate species. It inhabits the high-energy environment of exposed sandy beaches, where it forms extensive, dense beds. It is the most inshore surf clam species in Portuguese waters, occurring to 6m depth, with higher densities between 0 and 3 m depth. It is an excellent burrower, which makes it well adapted to life in the swash zone (Gaspar 1996).

2.5.3 Life cycle: General considerations

a) Gametogenic cycle

The gametogenic cycle of the commercial species that occur along the south coast of Portugal were established using standard histological techniques. For all species, six stages of gonad development were identified following those described by (Gaspar and Monteiro 1998):

Stage 0 (inactive).
Sexes are indistinguishable microscopically due to the total absence of follicles and gametes. The connective tissue occupies all the space between the liver, digestive tract and mantle.

Stage I (early active gametogenesis).
The connective tissue is abundant and the size of follicles is small. Initial stages of gametogenesis are present. In females the ovocytes lie at the periphery of the alveolar walls and are attached to the basal membrane by a stalk. In males spermatocytes proliferate toward the lumina.

Stage II (late active gametogenesis).
Interfollicular connective tissue scarce. The size of follicles increased. Initial stages of gametogenesis still present but restricted to the periphery of follicles. In females, most ovocytes are free in the lumina while some are still attached to the basal membrane by a thin stalk. Appearance of sperm in the lumina that form weak columns with tails orientated toward the centre.

Stage III (ripe).
The connective tissue has been replaced by follicles that are full of ripe gametes. In females the ovocytes take oval or polygonal shapes, and in males the lumina are packed with ripe spermatozoa.

Stage IV (partially spawned).
In this stage gametes are discharged. Depending on the degree of spawning the follicles are more or less empty. The follicle walls are broken. There are many empty spaces between and within the follicles.

Stage V (spent).
Abundant interfollicular connective tissue. Occasional residual sperm or ovocytes present.

b) Growth studies

For growth studies, internal growth patterns within the shell structure (using the acetate-peel technique) and external rings were used to estimate age and growth rate. Growth curves were fitted to size-at-age data using the von Bertalanffy growth curve.

2.6 *Spisula solida*

Sex-ratio

The sexes are clearly separate. Male and female white clams are distinguishable externally since the colour of the gonad in this species is reddish in females and yellowish-orange in males. Thus, gonads can be reliably sexed by macroscopic examination. On the south coast of Portugal, males usually made up a higher proportion (Gaspar and Monteiro 1999)

Reproduction

Both sexes shows a synchrony in gametogenic development and spawning. The gonadal cycle of *Spisula solida* was studied in 1995/1996 and is shown in Figure 2-14. In June 1995 the majority of the population (75%) were in the spent stage (stage V), while 25% were in the resting stage (stage 0). The clams were sexually inactive from July to September. A new gametogenic cycle began in October, with 80% of the clam population in the early active phase of development (stage I) and 20% in late active condition (stage II). The late active stage dominated the samples of November and December. By the end of December 65% of the specimens were late active (stage II). The ripe stage (stage III) first appeared in December, and in January 1996 all the specimens analysed were ripe. Some partially spawned (stage IV) clams appeared in the following months, and partially spawned clams dominated the samples from March to May. By this month some specimens were categorised as spent (stage V) (Gaspar and Monteiro 1999)

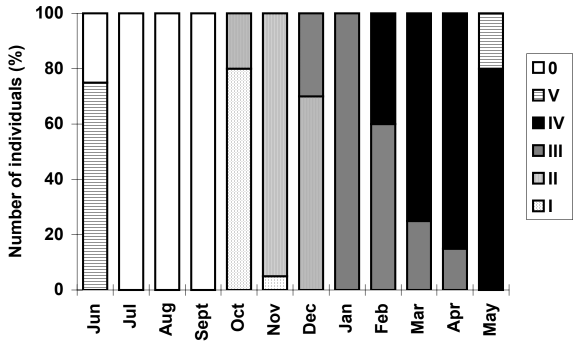


Figure 2-14 *Spisula solida*: Gonad developmental stages (percentage of individuals) based on six gonadal stages.

The condition index followed the gametogenic cycle of the species (Figure 2-15). This index increased before spawning, due to the gametogenic development that produced an increase in the size of the gonad, which resulted in a rapid increase of the index throughout the summer and autumn until mid-winter. From February to May the index decreased due to the spawning period. It is interesting to note that the condition index increased immediately after spawning, which indicates a rapid recovery and an accumulation of reserves that may be used in future gametogenesis. The changes of the condition index suggests that this species has a single protracted spawning period.

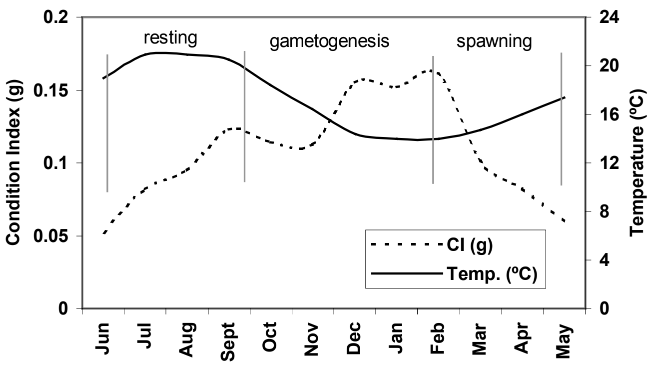


Figure 2-15 Changes in the condition index of *Spisula solida* and in the seawater temperature during the studied period**.**

The seasonal pattern of the sea surface temperature on the south coast of Portugal is characterised by low values during mid-winter, increasing in late winter and stabilising during the summer. The mean sea surface profile (Figure 2-15) exhibited a range in temperature from 14ºC (January—February) to 21ºC (August) over the study period. Gametogenesis in *Spisula solida* began when the seawater temperature started to decrease (late September, early October). The maturation of the gonad continued until late January when water temperature achieved its minimum. Spawning began in February when the seawater temperature started to increase. It is probable that the onset of spawning *in S. solida* may be correlated with increasing sea temperature (Gaspar and Monteiro 1999).

Length/Age of first maturation

All the specimens observed, ranging in length from 13 to 21mm, were late active or ripe independently of size. This result indicates that *Spisula solida* reaches maturity during the first year of life (Gaspar and Monteiro 1999).

Growth

Gaspar *et al.* (1995) demonstrated that the use of internal bands to estimate growth rates and age yields accuracy, and growth is only overestimated or underestimated when external shell lines are used. *Spisula solida* exhibited rapid growth during the first two years of life, reaching the minimum legal size of fishing (24mm) in about one year and a half. The estimated growth coefficient and asymptotic maximum size were 0.43 and 45.08mm respectively.

2.7 *Ensis siliqua*

Sex ratio

Ensis siliqua is gonochoric. The gonads of this species shows no colour differentiation in individuals of different sexes. Thus, the sex ratio must be assessed by examining gonadal smears. In general, females outnumber males for the first two age classes (Gaspar and Monteiro 1998).

Reproduction

Both sexes shows a synchrony in gametogenic development and spawning. The gametogenic cycle of *Ensis siliqua* was studied between June 1992 and May 1993. Figure 2-16 shows the percentage gonad condition each month for *Ensis siliqua*. In June 1992, only 10% of the razor clam population were in the partially spawn stage (stage IV) while 90% were in the spent stage (stage V). This species showed an extended inactive period from July to October. The gametogenesis began in November and by December 1992, 90% of the razor clams had developed to the late active stage (stage II). By January 1993, all the specimens examined were in the late active phase (stage II) of development and by March 90% of the specimens sampled were ripe (stage III), while the other 10% were partially spawned (stage IV). Spawning continued until May with a peak in April when all the individuals have spawned (Gaspar and Monteiro 1998).

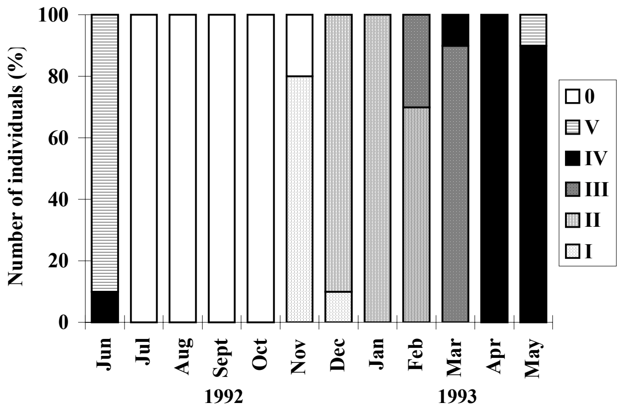


Figure 2-16. *Ensis siliqua*: Gonad developmental stages (percentage of individuals) based on six gonadal stages.

The condition index showed a similar change in *Ensis siliqua* (Figure 2-17) and followed the gametogenic cycle. After the spawning period, the condition index tended to increase. A steady increase was observed between November and February, until the beginning of spawning. The gonad index fell sharply as the percentage of spent individuals reached the maximum (Gaspar and Monteiro 1998).

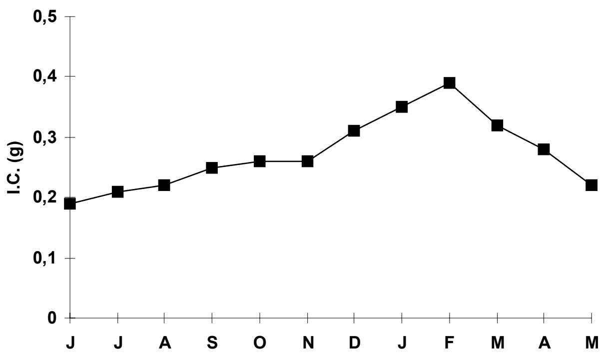


Figure 2-18 Monthly changes in the condition index of *Ensis siliqua*.

Length/Age of first maturation

All the specimens observed, ranging in length from 60 to 100mm, were late active or ripe, independently of size. This result indicates that *Ensis siliqua* reaches maturity during the first year of life (Gaspar and Monteiro 1998).

Growth

Acetate peels of shell sections of *Ensis siliqua* contain growth patterns, which vary in width along the entire length of the shell. Fast growth occurs during the winter when wide microgrowth increments are deposited, whilst slow growth occurs in the summer with the deposition of narrow growth increments and the formation of a cleft. The annual growth breaks appear to coincide with spawning in spring and early summer. The transference of energy normally allocate for shell growth to gonad development and spawning effort probably provokes the slowing of growth, with the subsequent formation of narrowing bands and a cleft, patterns that characterise the annual growth increments (Gaspar et al. 1995).

The analysis of von Bertalanffy growth curves has shown that the age of razor clams can be determined accurately from acetate peels rather than directly from the shell surface. The majority of shells present disturbances marks, seen externally as surfaces checks, caused by predation and dredging. Those individuals that did not present these disturbance marks could not be used to estimate age since they do not give rise to surface growth rings. The von Bertalanffy growth curve estimated for *Ensis siliqua* using internal bands was: Lt = 139.60 (1-e –0.65(t+0.28)) (Gaspar et al. 1995). This species exhibits fast growth in the first two years of life, reaching the minimum legal fishing size (100mm) at the end of one and half years.

2.8 *Chamelea gallina*: Portuguese waters

Sex ratio

Chamelea gallina is gonochoric. The gonads of this species show no colour differentiation in individuals of different sexes. Thus, the sex ratio must be assessed by gonadal smears. For the first two age classes females outnumber males (Gaspar and Monteiro 1998).

Reproduction

Both sexes show a synchrony in gametogenic development and spawning. The gametogenic cycle of *Chamelea gallina* was studied between June 1992 and May 1993.The percentage gonad condition each month for *Chamelea gallina* is shown in Figure 2-19 In June 1992, the majority of the population were partially spawned (stage IV). The spawning period ended by September when 5% were still spawning, 55% were in the spent stage (stage V) and 40% were in the inactive stage (stage 0). The inactive stage proceeded throughout October and November, and by the latter month, a new gametogenic cycle had begun. In the succeeding months, the number of individuals in the early active phase (stage I) rose rapidly. By February 70% of the gonads were in the late active stage and in March all clams were late active (stage II). About 90% reached the ripe stage (stage III) by April. Spawning (stage IV) began in May (Gaspar and Monteiro 1998).

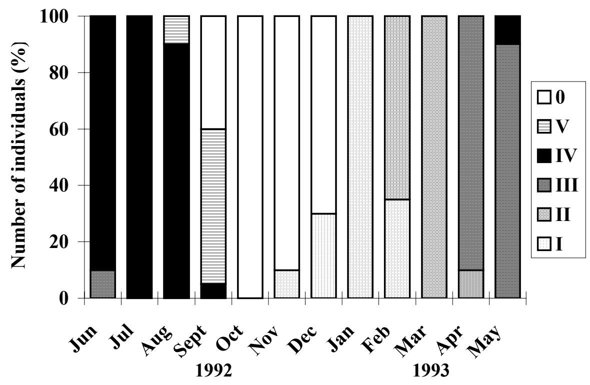


Figure 2-19*Chamelea gallina*: Gonad developmental stages (percentage of individuals) based on six gonadal stages.

The condition index followed the gametogenic cycle (Figure 2-19; Figure 2-20) After the spawning period the condition index tended to increase. A steady increase was observed during March, until the beginning of spawning. The gonad index fell sharply as the percentage of spent individuals reached the maximum (Gaspar and Monteiro 1998).

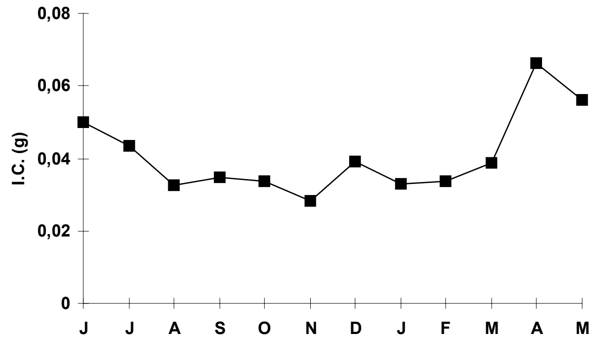


Figure 2-20. Monthly changes in the condition index of *Chamelea gallina*.

Length/Age of first maturation

All the specimens observed, ranging in length from 13 to 20mm, were late active or ripe independently of size. This indicates that *Chamelea gallina* reaches maturity during the first year of life (Gaspar and Monteiro 1998).

Growth

The pattern of microgrowth bands in shell sections of *Chamelea gallina* shows a seasonal variation in width. During the winter and late spring, between January and June, widely spaced growth bands are formed, whilst narrow growth increments are deposited in summer and early autumn between August and October (Gaspar 1996). There is no correlation between spawning and the formation of annual growth rings. Accurate age estimations were observed when internal bands were used. Thus the annual pattern of narrow and wide growth increments were used to estimate von Bertalanffy growth curves: Lt = 38.95 (1-e –0.47(t+0.24)). This species exhibits fast growth in the first two years of life, reaching the minimum legal fishing size (25mm) at the end of the second year (Gaspar 1996).

2.9 *Donax trunculus*

Sex ratio

Donax trunculus is gonochoric. Males and females are distinguishable externally since the colour of the gonad in this species is violet in the females and yellowish-orange in the males. Thus, gonads can be reliably sexed by macroscopic examination. On the south coast of Portugal, males usually made up a greater proportion (Gaspar et al. 1999).

Reproduction

Both females and males shows a synchronism in the gametogenic evolution and spawning. The gametogenic cycle of *Donax trunculus* was studied from December 1993 to November 1994 and is illustrated in Figure 2-21. The gametogenic cycle had already begun in December 1993 as 58% of individuals were in the early active stage, the remainder (42%) were in a late active stage. The late active stage dominated the samples of January and February. Partially spawned clams (75%) comprised the bulk of the sample in March. Spawning activity continued until August when 80% of the clams were spent. In September and October the entire population was in an inactive stage and by the end of November a new gametogenic cycle began. It is important to note that during the spawning period gametes within follicles were observed in several stages of maturation (Gaspar et al. 1999)

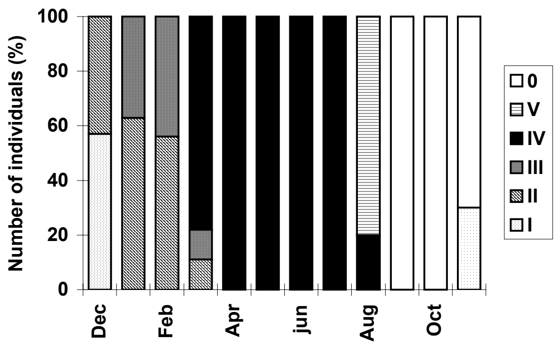


Figure 2-21. *Donax trunculus*: Gonad developmental stages (percentage of individuals) based on six gonadal stages.

Both the condition index (Figure 2-223) and the degree of gonadal development (Figure 2-21) showed the same pattern of variation A steady increase in the condition index of the population was observed after the initiation of gametogenesis in early December. This increasing trend continued until the beginning of spawning. The condition index decreased sharply as the percentage of spawning individuals reached maximum. During the inactive stage the condition of specimens increased slightly until October, when there was a decrease in the index. Between February and August the condition index showed an occurrence of two main spawning periods: in March and from May through August (Gaspar et al. 1999)

Length/ Age of first maturation

All the specimens observed, ranging in length from 13 to 21mm, were late active or ripe, independently of size. This result indicates that *Donax trunculus* reaches maturity during the first year of life (Gaspar et al. 1999).

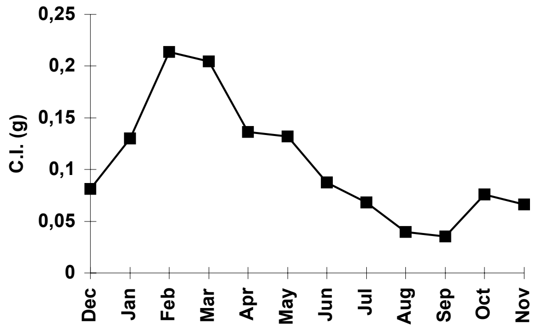


Figure 2-23 Changes in the condition index of *Donax trunculus.*

Growth

Donax trunculus showed rapid shell growth in spring and summer, when wide microgrowth increments were deposited, whilst slow growth occurred during late summer and early autumn with the deposition of narrow growth increments and the formation of a well-defined annual growth ring. The south Portuguese population of *Donax trunculus* does not show a period of cessation of growth through the winter months. In fact, this species renews growth in November, which then continues through until the following October which is a different pattern of seasonal growth than that found in other *Donax* populations in Europe (Gaspar et al. 1999).

The von Bertalanffy growth curve estimated from internal bands did not differ significantly from that obtained from the surface rings (Gaspar et al. 1999):

External rings: $L_t = 50.40\ (1-e^{-0.40(t+0.49)})$

Internal rings: $L_t = 47.30\ (1-e^{-0.51(t+0.52)})$

However, the age of clams can be determined more accurately from acetate peels than directly from surface rings. *Donax trunculus*, shows rapid growth during the first two years of life, reaching the minimum legal size of fishing (25mm) in about one year (Gaspar et al. 1999)

2.10 Clam species in French waters

Population dynamics

For these clam species the larval stage is a pelagic dispersal stage depending on current distribution and vertical migration behaviour. The larval stages can last for several weeks, depending on environmental constraints such as food, temperature and salinity, and therefore this affects spatial dispersion. However, thermal or hydrodynamic fronts in estuaries can limit larval dispersion. Survival rate is commonly a function of the temperature and salinity combination. However, many factors can effect recruitment including the availability of a suitable habitat. With their limited protection, this is a critical stage for shellfish larvae, which show at that time the greatest susceptibility to environmental changes, although this susceptibility decreases with age. Suitable environmental conditions are more critical than population size to obtaining successful recruitment and a sustainable population. This is demonstrated by shellfish population rebounds, following over-fishing, disease or introduction of alien species.

Venerupis rhomboides

Figure 2-24: ***Venerupis rhomboides*** **(fromQuéro and Vayne 1998)**

Habitat

Venerupis rhomboides is distributed from Norway to Morocco and in the Mediterranean Sea (Tebble 1966). It is found up to 180m deep, with maximum densities from 0 to 50m. It is a shallow burrower in coarse sand and gravel substrates, including muddy-gravel and coarse sand containing *Lithothamnion.*

Reproduction

It is a dioecious species with little external sexual dimorphism. The ratio of male:female is generally equal. The age of first maturity is 2 years old. Gametes are released into the water column all year, with the maximum during summer. Fertilisation is fully external and the pelagic life is 3 to 4 weeks before the larvae are ready to settle and metamorphose into benthic juveniles.

Growth

The growth of *V. rhomboides* is rapid (Figure 2-25). The median size is about 45mm and the maximum size about 70mm. Maximum longevity is 12 years.

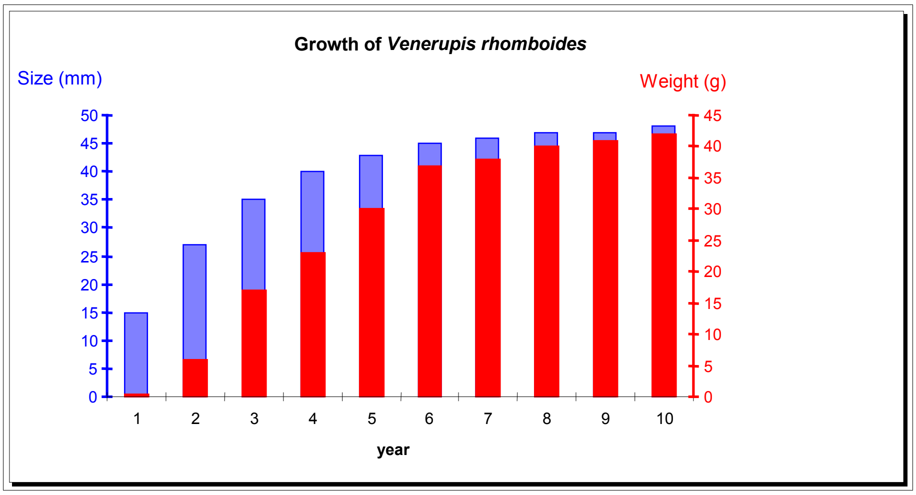


Figure 2-25: Growth of *Venerupis rhomboides* (from IFREMER DRV/RH).

Venerupis rhomboides is common in the Channel where it is mainly under-exploited, with catches varying according to market demand and recruitment fluctuations.

Glycymeris glycymeris

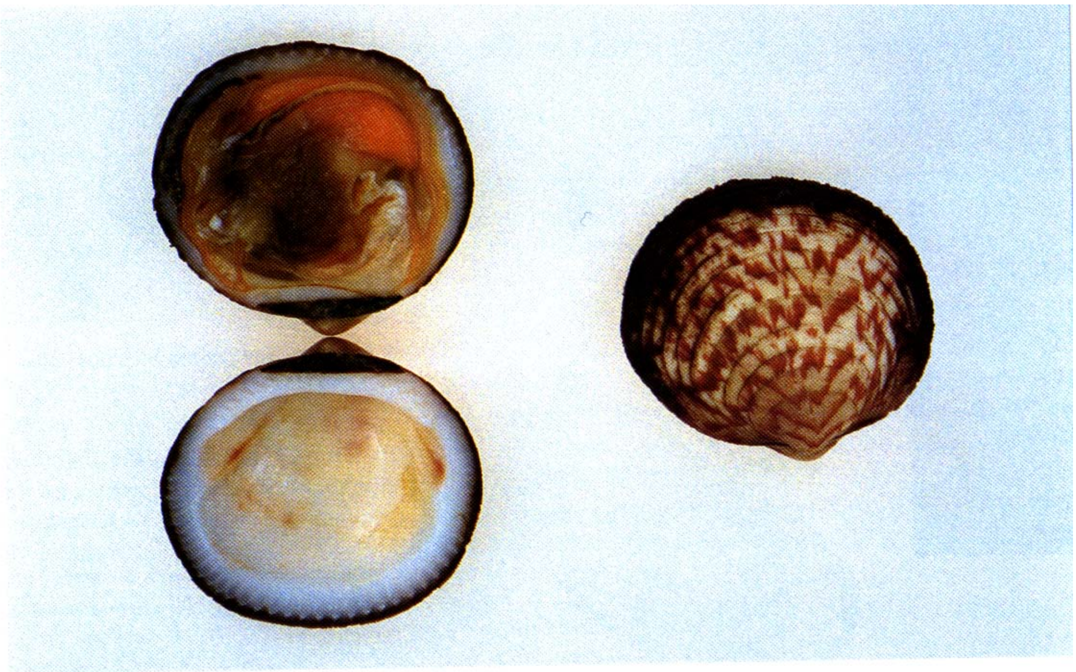


Figure 2-26: *Glycymeris glycymeris* (fromQuéro and Vayne 1998).

Habitat

Glycymeris glycymeris is distributed from Norway and the Baltic to the Iberian Peninsula, the Mediterranean, the Atlantic coast of Morocco to Madiera and the Canary Islands (Tebble 1966). It is a shallow burrowing suspension feeder that lives in muddy, sandy or shelly gravel, in areas characterised by strong water currents, from just offshore up to 80 meters deep.

Reproduction

Gametes are released from spring to autumn. Fertilisation is fully external. The pelagic life of the larva is 3 to 4 weeks.

Growth

The growth of *Glycymeris glycymeris* is very slow (Figure 2-27) and the median size of French populations is 40 – 60mm shell length which suggests that they are older than 18years, with a maximum size of about 80mm. In the Irish Sea, where detailed age and growth studies have been carried out (Steingrimsson 1989), *G. glycymeris* commonly reaches 40 years of age.

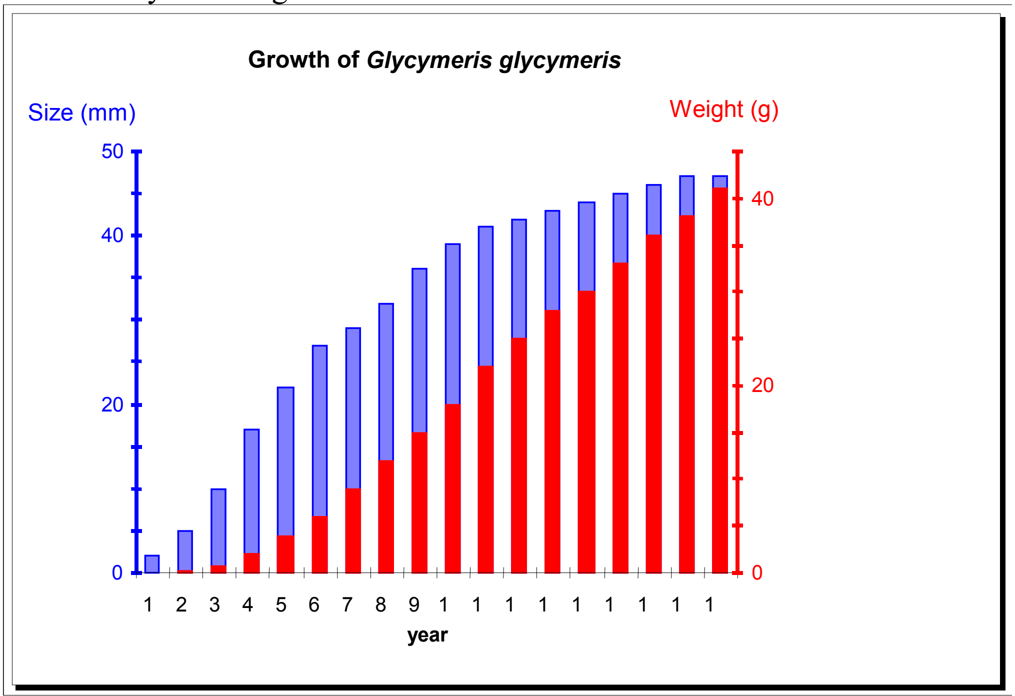


Figure 2-27: Growth of *Glycymeris glycymeris* (from IFREMER DRV/RH)

Glycymeris glycymeris is mainly under-exploited in the Channel, and catches vary according to the market conditions and recruitment fluctuations.

Spisula spp

Spisula ovalis and *Spisula solida*.

Figure 2-28: *Spisula solida* (Quéro and Vayne 1998).

Habitat

In the eastern Atlantic, *Spisula* sp. are distributed from the south Iceland and Norwegian Sea to Morocco and off Madeira (Tebble 1966). They occur from low in the intertidal to more 50m deep. They are shallow burrowing suspension feeders that often form very local, high density beds, mainly on sandy banks. The French beds are characterised by very large fluctuations of recruitment and are commonly of a single cohort.

Reproduction

Spisula is dioecious, with the ratio males females balanced. The age of first maturity is 18 months to 2 years old. Gametes are released into the water column all year with a maximum during summer. Fertilization is external, and the larvae are pelagic for 3 to 4 weeks, before settling and metamorphosing into benthic juveniles.

Growth

The growth of *Spisula* sp. is rapid, and from 5 years old the shell grows mostly in thickness.

Mytilus edulis

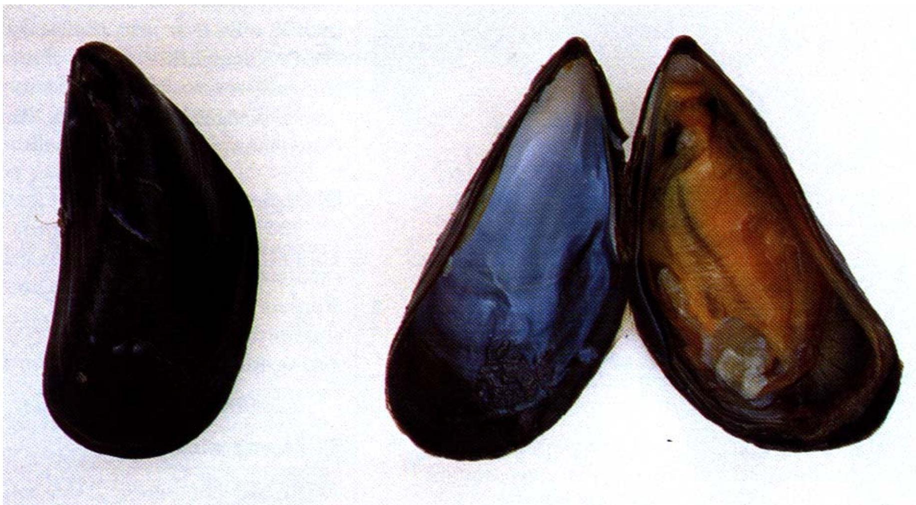


Figure 2-29 *Mytilus edulis* (from Quéro and Vayne, 1998).

Habitat

Mytilus edulis is widespread throughout the world. In Europe, it occurs in the Baltic Sea, the North Sea and along the Atlantic cost down to Portugal. It is common from high in the intertidal zone, usually to depths of 6 – 9 m. However, populations have been reported at 17 m in the North Sea and 30 – 40m in the Baltic Sea. It lives in dense masses, attached by byssus threads to rocky surfaces and suitable man-made structures

Description

Equal blue-black valves, with byssus. Self-regenerating population based on wild spat settlement that fluctuates annually.

Reproduction

Mytilus edulis is a dioecious species, and the sex ratio is equal. First maturity occurs at an age of 6 – 8 months. Gametes are released all year with the maximum during summer. Fertilization is external and the pelagic life of the larvae is 18 to 80 days before settlement and metamorphosis into benthic juveniles.

Growth

Growth is very variable, depends on local conditions. The maximum longevity also varies in different populations.

References for Section 2 Ecology and Population Dynamics

Aleffi F, Della Seta G, Goriup F, Landri P, Orel G (1998) Fattori climatici ed edafici e popolamenti bentonici dell'Adriatico settentrionale e del Golfo di Trieste. In Evoluzione dello stato trofico in Adriatico: analisi degli interventi attuati e future linee di intervento. Regione Emilia-Romagna, Provincia di Ravenna, Autorità di bacino del fiume Po, Marina di Ravenna

Allison EH (1993) The dynamics of exploited populations of scallops (*Pecten maximus* (L.)) and queens (*Chlamys opercularis* L.) in the North Irish Sea. Ph.D. thesis. University of Liverpool.

Allison EH, Brand AR (1995) A mark-recapture experiment on queen scallops, *Aequipecten opercularis*, on a North Irish Sea fishing ground. Journal of the Marine Biological Association of the United Kingdom 75: 323-335

Allison EH, Brand AR, Murphy EJ (1989) Mortality rates in North Irish Sea *Pecten maximus,* from tagging experiments 7th International Pectinid Workshop, Portland, Maine, 7pp

Allison EH, U. A. W. Wilson and A. R. Brand (1994) Age determination and the first growth ring in North Irish Sea populations of the scallop, *Pecten maximus* (L.). Journal of Molluscan Studies 60: 91-95

Amirthalingam C (1928) On lunar periodicity in reproduction of *Pecten opercularis* near Plymouth in 1927-1928. Journal of the Marine Biological Association of the United Kingdom 15: 605-641

Ansell AD, Dao JC, Mason J (1991) Three European scallops: *Pecten maximus*, *Chlamys (Aequipecten) opercularis* and *C. (Chlamys) varia*. In: (ed.) SE Shumway (ed) Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, pp 715-751

Aravindakshan I (1955) Studies on the biology of the queen scallop, *Chlamys opercularis* (L.). Ph.D. thesis, University of Liverpool.

Backeljiau T, Bouchet P, Gofas S, de Bruyn L (1994) Genetic variation, systematic and distribution of the venerid clam *Chamelea gallina*. J. Mar. Biol. Ass. U.K. 74: 211-223

Backhaus JO (1985) A three-dimensional model for the simulation of shelf-sea dynamics. Deutsche Hydrographische Zeitschrift 38: 165-187

Backhaus JO, Hainbucher D (1987) A finite difference circulation model for shelf seas and its application to low frequency variability on the North European shelf. In: Three dimensional models of marine and estuarine dynamics. Elsevier, Amsterdam

Baird RH, Gibson, F. A. (1956) Underwater observations on scallop (*Pecten maximus* L.) beds. Journal of the Marine Biological Association of the U.K 35: 555-562

Barber BJ, Blake, NJ (1991) Reproductive physiology. In: Scallops: biology, ecology and aquaculture. SE Shumway (ed) Elsevier, New York

Barillari A, Boldrin A, Mozzi C, Rabitti S (1978) Alcune relazioni tra natura dei sedimenti e presenza della vongola Chamelea gallina, nell'Alto Adriatico, presso Venezia. Atti Ist. Veneto Sci. Lett. Arti, cl.sci.fis.,mat.nat 137: 19-34

Beaumont AR, Gosling EM, Beveridge CM, Budd MD, Burnell GM (1985) Studies on heterozygosity and size in the scallop, *Pecten maximus* . In: Gibbs PE (ed) Proceedings of the19th European Marine Biology Symposium, Plymouth, Devon (UK),16-21 September, 1984., Cambridge University Press, pp 443-455

Bombace G (1992) Fisheries of the Adriatic Sea.In Marine eutrophication and population dynamics, Colombo G., I. Ferrari, V.U. Ceccherelli, R. Rossi (Eds), 25th European Marine Biology Symposium, Olsen & Olsen, Fridengburg- Denmark, pp 379-389

Bradshaw C, Veale LO, Hill AS, Brand AR (2000) The effects of scallop dredging on gravelly sea-bed communities. In: Kaiser MJ, de Groot SJ (eds) Effects of Fishing on Non-Target Species and Habitats. Blackwell Science, Oxford, pp 83-104

Brambati A (1992) Origin and evolution of the Adriatic Sea. In: Marine Eutrophication and Population Dynamics

Brand A R (1991) Scallop ecology: distributions and behaviour. In: Shumway S (ed) Scallops: Biology , ecology and aquaculture. Elsevier, Amsterdam, pp 517-584

Brand AR (2000) North Irish Sea scallop (*Pecten maximus* and *Aequipecten opercularis*) fisheries: effects of 60 years of dredging on scallop populations and the environment. Alaska Department of Fish and Game, Special Publication 14: 37-43

Brand AR, E. H. Allison and E. J. Murphy (1991) North Irish Sea scallop fisheries: a review of changes. In: Shumway, S E and Sandifer, P A (eds), An international compendium of scallop biology and culture. World Aquaculture Society, Baton Rouge, pp. 204-218.

Brand AR, J. D. Paul and J. N. Hoogesteger (1980) Spat settlement of the scallops *Chlamys opercularis* (L.) and *Pecten maximus* (L.) on artificial collectors. Journal of the Marine Biological Association UK 60: 379-390

Brand AR, Murphy EJ (1985) Estimation of mortality rates by a mark, release, recapture experiment for the Isle of Man scallop stocks 5th International Pectinid Workshop, La Coruña, Spain

Brand AR, Murphy EJ (1992) A tagging study of North Irish Sea scallop (*Pecten maximus*) populations: comparisons of an inshore and an offshore fishing ground. Journal of Medical and Applied Malacology 4: 153-164

Burnell GM (1983) Growth and reproduction of the scallop *Chlamys varia* (L.) on the west coast of Ireland. PhD thesis, National University of Ireland, Galway.

Burnell GM (1991) Annual variations in the spawning and settlement of the scallop *Chlamys varia* (L.) on the west coast of Ireland. In: Shumway SE, Sandifer PA (eds) An international compendium of scallop biology and culture. World Aquaculture Society, Baton Rouge, pp 47-59

Burnell GM, Slater J (1989) Scallop culture in Ireland: fact or fantasy? 7th International Pectinid Workshop, Portland, Maine

Caddy JF (1979) Long-term trends and evidence for production cycles in the Bay of Fundy scallop fishery. Rapport et Procès-Verbaux des Réunions. Conseil International pour l'Exploration de la mer 175: 97-108

Ceccherelli VU (1985) Ruolo dei bivalvi nella fascia costiera Adriatica. Nova Thalassia 7: 311-336

Chapman CJ, Main J, Howell T, Sangster GI (1979) The swimming speed and endurance of the queen scallop *Chlamys opercularis* in relation to trawling. Progress in Underwater Science: 57-72 (new series)

Conan G, Shafee MS (1978) Growth and biannual recruitment of the black scallop *Chlamys varia* (L.) in Lanveoc area, Bay of Brest. Journal of Experimental Marine Biology and Ecology 35: 59-71

Costa C, Bianchini M, Ceccarelli P, Orecchia P, Rambaldi E, Volterra L (1987) Indagine sui molluschi bivalvi di interesse commerciale (telline, cannolichi e vongole) delle coste della Toscana, del Lazio e della Campania, 1985 - 1987. Quad. Ist. Idrobiol. Acquacolt. Brunelli 7: n. doppio: 3-58; I-LXXVII.: 7: n. doppio: 3-58; I-LXXVII.

Darby CD, Durance, JA (1989) Use of the North Sea water parcel following model (NORSWAP) to investigate the relationship of larval source to recruitment for scallop (*Pecten maximus*) stocks of England and Wales International Council for

the Exploration of the Seas (ICES) Shellfish Committee Meeting Paper CM 1989/K:28
Dare PJ, Bannister RCA (1987) Settlement of scallop, *Pecten maximus*, spat on natural substrates off south west England: the hydroid connection. 6th International Pectinid Workshop, Menai Bridge, Wales, p12
Dare PJ, Darby CD, Durance JA, Palmer DW (1994) The distribution of scallops, *Pecten maximus*, in the English Channel and Celtic Sea in relation to hydrographic and substrate features affecting larval dispersal and settlement. In: Bourne NF, Bunting BL, Townsend LD (eds) Proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22-27, 1993. Volume 1 pp 20-27
Del Piero D (1998) Indagini sullo stock di *Chamelea gallina* (L. 1758), vongola comune nei compartimenti di Monfalcone (1984-1997) e Venezia (1990-1997). Biologia Marina Mediterranea 5: 395-399
Del Piero D, Fornaroli D (1998) Situazione dello stock di *Chamelea gallina* (L.) nel compartimento marittimo di Venezia (1984/1995). Biol. Mar. Medit 5: 393-403
Del Piero D, Fornaroli D, Balzo M (1998) Situazione dello stock di *Chamelea gallina* (L.) nel Golfo di Trieste dal 1984 al 1995. Biologia Marina Mediterranea 5: 382-392
Dickie LM (1955) Fluctuations in abundance of the giant scallop *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. Journal of the Fisheries Research Board of Canada 12: 797-857
Duggan NA (1987) Recruitment in North Irish Sea scallop stocks. Ph.D. thesis, University of Liverpool.
Eggleston D (1962) Spat of the scallop (*Pecten maximus* (L.)) from off Port Erin, the Isle of Man. Annual Report of the Marine Biological Station, Port Erin 74: 29-32
Elmhirst R (1945) Clam fishing in the Firth of Clyde. Transactions of the Buteshire Natural History Society 13: 113-116
Fonda Umani S (1996) Pelagic production and biomass in the Adriatic Sea. Scientia Marina 60: 65-77
Fonda Umani S, Franco P, Ghirardelli E, Malej A (1992) Outline of oceanography and the plankton of the Adriatic Sea. In: Marine Eutrophication and Population Dynamics.
Forester AJ (1979) The association between the sponge *Halichondria panicea* (Pallas) and scallop *Chlamys varia* (L.): a commensal-protective mutualism. Journal of Experimental Marine Biology and Ecology 36: 1-10
Franco P, Michelato A (1992) Northern Adriatic Sea: oceanography of the basin proper and of the western coastal zone. The Science of the Total Environment Supplement 1992: 35-62
Franklin A, G. D. Pickett and P. M. Connor (1980) The scallop (*Pecten maximus*) and its fishery in England and Wales Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft (U.K.) Laboratory Leaflet
Franklin A, Pickett GD (1980) Shell growth increments in scallops (*Pecten maximus*) from the English Channel. International Council for the Exploration of the Sea., Copenahagen (Denmark)
Franklin A, Conner, PM (1980) Cardigan Bay scallop survey, September 1980 Ministry of Agriculture Fisheries and Food, Directorate of Fisheries Research, Lowestoft Fisheries Notices
Froglia C (1975) Aspetti biologici, tecnologici e statistici della pesca alle vongole (Venus gallina). Quad. Lab. Tecnol. Pesca 9: 7-22.
Froglia C (1989) Clam fisheries with hydraulic dredges in the Adriatic Sea. In: Marine Invertebrate Fisheries: their Assessment and Management. Ed. J.F. Caddy, Wiley Interscience Publication

Gaspar MB (1996) Bivalves do litoral oceânico algarvio. Aspectos da biologia, ecologia e da pescaria dos mananciais de interesse económico: aplicação à gestão dos recursos. PhD Thesis, University of Algarve, Faro. pp 280

Gaspar MB, Castro M, Monteiro CC (1995) Age and growth rate of the clam *Spisula solida* L., from a site off Vilamoura, south Portugal, determined from acetate replicas of shell sections. Scientia Marina 59: 87-93

Gaspar MB, Castro M, Monteiro CC (1998) Influence of tow duration and tooth length on the number of damaged razor clams *Ensis siliqua*. Marine Ecology Progress Series 169: 303-305

Gaspar MB, Castro M, Monteiro CC (1999) Effect of tooth spacing and mesh size on the catch of the Portuguese clam and razor clam dredge. ICES Journal of Marine Science 56: 103-110

Gaspar MB, Monteiro CC (1998) Reproductive cycles of the razor clam *Ensis siliqua* and the clam *Venus striatula* off Faro, southern Portugal. Jour. Mar. Biol. Ass. UK 78: 1247-1258

Gaspar MB, Monteiro CC (1999) Indirect mortality caused to juveniles of *Spisula solida* due to deck exposure. J. Mar. Biol. Ass. UK 79: 566-568

Gruffydd LD (1972) Mortality of scallops on a Manx scallop bed due to fishing. J Mar Biol Ass U K 52: 449-445

Gruffydd LD (1974a) An estimate of natural mortality in an unfished population of the scallop *Pecten maximus* (L.). Journal du Conseil International pour l'Exploration de la Mer 35: 209-210

Gruffydd LD (1974b) The influence of certain environmental factors on the maximum length of the scallop, P*ecten maximus* L. Journal du Conseil International pour l'Exploration de la Mer 35: 300-302

Hall-Spencer J (1998) Conservation issues relating to maerl beds as habitats for molluscs. Journal of Conchology: 271-285

Hancock DA (1973) The relationship between stock and recruitment in exploited invertebrates. Rapport et Procès-Verbaux des Réunions. Conseil International pour l'Exploration de la mer 164: 113-131

Heipel DA, Bishop JDD, Brand AR (1999) Mitochondrial DNA variation among open-sea and enclosed populations of the scallop *Pecten maximus* in western Britain. Journal of the Marine Biological Association of the United Kingdom 79: 687-695

Heipel DA, Bishop JDD, Brand AR, Thorpe JP (1998) Population genetic differentiation of the great scallop *Pecten maximus* in western Britain investigated by randomly amplified polymorphic DNA. Marine Ecology Progress Series 162: 163-171

Le Pennec M (1974) Une novelle forme d'elevage margin: la pectiniculture. Penn. as Bed 2:(77): 328-341

Le Pennec M, Diss-Mengus B (1985) Rearing of *Chlamys varia* in commercial hatchery 5th International Pectinid Workshop, La Coruña, Spain, pp 9 pp

Lewis RI, Thorpe JP (1994) Are queen scallops, *Aequipecten (Chlamys) opercularis* (L.), self recruiting? 9th International Pectinid Workshop, April 22-27, 1993, Nanaimo, B.C., Canada, pp p 214-221

Light JM (1988) The status of *Chlamys varia* (L., 1758) and *Chlamys nivea* (MacGillivary, 1825); an appraisal using biometrics and geographical distribution. Journal of Conchology 33: 31-41

Lubet P (1959) Recherches sur le cycle sexuel et l'émission des gametes chez les mytilides et des pectinides (Mollusques bivalves). Revue de Travaux de l'Institute des Pêches Maritimes, Nantes 23: 387-548

Lucas A (1982) Evaluation of reproductive effort in bivalve molluscs. Malacologia 22: 183-187

Macleod JAA, J. P. Thorpe and N. A. Duggan (1985) A biochemical genetic study of population structure in queen scallop (*Chlamys opercularis*) stocks in the Northern Irish Sea. Marine Biology 87: 77-82

Mahéo R (1968) Observations sur l'anatomie et le functionnement de l'appareil byssogéne de *Chlamys varia* (L.). Cahiers de Biologie Marine 9: 373-379

Marano G, N. Casavola, C. Saracino (1980) Indagine comparativa sulla riproduzione di *Chamelea gallina* (L.), *Venus verrucosa* (L.), *Rudicardium tuberculatum* (L.) nel Basso Adriatico. Memorie Biol. mar. Oceanogr 10 (Suppl.): 229-223

Mason J (1957) The age and growth of the scallop, *Pecten maximus* (L.), in Manx waters. Journal of the Marine Biological Association of the United Kingdom 36: 473-492

Mason J (1958a) The breeding of the scallop, *Pecten maximus*, in Manx waters. Journal of the Marine Biological Association of the United Kingdom 37: 653-671

Mason J (1958b) A possible lunar periodicity in the breeding of the scallop, *Pecten maximus* (L.). Annals and Magazine of Natural History Series B 1: 601-602

Mason J (1969) The growth of spat of *Pecten maximus* (L.). International Council for the Exploration of the Sea, Shellfish and Benthos Committee Meeting Paper, CM 1969, Doc No K: 32

Mason J (1983) Scallop and queen fisheries in the British Isles. Fishing News Books Ltd (Buckland Foundation), Farnham (U.K.)

Mason J, Colman, JS (1955) Note on a short-term marking experiment on the scallop *Pecten maximus* (L.) in the Isle of Man. Annual Report of the Marine Biological Station, Port Erin,University of Liverpool, 67: 34-35.

McLoughlin RJ, Young, P., Martin, R., Parslow, J. (1991) The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. Fish Res 11: 1-24

Millward A, Whyte MA (1992) The hydrodynamic characteristics of six scallops of the Super Family Pectinacea, Class Bivalvia. Journal of Zoology, London 227: 547-566

Minchin D (1978) The behaviour of young escallops (*Pecten maximus* (L.) (Pectinidae) 2nd International Pectinid Workshop. 8-13 May 1978, Brest, France, pp 11

Minchin D (1981) The escallop *Pecten maximus* in Mulroy Bay. Fisheries Bulletin, Dublin 1: 21pp

Minchin D (1992a) Biological observations on young scallops, *Pecten maximus*. J. Mar. Biol. Assoc. U.K. 72: 807-819

Minchin D (1992b) Induced spawning of the scallop, *Pecten maximus*, in the sea. Aquaculture 101: 187-190

Minchin D, Duggan CB, King W (1987) Possible effects of organotins on scallop recruitment. Marine Pollution Bulletin 18: 604-608

Ministero delle Politiche Agricole (1998) Piano Vongole 1998 (Legge 164/98). Rapporti Tecnici a cura del Ministero per le Politiche Agricole.

Ministero delle Risorse Agricole Alimentari e Forestali (1996) Risorsa Molluschi. A cura del C.I.R.S.P.E, pp 86pp

Ministero delle Risorse Agricole Alimentari e Forestali (1998) Risorsa Molluschi a cura del C.I.R.S.P.E.

Ministero per le Politiche Agricole (1998) Decreto Ministeriale 21 luglio 1998

Mizzan L (1992) Malacocenosi e faune associate in due stazioni altoadriatiche a substrati solidi. Boll. Mus. civ. Stor. nat. Venezia 41 (1990) 1992: 7-54

Murphy EJ (1986) An investigation of the population dynamics of the exploited scallop, *Pecten maximus* (L.), in the North Irish Sea. Ph.D. thesis, University of Liverpool.

Naidu KS (1988) Estimating mortality rates in the Iceland scallop, *Chlamys islandica* (O.F. Muller). J. Shell. Res 7: 61-71
Nojima S, Russo GF (1989) Struttura di popolazione di bivalve *Chamelea (Venus) gallina* (L.). Oebalia XV: 189-201
Orel G, Del Piero D (1988) Relazione sulle ricerche condotte sullo stocks di *Chamelea gallina* nel Golfo di Trieste. Atti dei Seminari delle unità operative responsabili dei progetti di ricerca promossi nell'ambito dello schema preliminare di piano nella pesca e l'acquacoltura1: 321-336
Orel G, Vio E, Aleffi F (1989) Biocenosi bentoniche e loro modificazioni in seguito a stress anossici. In Curzi, P.V., F. Tombolini (Eds). Atti Convegno Nazionale per la Difesa dell'Adriatico, Ancona: 59-63
Orlic M, M. Gacic, P. E. La Violette (1992) The currents and circulation of the Adriatic Sea. Oceanologica Acta 15: 109-124
Paul JD (1978) The biology of the queen scallop, *Chlamys opercularis* (L.) in relation to its prospective cultivation. Ph.D. thesis, University of Liverpool.
Pellizzato M, Cornello M, Folin D, Grim M, Libralato M, Nesto N, Rocco R, Trigg RE, Vendramini A (1998) Sperimentazione della gestione dei banchi naturali di molluschi bivalvi della specie *Chamelea gallina* (L.) nei compartimenti marittimi di Venezia e Monfalcone (Nord Adriatico) (periodo Novembre 1997 - Aprile 1998). Biologia Marina Mediterranea 5: 385-394
Pingree RD, Griffiths,KD (1978) Tidal fronts on the shelf seas around the British Isles. Journal of Geophysical Research 83: 4615-4622
Prioli G, Fiori F, Mietto N (1998) Sperimentazione della gestione dei molluschi bivalvi nel compartimento di Chioggia. Biol. Mar. Medit. 5: 418-427
Quéro JC, Vayne JJ (1998) Les fruits de la mer et des plantes marines des peches françaises. Edition Ifremer: 256 pages
Ramster JW, Hill, HW (1969) Current systems in the northern Irish Sea. Nature 224: 59-61
Reddiah K (1962) The sexuality and spawning of Manx pectinids. Journal of the Marine Biological Association of the U.K. 42: 683-703
Riedl R (1991) Fauna e Flora del Mediterraneo. Dalle alghe ai mammiferi: una guida sistematica alle specie che vivono nel Mar Mediterraneo. Franco Muzzio Editore: 311-336
Roberts CD (1975) Investigations into a *Modiolus modiolus* (L.) (Mollusca; Bivalvia) community in Strangford Lough, N. Ireland. Report of the Underwater Association 1: 27-45
Rodhouse PG, Burnell GM (1979) *In situ* studies on the scallop *Chlamys varia*. In: Gamble JC, George JD (eds) Progress in Underwater Science. Pentech Press, Plymouth, pp 87-98
Rolfe MS (1973) Notes on queen scallops and how to catch them. Ministry of Agriculture Fisheries and Food Shellfish Information Leaflet 27.
Round FE, Sloane, J.F., Ebling, F.J. and Kitching, J.A. (1961) The ecology of Loungh Ine. X. The hydroid *Sertularia operculata* (L.) and its associated flora and fauna: effects of transference to sheltered water. J. Ecology 49: 617-629
Russo A, P. E. Artegiani (1996) Adriatic Sea hydrography. Scientia Marina 60: 33-43
Shafee MS (1980) Application of some growth models to the black scallop, *Chlamys varia* (L.) from Lanveoc, Bay of Brest. Journal of Experimental Marine Biology and Ecology 43: 237-250
Shafee MS, Lucas A (1980) Quantitative studies on the reproduction of black scallop, *Chlamys varia* (L.) from Lanveoc area (Bay of Brest). Journal of Experimental Marine Biology and Ecology 42: 171-186

Shafee MS, Lucas A (1982) Variations saisonnières du bilan énergétique chez les individus d'une population de *Chlamys varia* (L.): Bivalvia, Pectinidae. Oceanologica Acta 5: 331-338

Slater J (1995) Scallop spat collection in Mulroy Bay, Ireland, 1979-1994. 10th International Pectinid Workshop, Cork, Ireland, pp 68-69

Socal G, P. Franco , Franco P (1995) L'Adriatico settentrionale. Regione del Veneto. Piano per il rilevamento delle caratteristiche qualitative e quantitative dei corpi idrici della Regione Veneto, pp 7-12

Soemodihardjo S (1974) Aspects of the biology of *Chlamys opercularis* (L.) (Bivalvia) with comparative notes on four allied species. Ph.D thesis, University of Liverpool.

Steingrimsson SA (1989) A comparative ecological study of two *Glycymeris glycymeris* (L.) populations off the Isle of Man. Ph.D thesis, University of Liverpool.

Stella P, Rodinò E (1986) Ricerche sulla variabilità genetica del bivalve *Chamelea (Venus) gallina* (L.). Atti Ist. Veneto Sci. 144: 49-62

Tang SF (1941) The breeding of the scallop (*Pecten maximus* (L.)) with a note on growth rate. Proceeding and Transactions of the Liverpool Biological Society 54: 9-28

Tebble N, 1966. (1966) British bivalve seashells. A handbook for identification. *British Museum*, Edinburgh:

Wanninayake T (1994) Seasonal cycles of two species of scallop (Bivalvia: Pectinidae) on an inshore and an offshore fishing ground. Ph.D thesis, University of Liverpool.

Wilson JH (1987) Spawning of *Pecten maximus* (Pectinidae) and the artificial collection of juveniles in two bays in the west of Ireland. Aquaculture 61: 99-111

Wilson UAW (1994) The potential for cultivation and restocking of *Pecten maximus* (L.) and *Aequipecten (Chlamys) opercularis* (L.) on Manx inshore fishing grounds. PhD thesis, University of Liverpool.

3 DREDGE DESIGN

Dredge design is an ongoing process progressed by the experience of those involved with the manufacture and operation of dredges. Dredge designs have evolved over the years to suit the fisheries prosecuted; generic types are also adapted to particular environments mostly by trial and error. They show significant variation in terms of catching efficiency, selectivity and operation.

Dredges may be regarded as comprising three essential components: a structure to provide support, correct seabed contact and a towing point; a harvesting system to remove animals from the seabed and a collecting system to store the catch. All dredges incorporate these components, although designs can vary greatly depending on harvesting objectives. For example, designs range from that of a simple hand rake to those of sophisticated hydraulic clam dredges that comprise complicated dredge heads and pneumatic lifting systems.

In designing dredge components many factors have to be considered, most importantly: substrate composition, the target species' location and behavioural characteristics, local regulations and quality considerations. For example, wide rigid box dredges, with deep solid blades, are effective at excavating animals from soft sediments whereas narrow flexible dredges, with toothed harvesting blades and chain mail collecting bags, are more suitable for hard stony ground. Other designs, such as the Blake queenie dredge, exploits specific behavioural patterns by using tickler chains to cause animals to swim up from the seabed into the bag.

Component design is also influenced greatly by target species and sea bed types. Selectivity can occur at the seabed during the harvesting or collection process, as in the above designs, or on the vessel as in some hydraulic cockle dredges. Thus, in considering dredge design, it is extremely important to determine the dredge's operational environment, and the objective and design of each component.

The following section summarises the main dredge designs and their operations.

3.1 European dredge designs

3.1.1 Manual dredges

Manual dredges are operated mainly for recreational purposes. A dredge used in Italy to catch *C. gallina* consists of a crescent shaped steel loom (2.0 m wide and 1.0 m high), a steel mesh base, netting sides, and a blade on the lower part of the loom to penetrate the sediment Figure 3-1. The dredge weighs approxamately120 Kg (Pellizzato and Giorgiutti 1997).

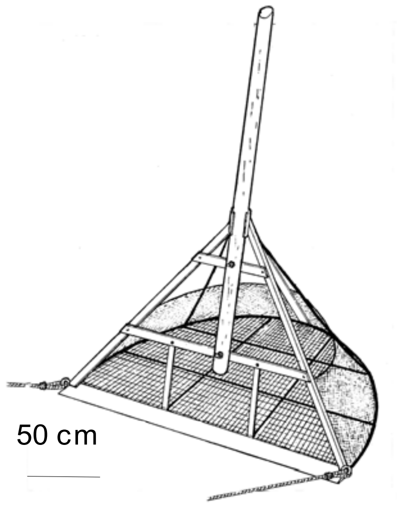
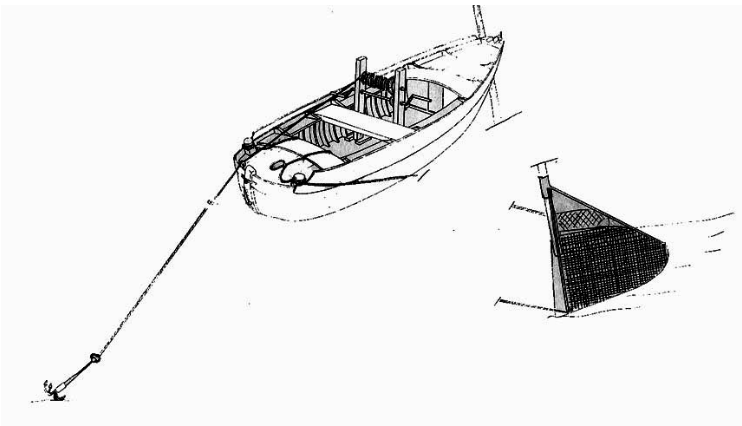


Figure 3-1 Manual dredge for *C. gallina*

The dredge is manoeuvred using an 8m long handle. The vessel tows by manual hauling on the anchor over the stern.



Fishing operation

A dredge used to harvest *Donax* clams in Portugal is shown in Figure 3-2. The gear comprises a steel arch attached to a grill and either a tooth bar or blade. The net bag is attached to the back of the grill. The dredge is pulled from the waist and held with the long-handled pole.

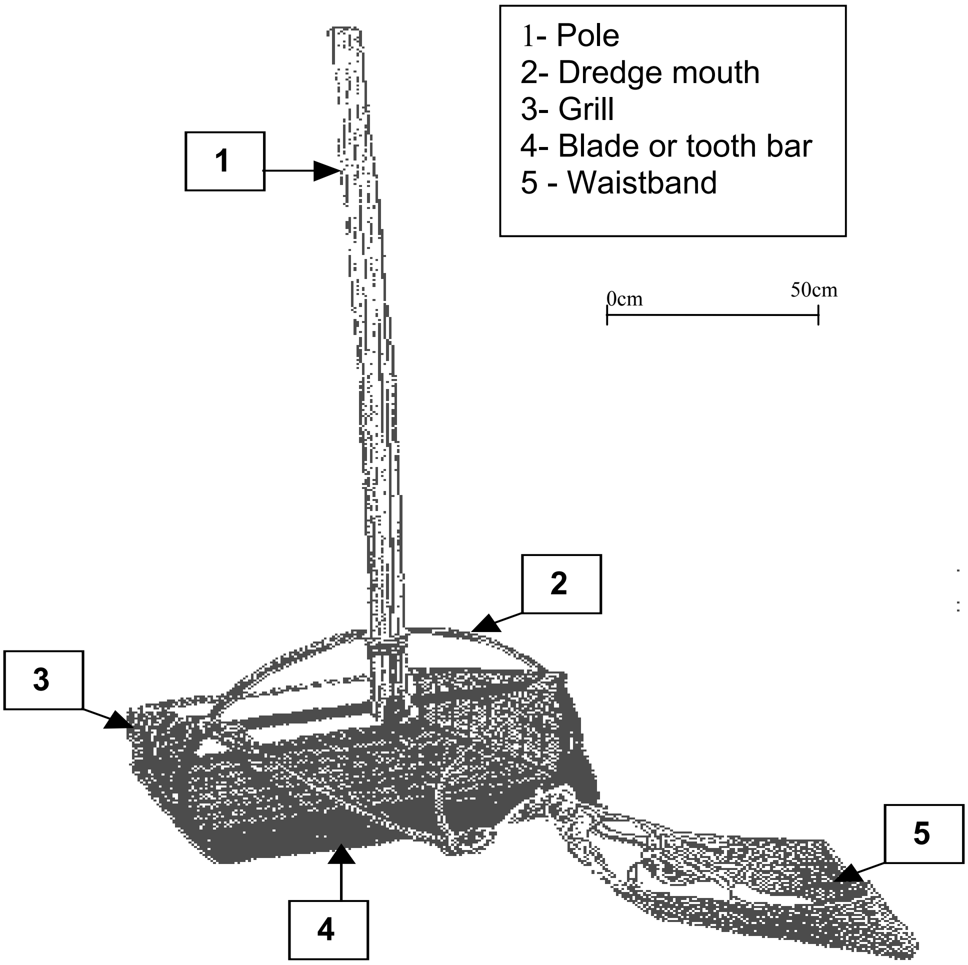


Figure 3-2 Manual dredge used to harvest *Donax trunculus*.

The dredge described in Figure 3-3 is used by recreational fishermen in France, is 25-40cm wide, with diving teeth and a towing handle.

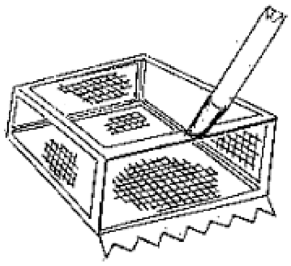


Figure 3-3 Hand dredge with wooden towing handle

A professional hand dredge used for harvesting *Donax trunculus* in France is shown in Figure 3-4.

Figure 3-4 Hand-dredge for *Donax*

It is more sophisticated, comprising a diving vane, wheels and a harness facility. Professional gear is limited to an overall width of 70cm, an internal mouth width of 50cm, and cage construction of longitudinal or transverse bars, with a minimal space between two bars of 8mm.

3.2 Box designs

Clam dredge

Clams (*Mercenaria mercenaria)* in the UK are caught most commonly with a box dredge, Figure 3-5. The dredge comprises a rigid steel structure consisting of a diving vane, a toothed digging blade (max 1.2m wide) and a mesh collecting box. Skids on the frame head prevent excessive tooth penetration.

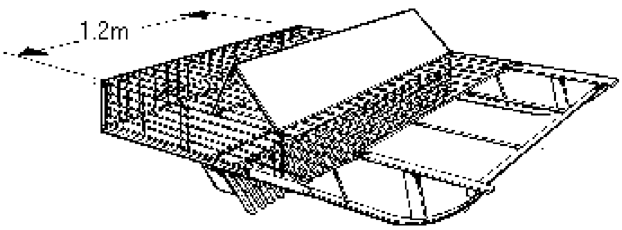


Figure 3-5 Clam dredge used in UK waters.

Gear is towed by a vessel; small vessels work single dredges, while larger vessels sometimes work two dredges, which are shot and hauled alternately.

Warty venus dredges

The warty venus dredge Figure 3-6, which is used in France (Normand-breton gulf) to catch *Venus verrucosa*, comprises a flat digging blade and rectangular collecting box fabricated from steel bar. Box dimensions vary from 1.8-2.2m length, 0.3m height and 0.5- 0.7m width. Bar spacing is 21-25mm and the blade is 10-15mm deep. Typical weight is 250-300kg.

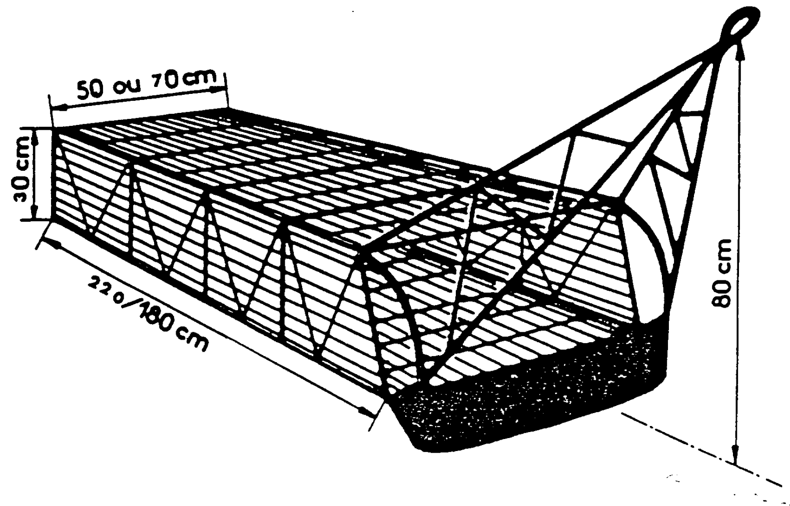


Figure 3-6 Warty venus dredge used in Normand-breton gulf.

Dredges used in Granville have a diving vane on the back to maintain bottom contact when the digging blade encounters resistance, Figure 3-7. Bar spacing is 21-25mm and the digging blade is 10-50mm deep.

Figure 3-7 Warty venus dredge with diving vane

Figure 3-8 Granville dredge

Small bivalve dredges

The dredges shown in Figure 3-8 and Figure 3-9 are used in France to harvest small bivalves. The dredge in Figure 3-8 comprises a rigid rectangular frame (2.2m x 0.9m) with narrowly space bars (18mm spacing) and a short, curved blade. The dredge used for catching small bivalves in Paimpol and Erquay (France), Figure 3-9, comprises a rigid rectangular frame (2.0m x 0.8m) with narrowly space bars (18mm bar spacing) and a deep, curved blade 40cm in depth.

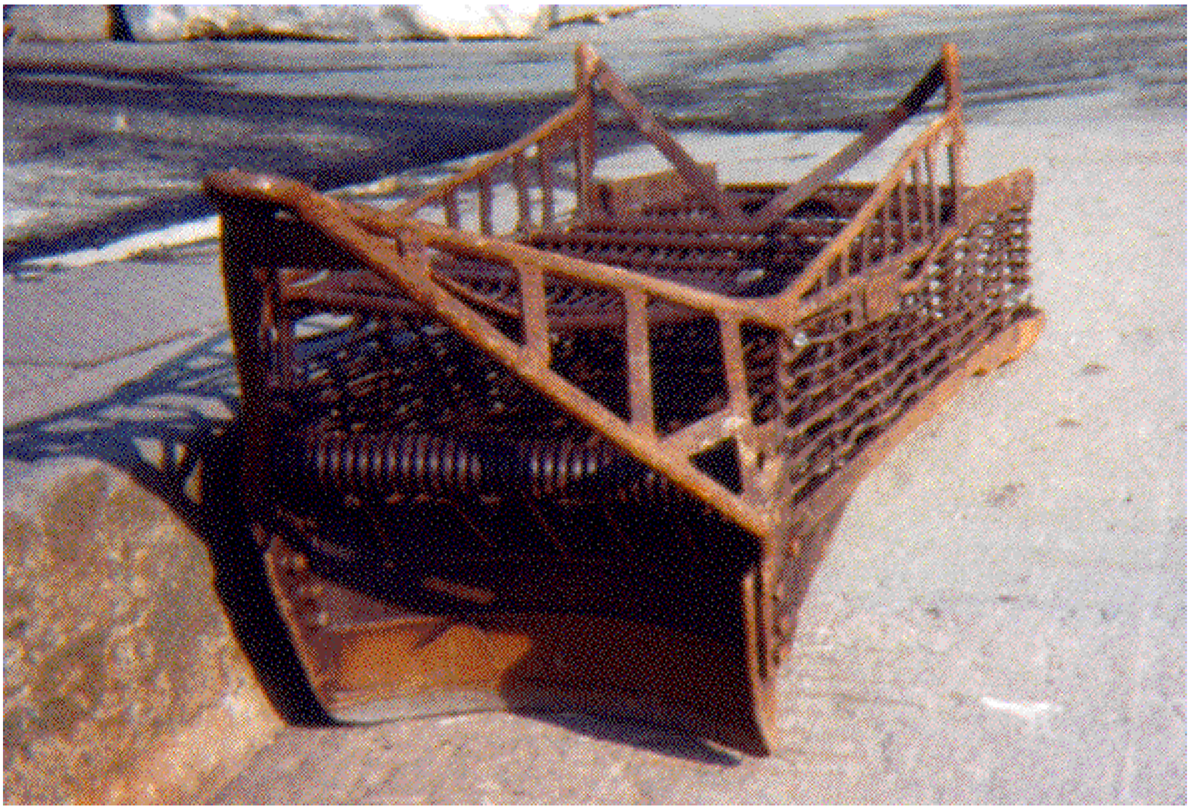


Figure 3-9 Dredge used in Bay of St. Brieuc (Pampol/Erquay)

3.2.1 Flexible designs

Fixed blade 'Oyster' dredge

The dredge used almost exclusively to catch common oyster (*Ostrea edulis)* in UK and Ireland is shown in Figure 3-10. The dredge employs a digging blade (max 1.2m wide) and collecting bag made from 5cm square mesh wire. Features considered most likely to influence selectivity are the digging blade (teeth) and mesh configuration. Small vessels tow one dredge whilst larger ones tow two which are shot and hauled alternatively.

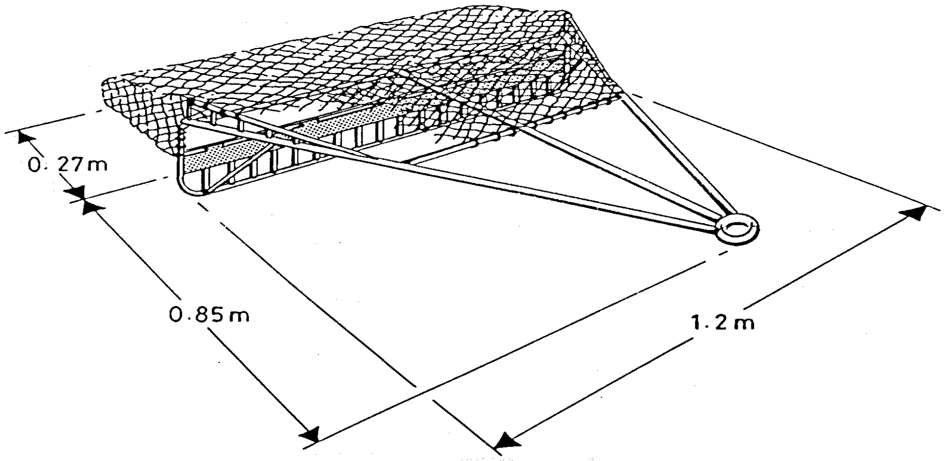


Figure 3-10 Traditional Oyster dredge

Fixed blade 'Dutch' Mussel dredge

The 'Dutch dredge', Figure 3-11, employs a cutting bar (1.7m wide) and a collecting bag comprising a chain mat belly and nylon netting mesh top (back). Features considered most likely to influence selectivity are the digging bar, steel rings and mesh configuration.

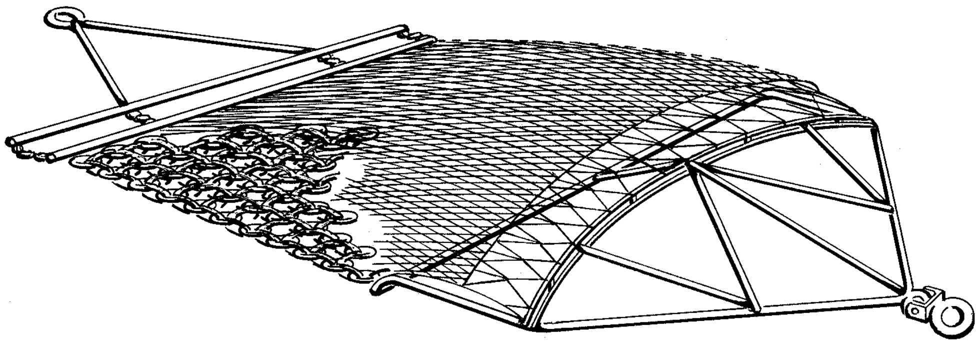


Figure 3-11 Dutch Mussel dredge

Small vessels work one or two dredges that are shot and hauled alternately, while larger vessels usually work two to four dredges that are shot and hauled together.

Flexible dredge for mussels

A dredge used in France to catch mussels (*Mytilus edulis)* comprises a heavy metal frame with a netting bag that is protected above and below by rubber covers. A digging blade, 10cm maximum length, is fixed around the mouth. Dredges used on muddy substrate are lighter and do not have digging blades.

Dredges used inshore, Figure 3-12, are usually smaller; the mouth being 0.75m wide and 0.40m high. The blade surrounding the mouth is inclined at 45 degrees. Mussels are collected into a bag that is 1.50m long and protected by rubber covers.

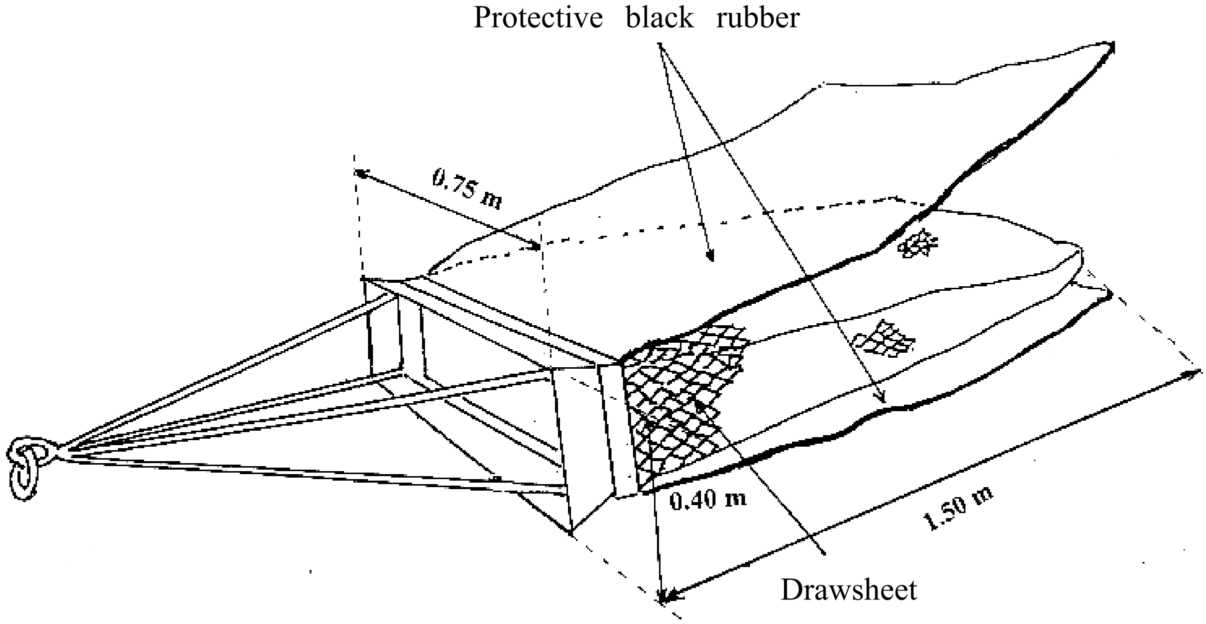


Figure 3-12 Dredge for mussels

The dredge used in the eastern Channel, Figure 3-13, employs a single digging bar, is larger (1.60m width and 3.1m long) and has anti abrasion panels on the underside only.

Gear operation

The dredge is towed with a cable normally at 3:1 warp to depth ratio, which can vary according to currents and the bed type. Boats operating in deep water tow only one dredge, usually at 3 knots speed.

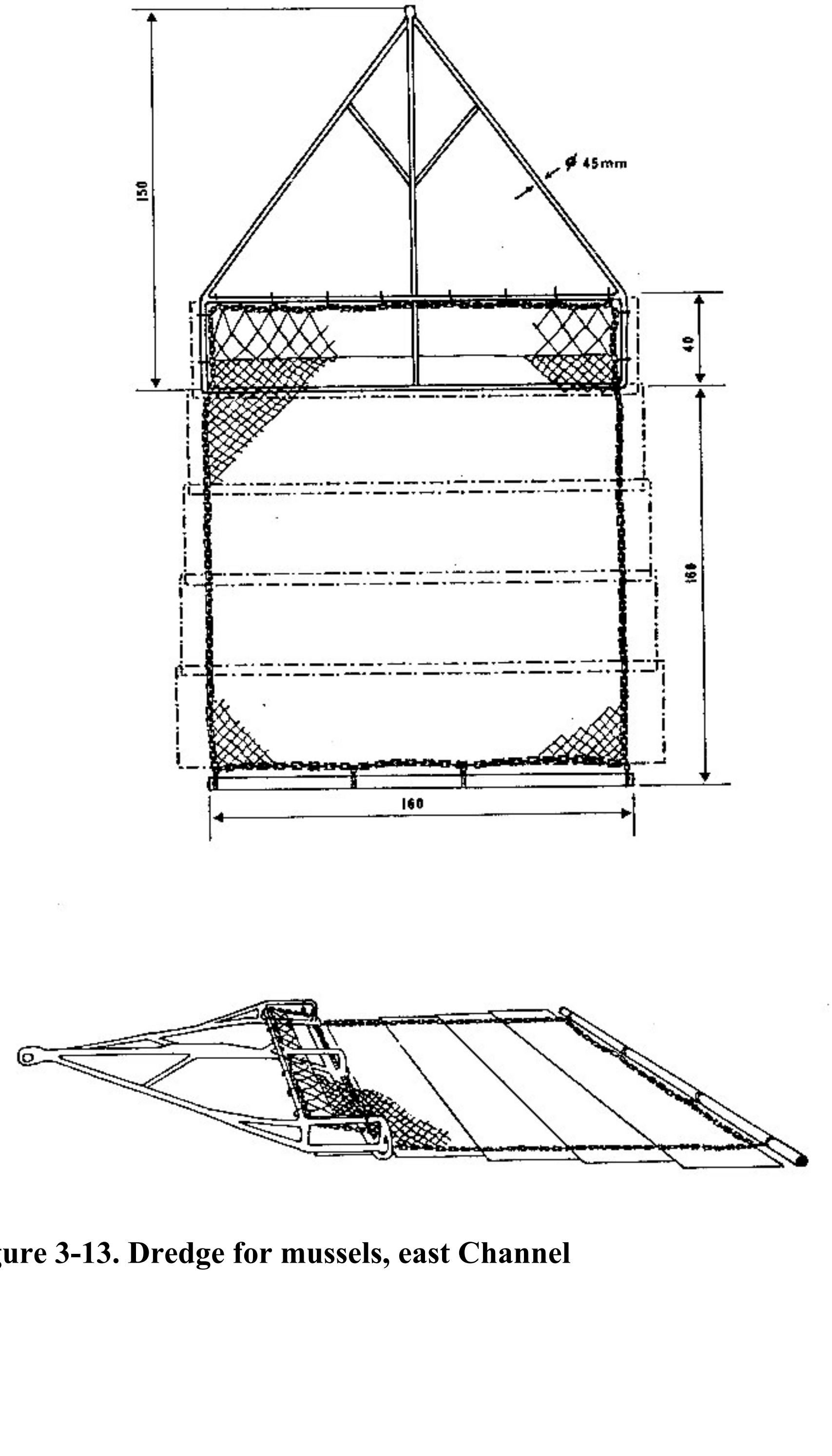


Figure 3-13. Dredge for mussels, east Channel

Fixed bar 'Ostreghero' and 'Sfogliara' dredges

"Ostreghero" and "Sfogliara" dredges, which are used in Italy, comprise a mouth and a collecting bag. The main species caught are oysters, mussels, scallops and clams, and flatfish such as soles.

The "Ostreghero" dredge, Figure 3-14, consists of an 8m long net bag and a 2m wide mouth. A lead fishing rope is fixed to the bar and there are no sled runners at the ends. The bag, which is fabricated from either textile or metal netting, is mounted over the bar and the lead file.

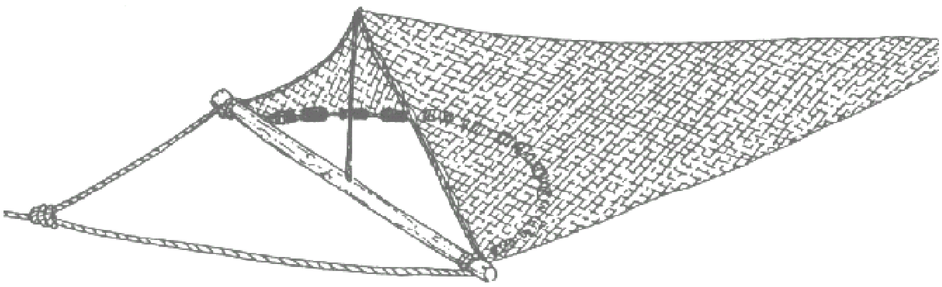


Figure 3-14. "Ostreghero" dredge (from Pellizzato & Giorgiutti, 1997)

The "Sfogliara" dredge, Figure 3-15, consists of a bar with two sled runners at the ends, with a rope or chain lead file and with a bag or a large net (Pellizzato and Giorgiutti 1997).

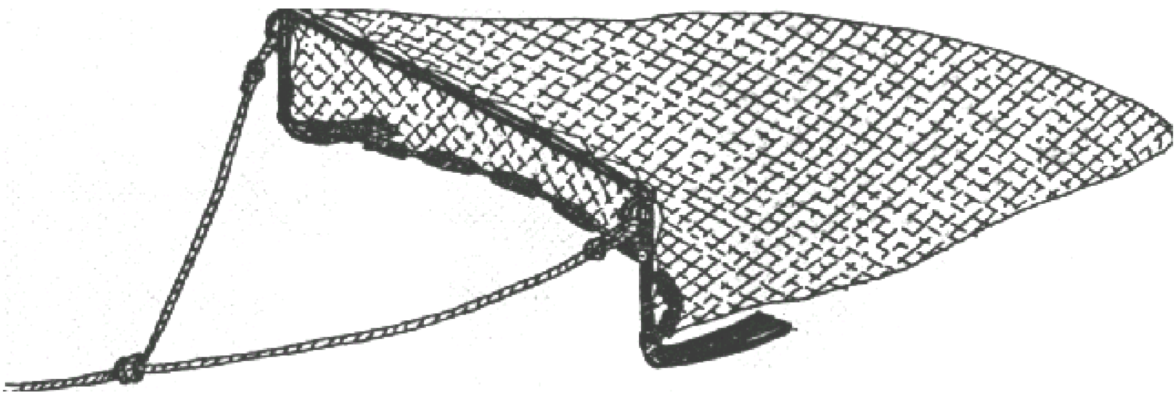


Figure 3-15. "Sfogliara" dredge (from Pellizzato & Giorgiutti, 1997)

By law, both the "Sfogliara" dredge and the "Ostreghero" dredge are restricted to a maximum mouth width of 1.6m and a minimum mesh size of 60mm, when fishing for molluscs.

Fixed bar 'Cassa' dredge

The "Cassa" dredge, Figure 3-16, is used in Italy to catch mainly oyster, mussels and clams (Pellizzato and Giorgiutti 1997). The dredge comprises a rectangular metal bar mouth (1.6m long and 0.3m high).

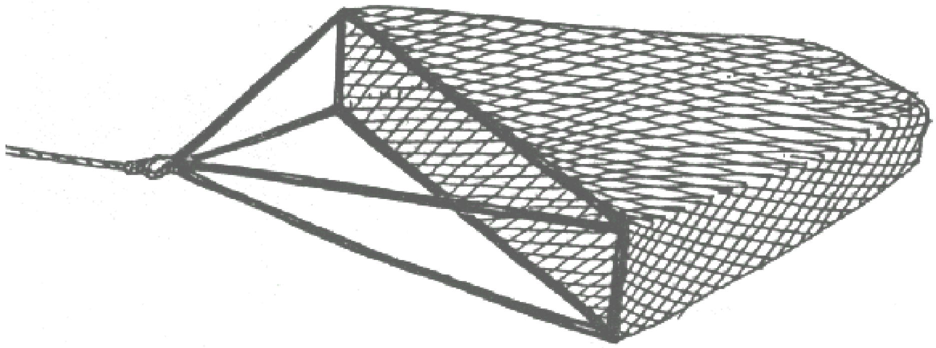


Figure 3-16. "Cassa" dredge (from Pellizzato)

Welded onto the mouth are stiffening bars that form a frame with a towing ring. A net bag is attached directly around the mouth. Regulations limit the mouth width to 1.6m and the mesh size to 60mm.

Toothed 'rake' dredges

Toothed vessel 'rake' dredges, which in Italy can be used only in the Tyrrhenian Sea, are tools formed by a rigid mouth with long metal teeth on its lower part. A net bag comprising of a single piece of netting is mounted around the mouth, a handle is used for regulating tooth inclination with respect to the bottom and the length of teeth are varied to suit sediment conditions. The fishing process consists of recovering the anchor rope through the winch. Each vessel tows two rakes, which each have a separate towing rope (Pellizzato and Giorgiutti 1997).

Toothed vessel rakes are restricted to a maximum mouth width of 1.5m, a minimum mesh size of 20 mm for *Donax trunculus* and 30mm for other molluscs, and a maximum net bag length of 2m.

Fixed tooth bar 'Baird' Mussel dredge

The 'Baird' dredge, Figure 3-17, which is used in the UK to catch *Mytilus edulis*, employs a diving vane, digging blade (max 1m wide) and mesh wire collecting bag. Features considered most likely to influence selectivity are the digging blade (teeth) and mesh configuration. Small vessels work single dredges while larger vessels usually work two dredges that are shot and hauled alternately.

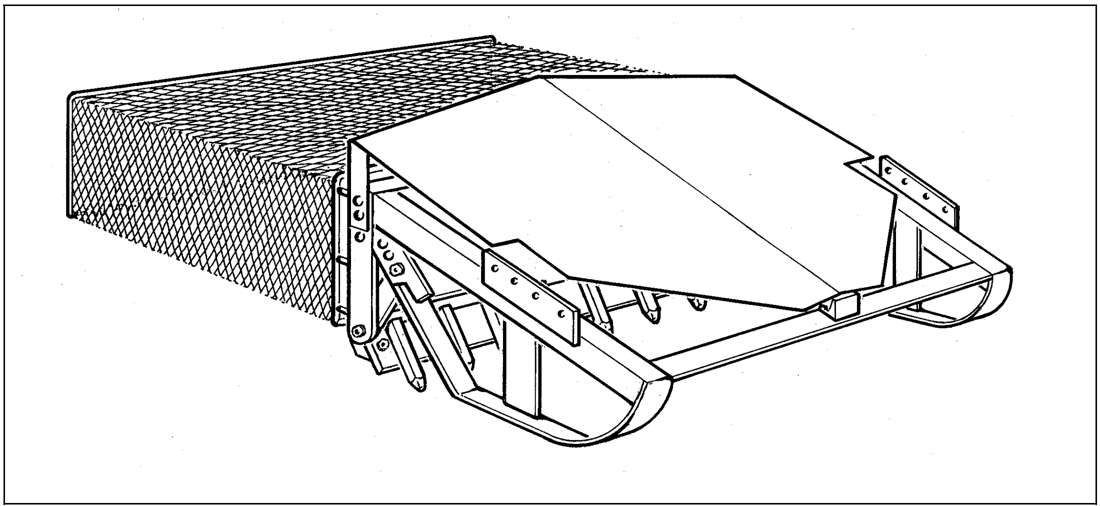


Figure 3-17. Traditional 'Baird' Mussel dredge.

*French Scallop (***P. maximus***) dredge*

The 'French' dredge, Figure 3-18, is used to catch king scallop, *Pecten maximus*, in the UK and France. It employs a digging blade (max 2.0m wide) and collecting bag made from steel rings of diameter 75-92mm, and usually a diving vane ('Saint-Bruiec dredge'). Typical weight without diving vane is 150-200kg and 250-300kg with, and size of meshes in netting backs is usually 85mm, except 92mm in Bay of Saint-Briec.

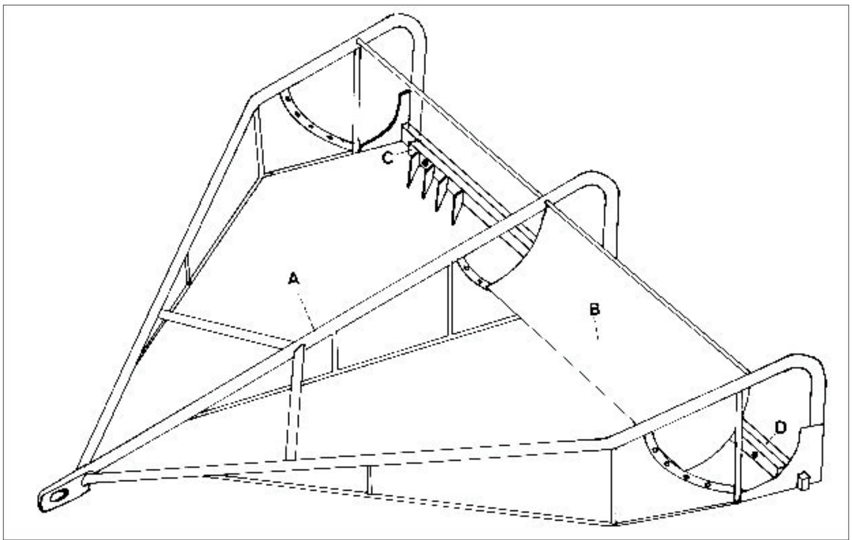


Figure 3-18. French *P. maximus* dredge used in VIIe and VIIId. Main frame – B: Diving vane, C: Tooth bar, D: Blade. This dredge may or may not be equipped or with a diving vane.

In France tooth spacing is 9cm. Dredges used off-shore are usually larger and more robust. Features considered most likely to influence selectivity are the digging blade, teeth and ring configuration.

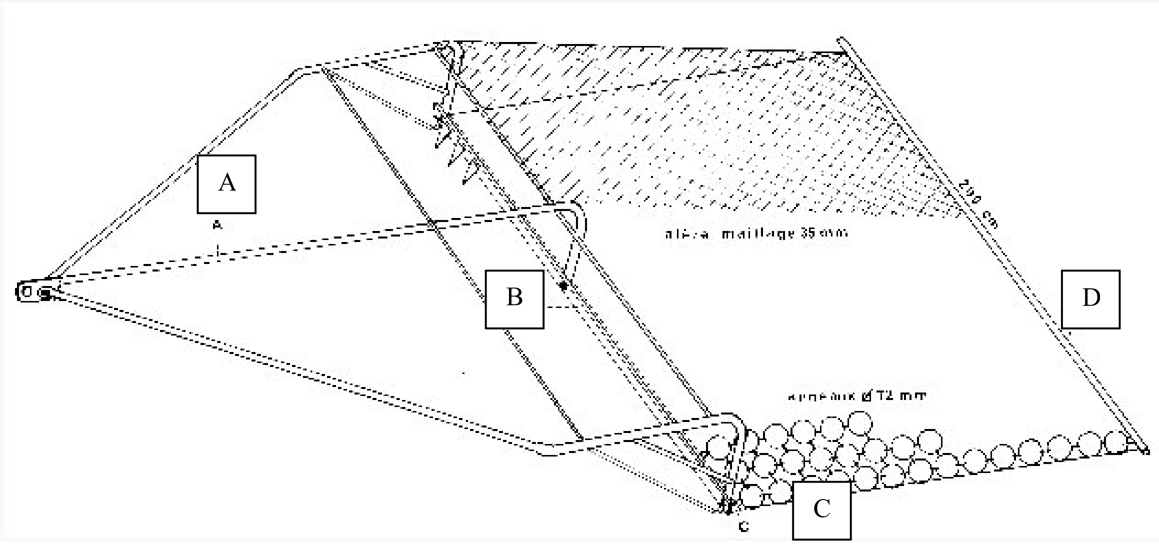


Figure 3-19. Traditional 'heavy Breton' dredge used in Bay of Brest A: Frame B: Blade with teeth (space between teeth 9cm, length teeth 10cm) C: Square for fixing the bag (chain belly and back netting, diameter of metal or nylon rings 72, 92 or 85mm D: Bar (width 1.8 to 2m).

A variant of the 'French' dredge is the traditional "heavy Breton dredge", Figure 3-19, which does not have a diving vane and is used only in France on the scallop beds of Belle-Ile, Lorient, Groix, Glénan, Concarneau, Douarnenez, and Brest. The dredge is typically 1.8 to 2m wide and has 9cm spacings between the teeth. Diameter of metal or nylon rings varies between 72mm (Lorient/Groix) and 92mm (Bay of Brest), but is typically 85mm (regulation for Atlantic and Western English Channel listed beds). Dredge weight and the tooth length are not regulated, apart from dredges fishing on the scallop stocks of the Bay of Brest where the maximum allowed weight is 170kg and the total length of teeth is 10cm. Dredges are worked individually by medium sized boats (4 dredges per vessel) or on wheeled towing beams (4-6m) by large 'beamers' using up to 10 dredges per vessel.

Fixed tooth bar 'Queenie' dredge

The dredge used mainly to catch 'black and white' queen scallops, *Chlamys varia and Aequipecten opercularis*, in France is shown in Figure 3-20. The dredge, which measures 1.8m by 3.2m and weighs 120kg, employs a fixed digging blade (max 0.66m wide) and collecting bag made from steel rings (42mm diameter) and mesh netting. Features considered most likely to influence selectivity are the blade and ring configuration. Small vessels work up to 6 dredges, whereas large vessels can operate up to 24 dredges.

Figure 3-20 Queenie dredge

Fixed blade dredge for Warty venus

A lightweight dredge used in France (Rade of Brest) to catch *Venus verrucosa* is shown in Figure 3-21. It measures 1.5m x 3.0m, weighs 90kg and comprises a toothed digging blade and metal ring (35mm diameter) collecting bag. The space between the screen bars is 21 to 25 mm. Small vessels work up to 6 dredges, whereas large vessels can operate up to 24 dredges.

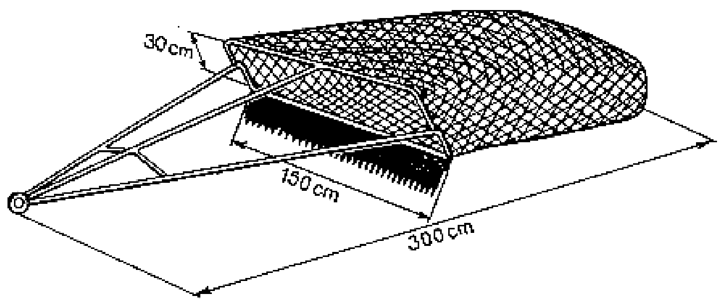


Figure 3-21. Warty venus dredge used in the Rade of Brest

Dredges are sometimes operated singly, but more usually in pairs. The main season is September-April.

'Thick trough shells dredge'

The dredges described in Figure 3-22 and Figure 3-23 are used in France (south Brittany) to catch 'Bittersweet' (*Glycymeris glycymeris)*; 'Warty venus' (*Venus verrucosa)*, *Spisula* sp, and palourd (*Venerupis rhomboïdes)*.

Figure 3-22. Thick trough shells dredge with short blade

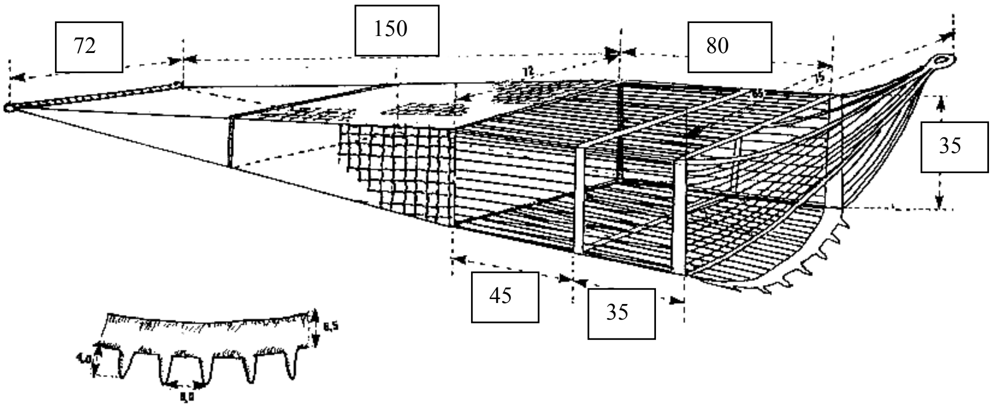


Figure 3-23. Thick trough shells dredge with blade and teeth.

Gear operation

Dredges used to catch *G. glycymeris* and *V. verrucosa* are usually 0.6-0.8m wide and fitted with a curved blade. The space between the screen bars is 21 to 25mm. Dredges are usually fished in pairs, but occasionally individually.

Dredges used to catch *Spisula* sp, and *V. rhomboïdes* are 0.6m-1m wide box-type construction with an average weight of 300kg. Spaces between bars are about 15mm for *Spisula* and 18mm for *V. rhomboïdes*. Dredges are usually fished in pairs. In the bay of Douarnenez, Iroise and south Britanny dredges are fitted with a wire netting bag, weigh less than 100kg, and are fished individually.

Spring tooth bar 'Newhaven' Scallop dredge

The dredge used commonly in UK, Isle of Man, Ireland and France to catch king scallop (*Pecten maximus*) is shown in Figure 3-24. The dredge, typically 0.8m by 1.4m and 350kg, employs a sprung-toothed digging blade (approx. 0.7m wide) and collecting bag made from steel rings (74-85mm internal diameter) and, usually, mesh netting. Features considered most likely to influence selectivity are the teeth, and ring configuration.

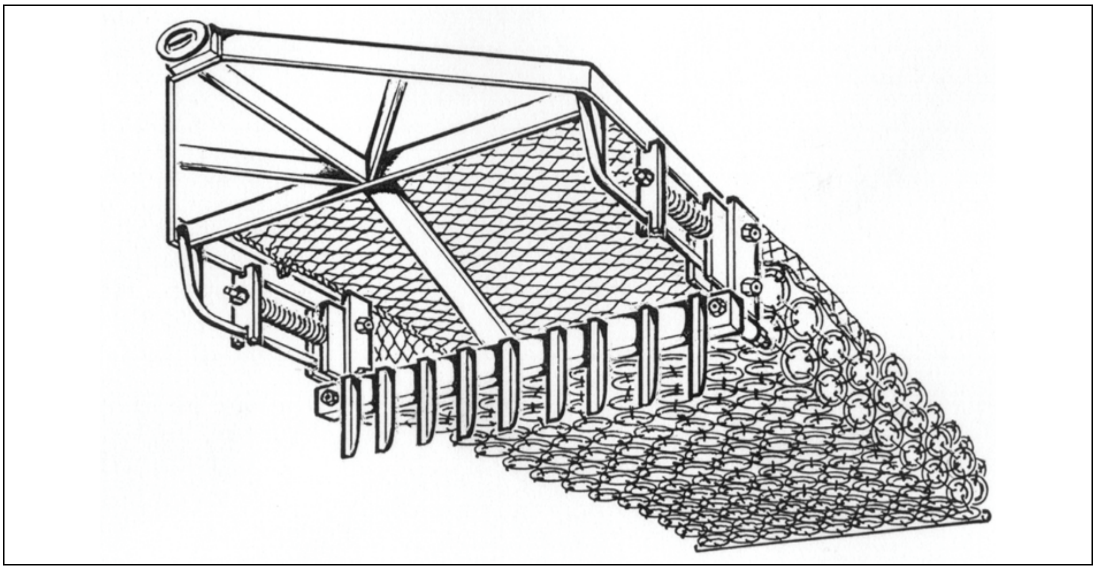


Figure 3-24. Newhaven 'spring' Scallop dredge

Gear is towed by a vessel using wheeled towing beams, typically 4-6m, Figure 3-25. Small vessels work 6–16 dredges whereas larger vessels work up top to 24 dredges. Spring-loaded dredges are used normally for all small vessels and for many large vessels.

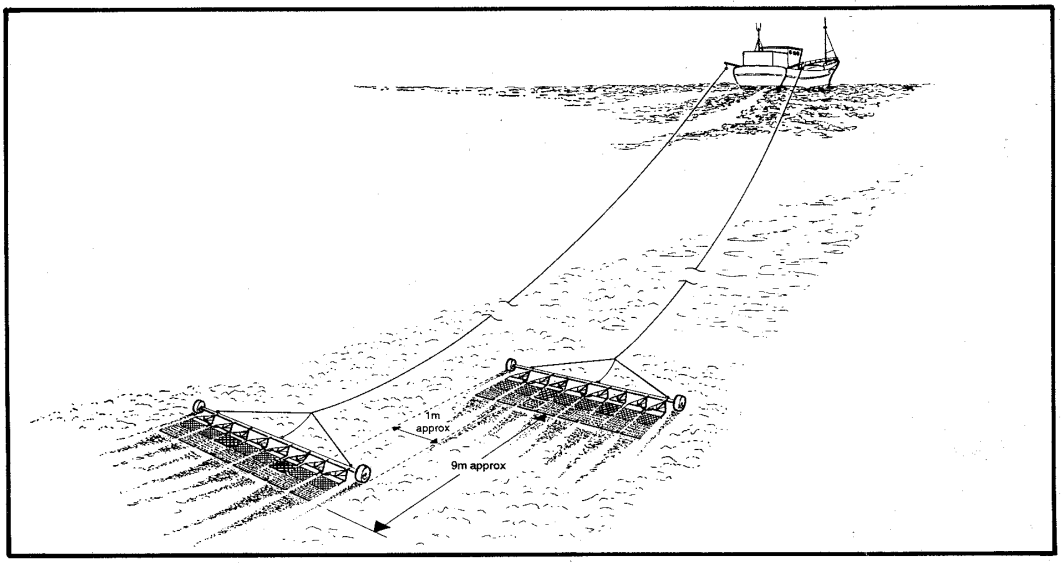
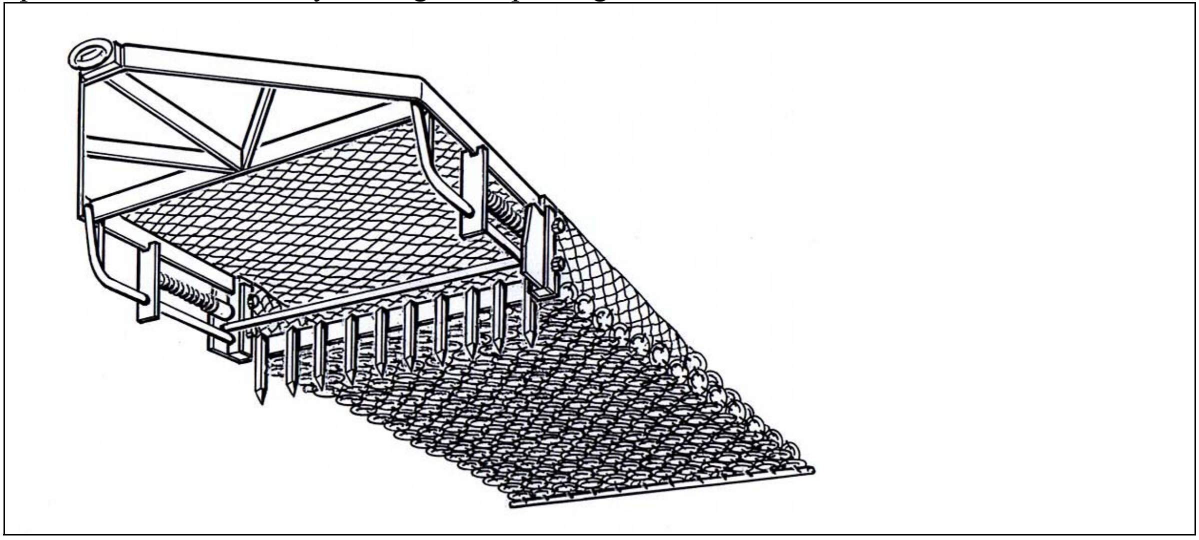


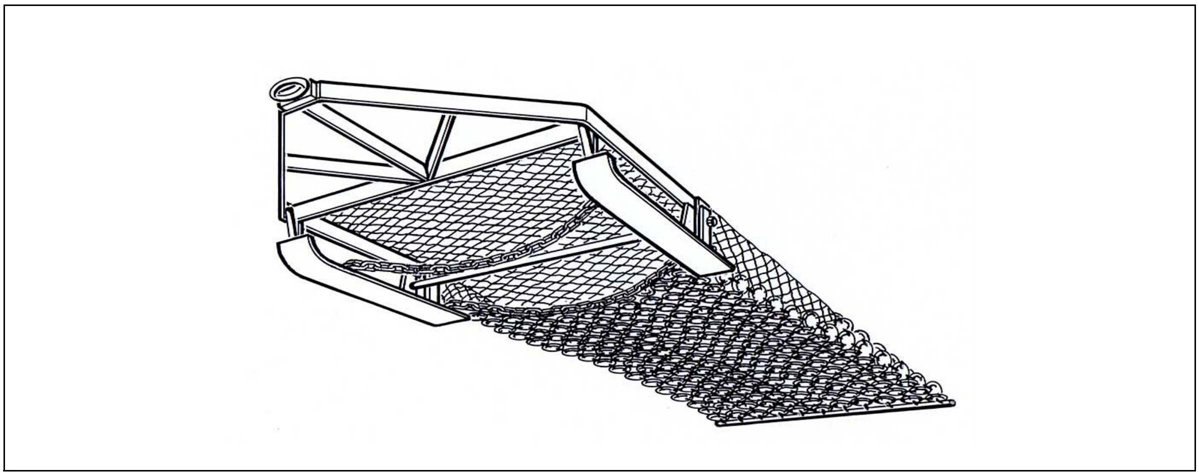
Figure 3-25. Newhaven 'Spring' scallop dredge: Fishing operation

'Queenie' dredges

Two types of dredges are used in British waters for queen scallop (*Aequipecten opercularis*). Toothed dredges (Figure 3-26A) employ a sprung tooth bar and are similar to Newhaven spring scallop dredges except that the teeth are spaced closer together and are, in some cases shorter an thinner. Skid dredges (Figure 3-26B) use skids and tickler chains instead of teeth. In both cases the belly rings are around 60-70 mm. internal diameter. They are towed and operated in the same way as king scallop dredges.

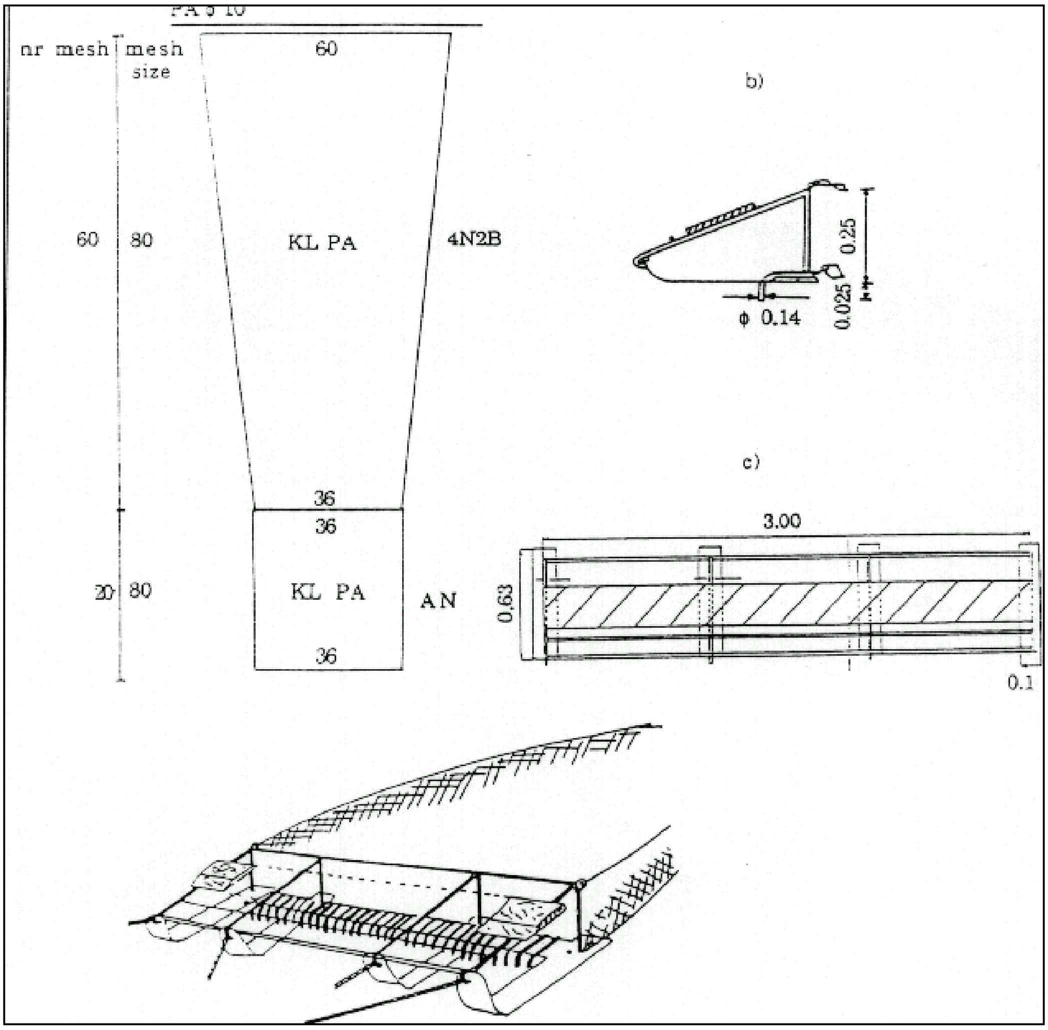


A



B

Figure 3-26. Toothed and skid 'Queenie' dredges



Fixed tooth bar 'Rapido' Scallop dredge

Figure 3-27. Typical "Rapido" dredge used in Adriatic Sea: a) net arrangement, (abbreviations are referred to ISO Rules N° 1532 and 3169); b) lateral view, c) upper view (Giovanardi et al. 1998).

The 'Rapido' dredge, which was designed originally for catching flatfish, is used in Italy to catch *Pecten jacobaeus,* Figure 3-27. The dredge has short teeth, a fixed mouth, and is towed quickly at 4-5 knots. A rigid frame, 20-40cm high forms the mouth, and the dredge bar has curved teeth, almost 40cm long. Four sled runners prevent the teeth from digging too deeply into the sediment and a diving vane situated on the upper frame bar improves ground contact. The mesh size of the bag is variable, and the underside is protected against wear by an apron of coarse plastic netting.

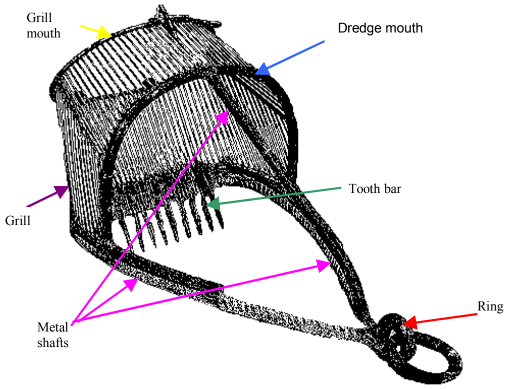
By law, the mouth and mesh size of a rapido dredge used for catching scallops is restricted to 1.6-3.2m, and 50mm respectively. The size and number of rapido dredges operated simultaneously can vary according to vessel power (Mattei and Pellizzato 1997).

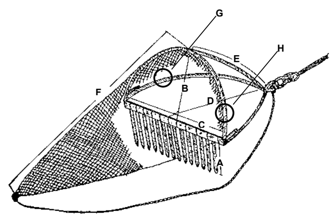
This type of dredge is used only in the Adriatic Sea; the scallops *Pecten jacobaeus*, *Aequipecten opercularis* and *Chlamys* sp. are caught offshore, whereas *Solea* sp. are caught in shallow coastal water between 3 and 5 miles from the coast.

Portuguese Clam and Razor clam dredge

The basic clam and razor dredge used along the south and southwest coast of Portugal, comprises a small, heavy semicircular iron structure, with a net bag and a toothed lower bar at the mouth, Figure 3-28. The tooth bar has 12 to 14 teeth spaced 1.5 to 2.5cm apart with a maximum length of 55cm. A grid is often welded to the posterior part of the dredge mouth to filter out sand.

Figure 3-28. Portuguese clam and razor clam dredge used along the South and Southwest coast.





Gear specifications

	Clam dredge	Razor clam dredge
A	20cm	55cm (max.)
B	54cm	
C	64cm	
D	84cm	
E	91cm	
F	200cm	
G (diameter)	2.46cm	
H (diameter)	2cm	
tooth bar Thickness	2.2cm	
tooth bar Height	5.2cm	
Space between teeth	2.5cm	1.5cm
Diameter of the teeth	1.4cm	1.4cm
Dredge structure	iron	

The dredge used on the Northwest coast, Figure 3-29, is similar to the one described above, except that the iron structure is semicircular, not rectangular.

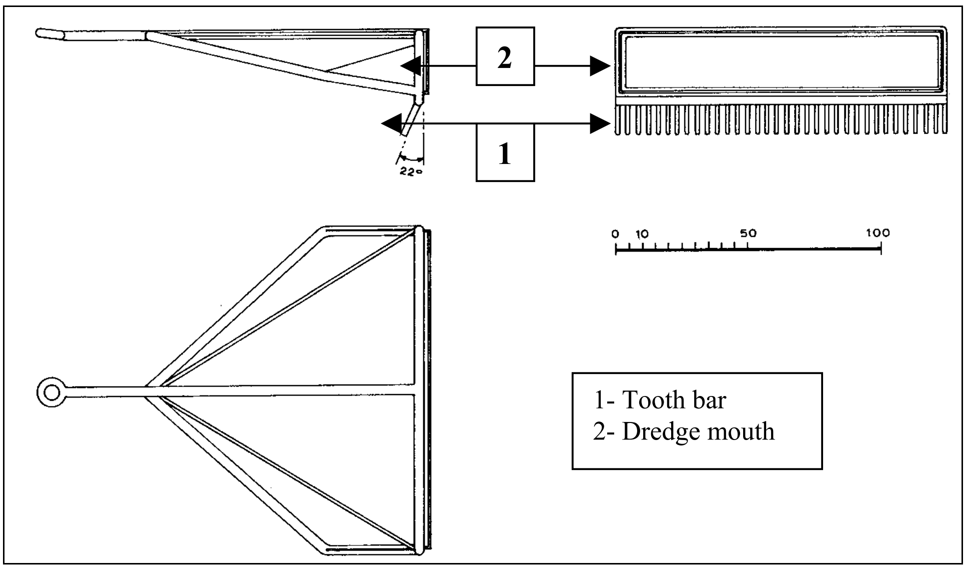


Figure 3-29. Portuguese clam dredge used along the Northwest coast.

Gear operation

A vessel tows the gear, small local vessels work single dredges while larger coastal vessels work two dredges simultaneously. However, on the south west coast vessels of all sizes work only one dredge. Each dredge is secured to the boat by a single towing rope (3:1 warp to depth ratio).

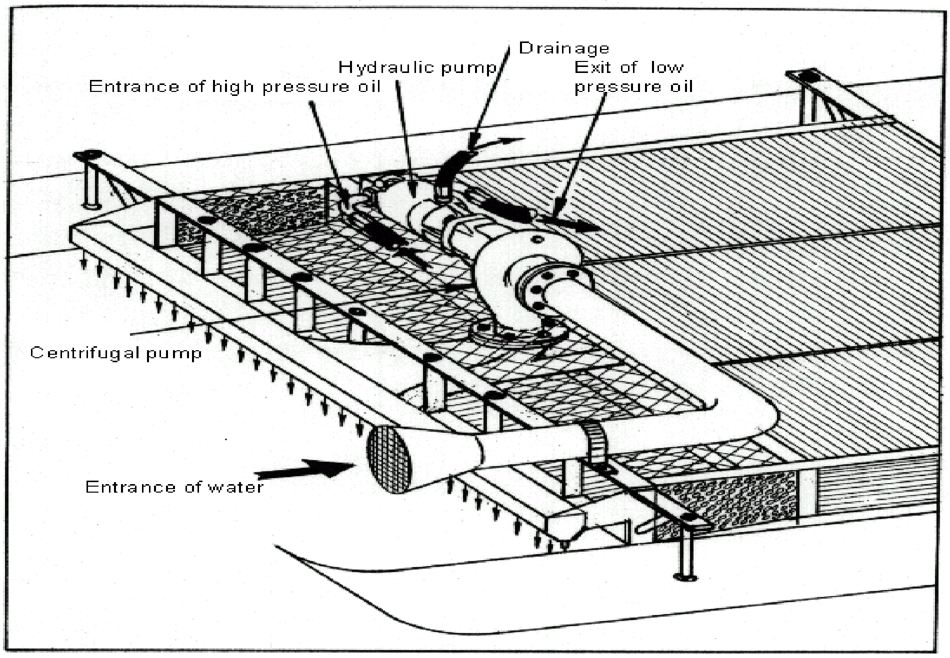
When a clam bed is found a buoy is laid and the vessel starts to fish. Each tow lasts 1 to 20 minutes, usually at a speed of 1 to 1.5 knots. At the end of the tow a two-drum winch hauls the dredges and the catch is placed into a collecting box. Catches are sorted manually or using a sieve (manual or mechanical), usually at the end of the fishing day.

3.2.2 Hydraulic dredges

Hydraulic dredge are capable of penetrating several centimetres into the sea bottom and extracting epi- and benthic marine organisms using the action of water jets. Sand and mud drawn up by the gear are expelled by pressurised water, while the molluscs are retained within a cage structure althoug some systems suuch as the cockle dredge have means for continious delivery to the deck.

Gear consists typically of a system for delivering pressurised water through jets, and a blade for cutting the sediment. Water jets are often fixed in various parts of the gear to wash the shellfish, Figure 3-30 to Figure 3-31.

Figure 3-30. Detail of a hydraulic apparatus with submerged pump (from Ferretti *et al.*, 1990).



The hydraulic dredge is characterised by:

- a horizontal opening (mouth);
- a rigid cage structure, made of steel bars, for collecting the catch;
- jets from which pressurised water is expelled; and
- either a large pipe that transports water from the vessel to the jets or, if the pump is located on the dredge, a system of hydraulic oil pipes, Figure 3-30.

The main attributes of hydraulic gear used typically in Italy for the above species are shown in Figure 3-30 and Figures 3-31. The rigid cage and sledge arrangement, which prevents the dredge from sinking in the mud, it is the most important feature because the catch rate depends on its correct orientation and operation.

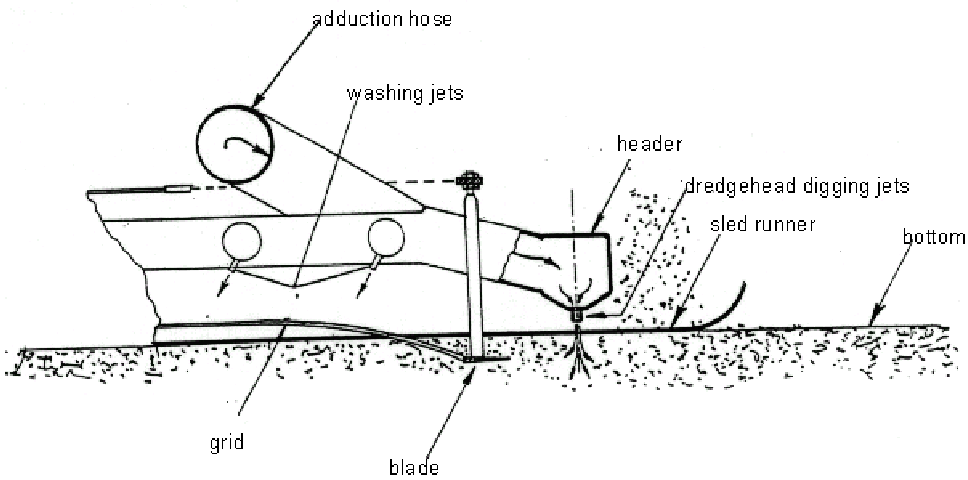


Figure 3-31. Hydraulic dredge section (Ferretti et al. 1990)

High-pressure water expelled from the jets fluidises the sediment allowing the blade to cut easily and elevate the clams. Inadequate water pressure compromises the operation of the blade, whereas excessively high water pressure can raise the cage from the seabed, so reducing the useful width of the mouth for the catch.

The front of the cage (header), together with the breaking and washing jets, form a single system of pipes that is entirely independent from the mouth. The breaking jets are oriented perpendicularly with respect to the sediment whereas the washing jets point backwards to direct catch into the cage, Figure 3-31.

The water pressure which the fishermen use is influenced by the nature of the sea-bed and the location of clams in the sediment. With hard sediments, especially in winter, it is necessary to increase hauling speed when increasing water pressure, otherwise animals will be 'blown away' from the mouth of the dredge. Similarly, when using lower water pressure in soft sediments in summer low hauling speeds are required otherwise the cage becomes clogged with fine sediment. (Ferretti et al. 1990).

Chamelea gallina, hydraulic dredge

This type of dredge, Figure 3-32 and Figure 3-33, is used in Italy and has, in addition to the general attributes described previously, the following specific characteristics:

- a minimum spacing in the cage of 12mm for bars, 17mm for square metal meshes, 25x12mm for rectangular meshes and a 21mm diameter for perforated plates with round holes;
- the catch must be separated by sieves having bars at least 12mm apart, 17mm for square metal meshes, 25 x 12mm for rectangular meshes and a 21mm diameter for perforated plates with round holes (with a tolerance of 1 mm); and
- the sieve must be easy to inspect and be of approved construction; a special facility should be provided for opening it near the collection side (Ministero per le Politiche Agricole 1998b, a).

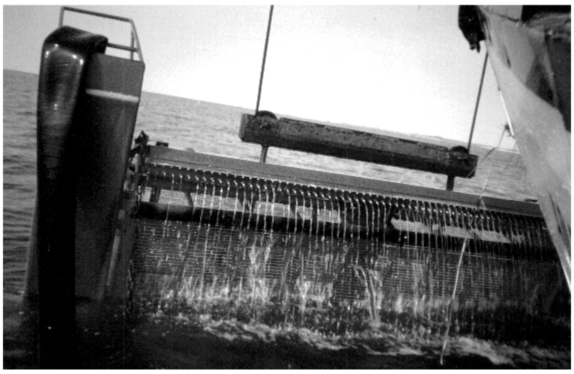


Figure 3-32. **Figure 3-33.**

Vessel equipped with hydraulic dredge for clams (*C. gallina*) (by M. Pellizzato).

Razor clams dredge

This type of dredge, Figure 3-34 and Figure 3-35, which is used to catch *Ensis* sp. and S*olen* sp in Italy has, in addition to the general attributes, the following specific characteristics:

- jets that direct pressurised water in the front of the blade to penetrate into the sediment;
- a minimum spacing of 7mm between the bars at the lower part of the cage;
- bars that cannot be substituted by metal meshes; and
- no sieving facility: catch must be selected manually and the other animals, except for *Sipunculus nudus,* must be returned to the sea (Ministero per le Politiche Agricole 1998a).

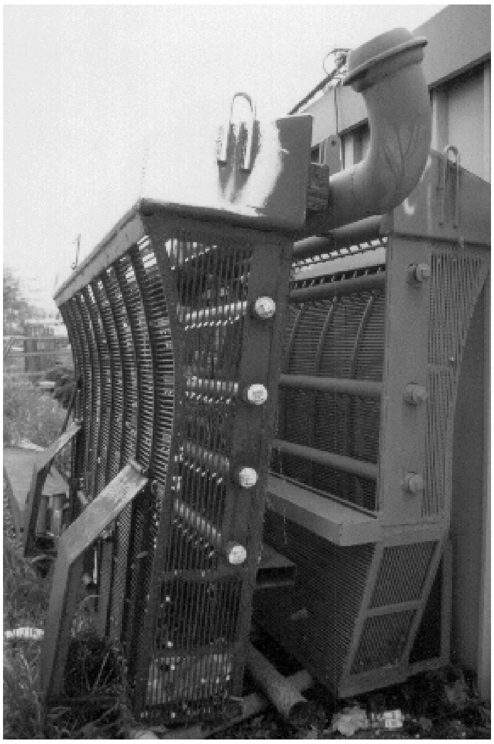


Figure 3-34. **Figure 3-35.**

Hydraulic dredge for razor clams (*Ensis siliqua minor*) (by M. Pellizzato).

Venus clam dredges

This type of dredge, Figure 3-36 and Figure 3-37, must have, in addition to the general attributes of the hydraulic dredge, the following specific characteristics:

- a minimum spacing of 25mm between bars at the lower part of the cage; and
- no sieving facility (Ministero per le Politiche Agricole 1998b, a).

Figure 3-36. **Figure 3-37.**

Hydraulic dredge for brown Venus clams (*Callista chione*) (by M. Pellizzato).

Fishing operation

Vessels using hydraulic clam dredges in Italy are 8-12m long, with a gross tonnage slightly below 10 tons, a maximum engine power of 150 HP and a crew of 2-3 fishermen. The dredge is connected to the vessel by two towing warps whose length is about twice the fishing depth.

When fishing, the stern anchor is dropped and 250 - 300m of steel cable unravelled as the vessel moves forward. The dredge is then lowered, and the water system pressurised. The vessel tows the dredge by warping on the anchor, and moving astern, Figure 3-37

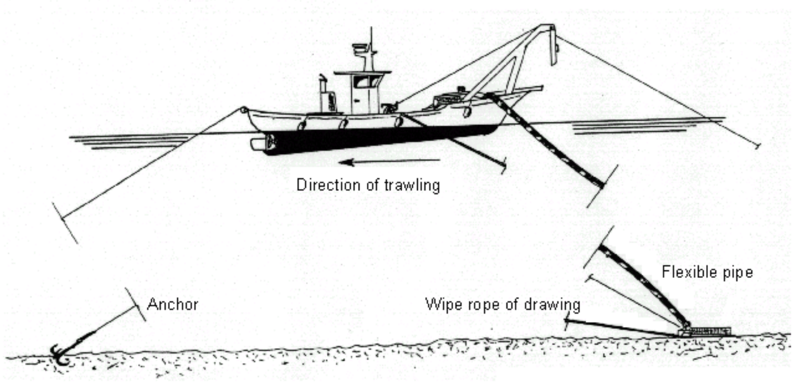


Figure 3-38. Trawling system for hydraulic dredge (Ferretti *et al*. 1990)

Two sled runners prevent the dredge from digging too deeply into the bottom. In clam fisheries the dredge penetrates 4-6cm into the sediment, while for razor clams it penetrates 10-30cm. At the completion of a tow, the dredge is hauled onto a frame located above a collection box, its rear surface unhinged, and the catch emptied into the collecting box. The catch is conveyed to a sieve or sorter that usually consists of two or three coaxial revolving grid drums, which sort and retain clams of commercial size, and discards undersized clams and other organisms.

The duration of a tow is typically 10-15 minutes and is carried out at a speed of 0.6-1.0 knots. With high catch rates the anchor is not hauled and the next tow is made on a course that is a few degrees from the preceding one; thus at the end of the fishing operations, the dredge has covered one or more circular sectors. During a tow, the previous catch is sieved and packed in plastic net bags. The gear efficiency appears to be close to 100% (Froglia 1989).

The brown Venus clam fisheries are targeted by vessels using hydraulic power of 2-3.5 atmospheres. Hauls are 120m long and last about 15 minutes. Longer hauls, especially on bottom rich in shells and benthos, can choke the dredge and compromise gear recovery. A typical vessel used for catching Venus clams is shown in Figure 3-39. Hydraulic clam dredges are used in the UK to dredge clams, *Mercenaria mercenaria and Tapes decussata,* in these there is a conveyer system for delivering the clams to the deck

Figure 3-39. Vessel equipped with hydraulic dredge (by M. Pellizzato).

Cockle dredge

The gear used most extensively to dredge cockles (*Cerastoderma edule)* in the UK is shown in Figure 3-40. The solids handling suction dredge (0.75m width x 1.8m length) employs a pressurised digging water jet and a solids-handling pump lift system. Features considered most likely to influence selectivity are suction 'pressure' and the configuration of the bars of the collecting box. Gear is towed by a vessel (usually not less than 10m), Figure 3-41, at speeds of 2-5 knots

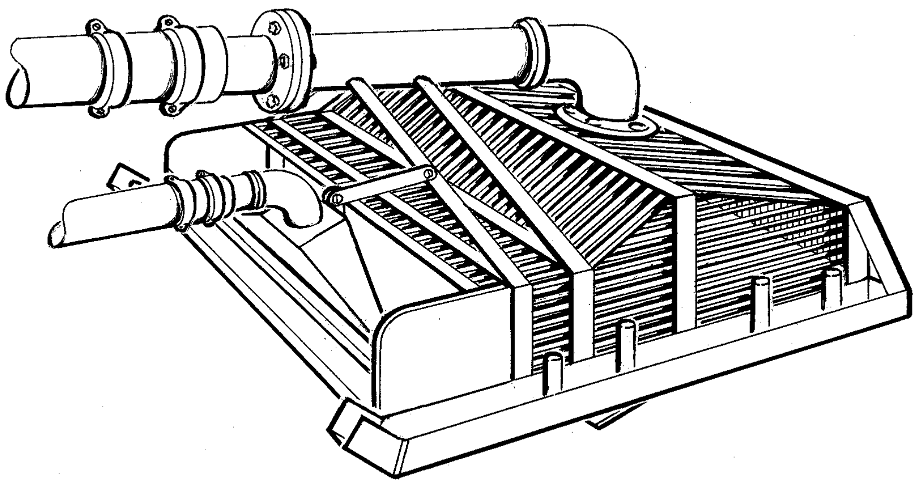


Figure 3-40. Hydraulic cockle dredge

.

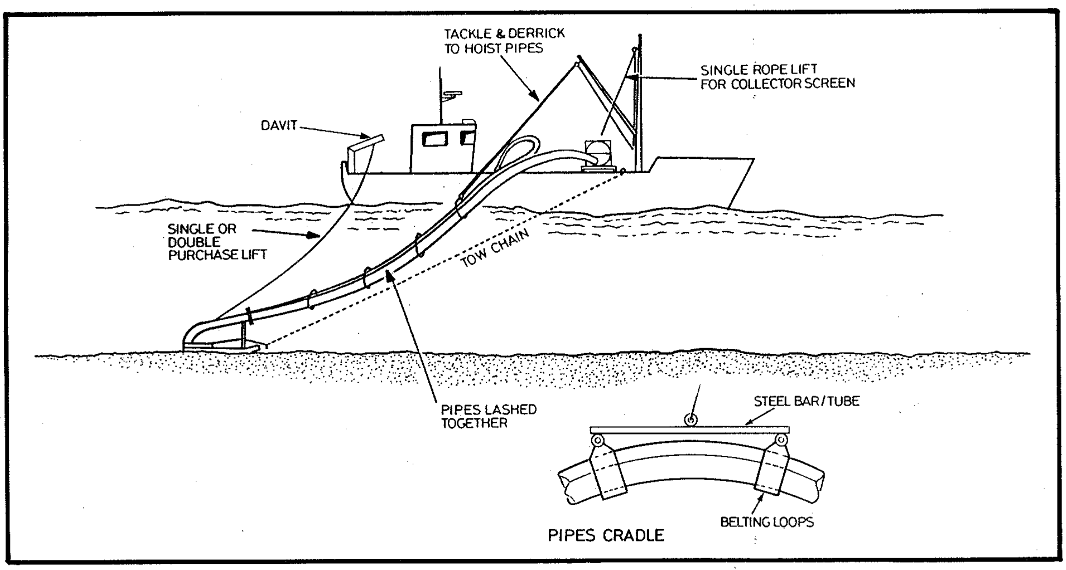


Figure 3-41. Towing operation

3.3 Dredge designs elsewhere

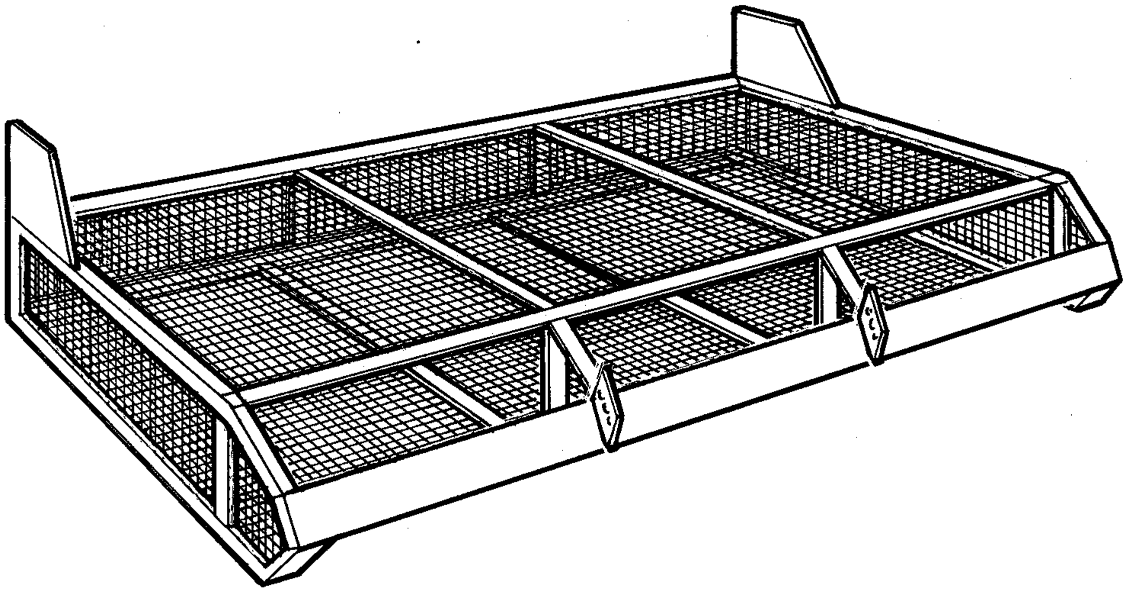
This section covers dredge designs used to catch shellfish in countries outside Europe. The dredges have been classified according to design type; either rigid mesh box or flexible ring mesh bag.

3.3.1 Rigid Box dredges

The Australian toothed mud dredge

The Australian Toothed Mud dredge, Figure 3-42, is a steel structure consisting of a rigid mesh box on skids with stabilising fins, teeth or a cutting bar that penetrates the substrate, and a forward mounted depressor plate. It is typically 1.7m long, 3.3m wide and 0.38m high. It is used primarily for 'raking up' sedentary scallops from 'flat' sandy and muddy substrates.

Figure 3-42. Australian Toothed Mud dredge



Other similarly designed box dredges used in Australia are the Peninsula and Bay dredge, which are typically 1.2m long and 2.2m to 4.6m wide. They have extended skids to reduce undulation, and weighted boxes to improve bottom contact and reduce dynamic movement.

The American/Canadian dredge

The American/Canadian dredge (experimental), Figure 3-43, comprises a rigid frame with a plastic coated mesh back and flexible ring mesh sides and belly. It incorporates a diving pressure plate and chains (diamond, tickler and rock) to 'tickle' scallops from the seabed into the box. It is used primarily on rough ground.

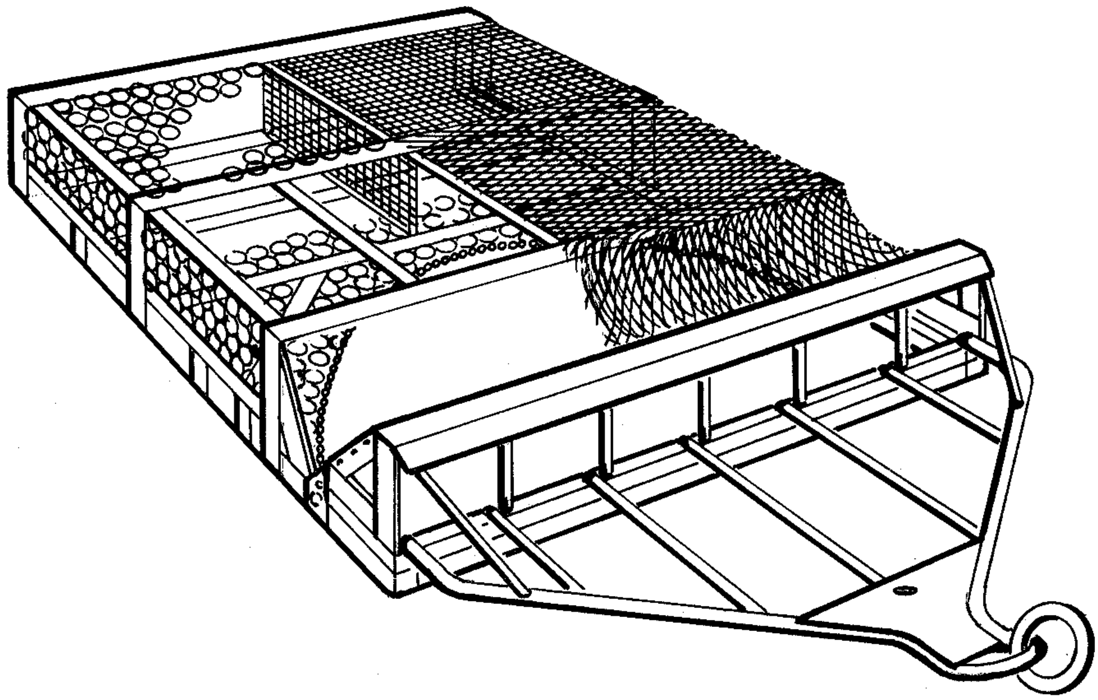


Figure 3-43. American/Canadian experimental dredge.

The CSIRO Southern Scallop Harvester

The CSIRO Southern Scallop Harvester, Figure 3-44, which is used extensively in Australia, is a modified version the American/Canadian dredge. The towing frame has been replaced with a diving pressure plate with towing lugs.

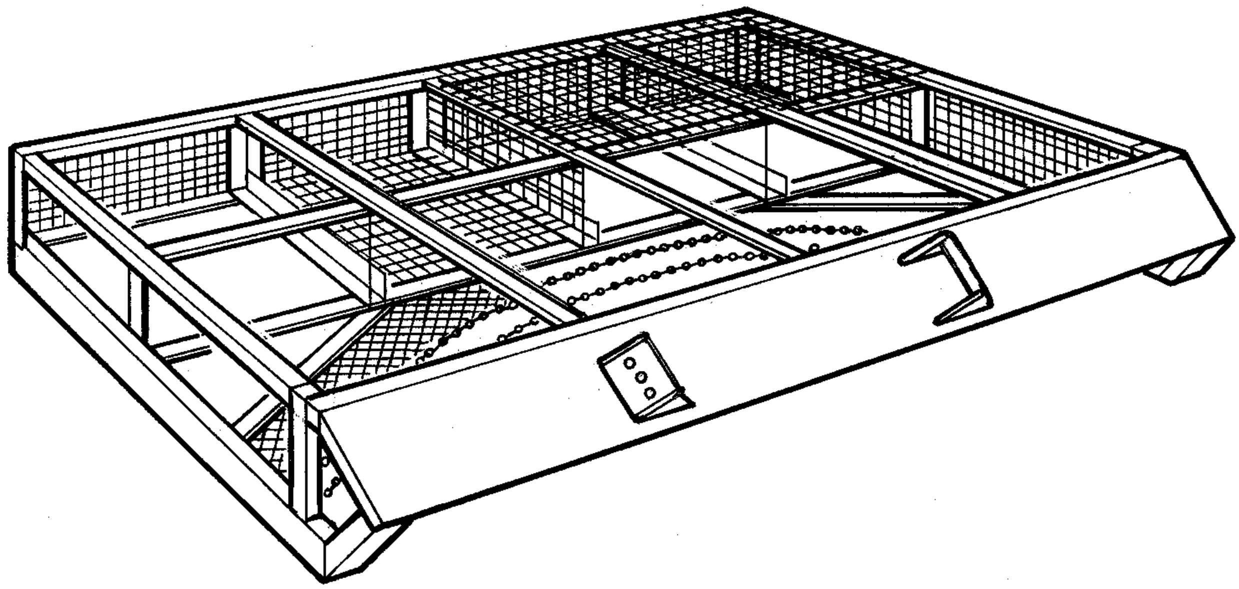


Figure 3-44. The CSIRO Southern Scallop Harvester

3.3.2 Flexible dredges

The New Zealand Dredge

The New Zealand Dredge, Figure 3-45, which evolved from the traditional English beam trawl design, is simple and lightweight. It comprises a head frame, tickler chains, flexible ring mesh belly, nylon mesh back and a tipping bar. It is typically 2.7m long, 2.4m wide and 0.6m high. In other fisheries, where soft muddy substrate exists, dredges are similar but utilise heavier tickler chains.

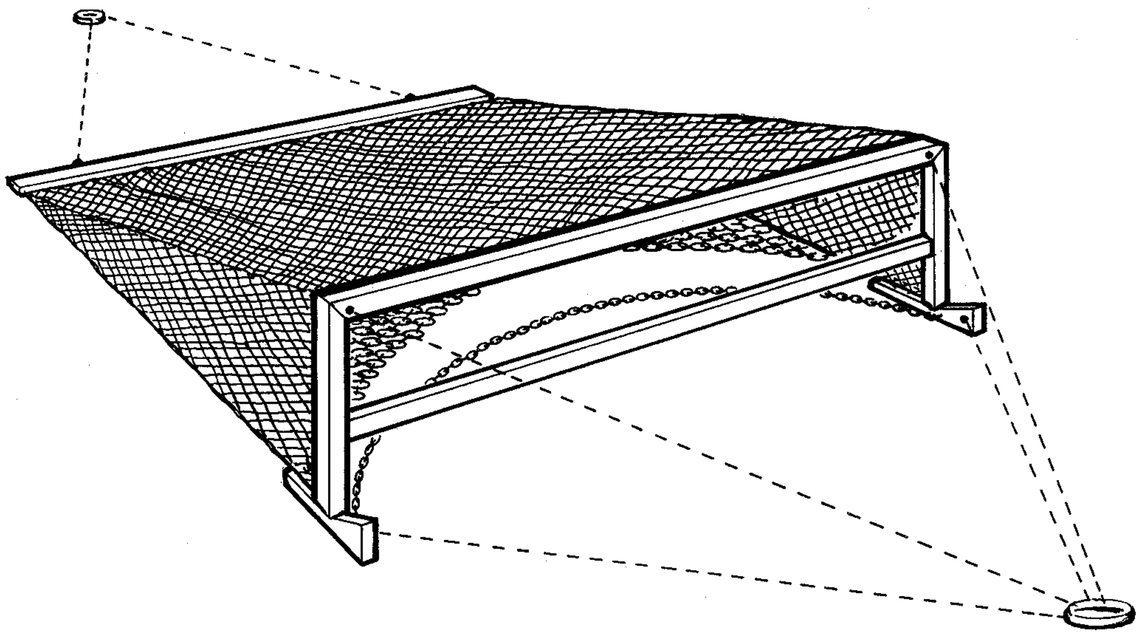


Figure 3-45. The New Zealand Dredge

The Japanese Keti-ami dredge

The Japanese Keti-ami dredge, Figure 3-46, consists of an elaborate tow frame with very large teeth (tines) that project downwards from the top rear of the frame and are angled backwards. The dredge is typically 4.7m long and 2.0m wide with 0.6m long tines. It has tickler and rock chains, a flexible ring mesh bag with a nylon mesh top, and a tipping bar. The dredge is used on hard or mixed sandy ground where it is designed to ride over rocky obstacles and not pick up rocks or trash.

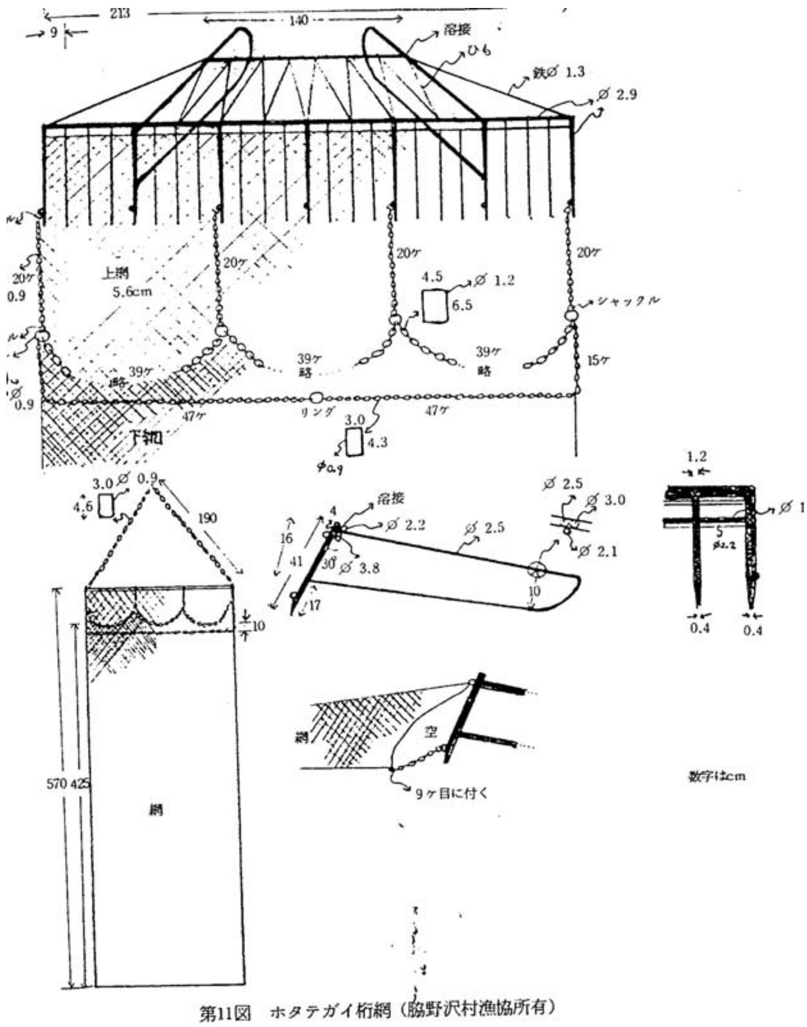


Figure 3-46. Japanese Keti-ami scallop dredge

Figure 3-47. Japanese Keti-ami dredge in use to catch scallops

Canadian Scallop dredge

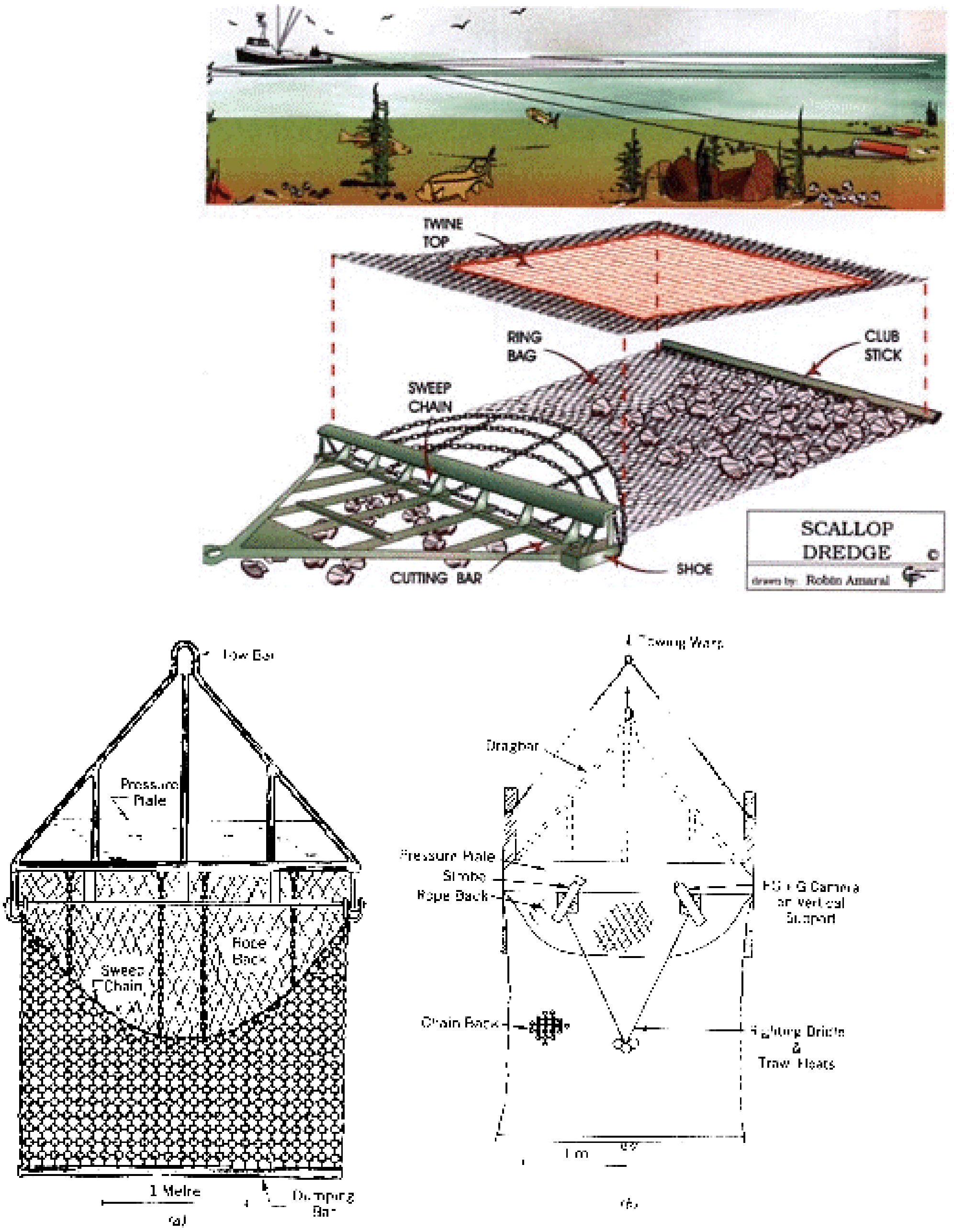


Figure 3-48. Canadian and USA Scallop dredge

3.3.3 Hydraulic dredges

The hydraulic dredge to catch Surf clams in USA and Canada is shown in Figure 3-49 and Figure 3-50

Figure 3-49. Hydraulic dredge filled with surf clams being hauled on board

Figure 3-50. On board surf clam sorting, measuring and storage in wire cages

Figure 3-51. Typical Canadian clam vessel showing clam dredge

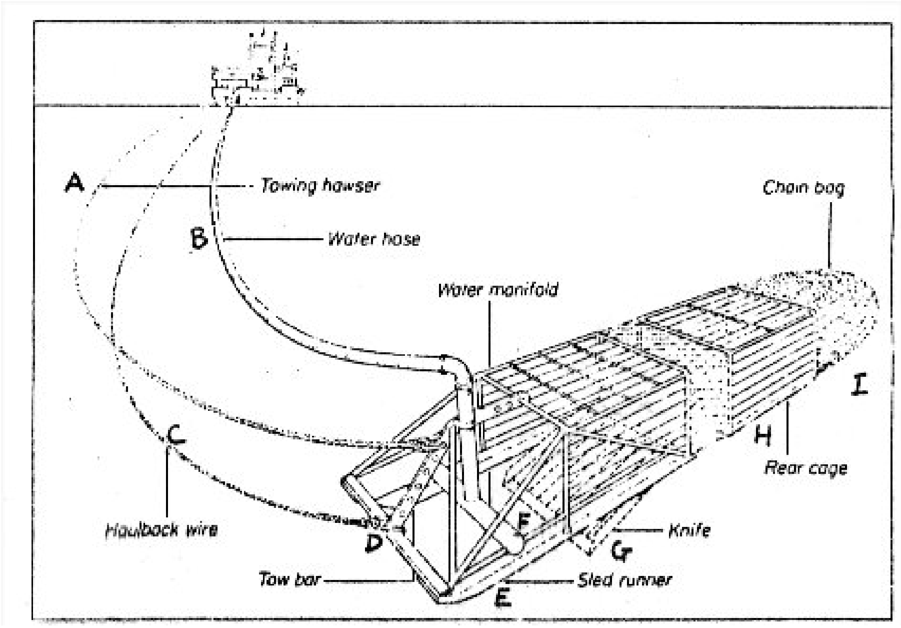


Figure 3-52. Hydraulic clam dredge with pump located on vessel as used in Canada and USA

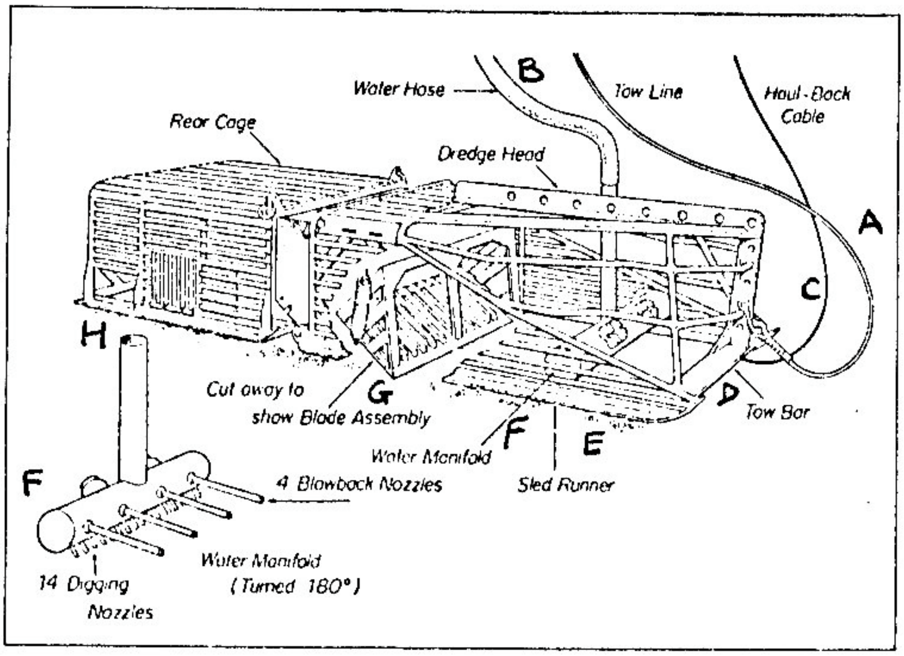


Figure 3-53. Hydraulic clam dredge as used in Canada and USA, showing water jet assembly

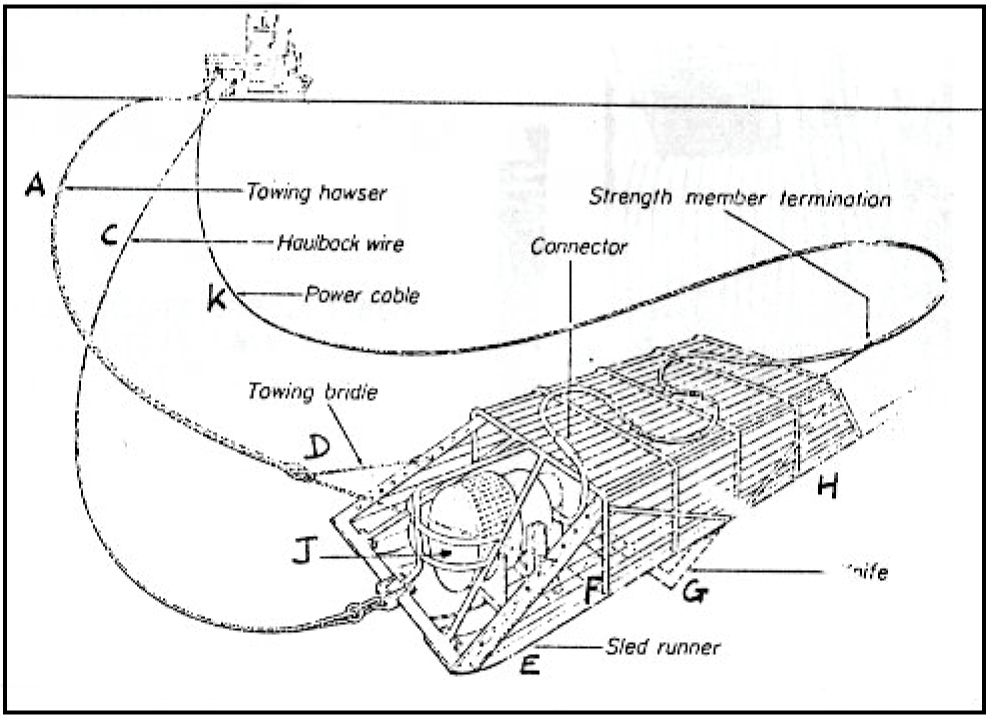


Figure 3-54. Hydraulic clam dredge showing pump located in dredge structure, as used in Canada and USA.

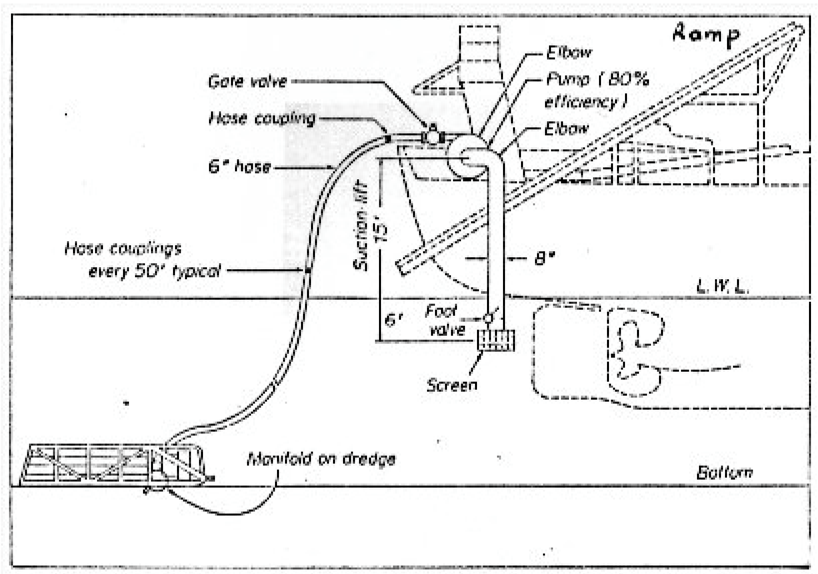


Figure 3-55. Vessel arrangement for hydraulic clam dredge with pump located on vessel as used in Canada and USA.

References for Section 3 Dredge design

Ferretti, M., F. Lombardo and G. Romani (1990). Metodi di Pesca dei Molluschi Bivalvi. Vongolare tradizionali e turbo soffianti. Quaderni ICRAP Pesca , 157 pp. 1 - II edizione. Ministero delle Politiche Agricole, 1998a.

Froglia, C. (1989). Clam fisheries with hydraulic dredges in the Adriatic Sea. In: Marine Invertebrate Fisheries: their Assessment and Management., Ed. J.F. Caddy, Wiley Interscience Publication.

Giovanardi, O., F. Pranovi and G. Franceschini (1998). "Rapido" trawl fishing in the Northern Adriatic: preliminary observations of the effects on macrobenthic communities. Acta Adriatica 39(1): 37-52.

Mattei, N. and M. Pellizzato (1997). Mollusk fisheries and aquaculture in Italy NOAA 129,3201-216

Ministero per le Politiche Agricole (1998a). Decreto Ministeriale 21 luglio 1998.

Ministero per le Politiche Agricole (1998b). Piano Vongole 1998 (Legge 164/98).

Pellizzato, M. and E. Giorgiutti (1997). Attrezzi e sistemi di pesca nella provincia di Venezia. Provincia di Venezia Venezia, A.S.A.P.

4 EUROPEAN DREDGE FISHERIES

The following section describes the bivalve dredge fisheries in each of the partners' countries. Fisheries within each county are described under the following species groups: pectinid, clam, oyster and mussel.

4.1 England and Wales

The main fishing grounds for bivalve species dredged around the UK are shown in Figure 4-1.

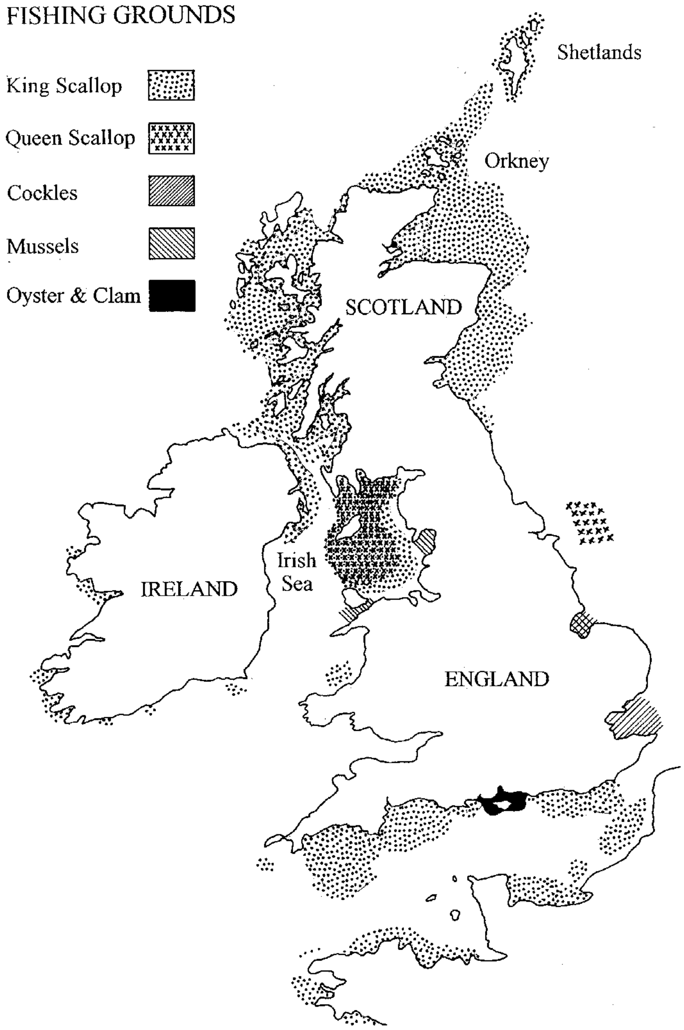


Figure 4-1. Bivalve fishing grounds around the British Isles

King scallop (*Pecten maximus)* is exploited throughout Scottish, The Channel and The Irish Sea waters, whereas the queen scallop (*Aequipecten opercularis)* is caught mainly in the Irish Sea and off the east coast of England. The common cockle (*Cerastoderma edule)* is caught in the Thames esturay SE England and The Wash. The common mussel (*Mytilus edulis)* is explioted in North Wales and The Wash. Oysters (*Ostrea edulis)* and clams (*Tapes spp.)* are caught only along the south coast of England.

4.1.1 Pectinid group

Target species and by-catch

The target species are *Pecten maximus,* known as the king or great scallop, and *Aequipcten opercularis,* known as the queen scallop. The main by-catch is sole (*Solea solea),* angler fish (*Lophius sp*) and plaice (*Pleuronectes platessa)*

Gear

P. maximus is caught using the 'Newhaven' spring dredge (Figure 3-24) and *A. opercularis* is caught using the queenie spring and skid dredges (Figure 3-20).

Fishing areas

P. maximus is caught off Southern England where large and medium size offshore vessels operate from Portsmouth, Brixham, Plymouth, Newlyn, Portsmouth, Newhaven, Rye and Brighton. Small and medium size vessels operate inshore, mainly from Weymouth, Exmouth, Teignmouth, Mevagissey, Looe, Fowey, and Falmouth. *A. opercularis* is caught in Irish Sea (main port is Kirkcudbright) and off the east coast of England (Yorkshire coast: main port is Whitby).

Resource characteristics

In south west England three main areas receive variable, but regular, recruitment of *P. maximus*. Harvesting occurs all year round with a peak in summer. MLLS is 100mm and is attained in 2-3 years in Lyme Bay, and 4-5 years elsewhere. In south east England resource exhibits irregular recruitment, possibly originating as a larval overflow from the stock in the Bay of the Seine (Figure 2-2). Harvesting occurs during the winter season at 110mm MLLS at 3 years old.

A. opercularis exibits variable recruitment at 1.5-2.0 years, at approximately 45mm; imposed by the market criteria there is no MLLS. Harvesting occurs all year round. There is evidence of large-scale movement of queens, which can lead to sudden aggregations.

Fishing strategy

In southern England, dredging for *P. maximus* with spring dredges is conducted mainly on gravelly/sandy grounds. Large vessels fish eastern grounds vessels from December to April (roes in best condition) and western grounds from April to late summer. Small vessels operate inshore within their locality (following the same seasons). French dredges are used on fine/muddy grounds in southern England throughout the year. Dredging for *A. opercularis* is conducted mainly on gravelly/sandy grounds throughout the year.

Interactions

In southern England competition for resource with occurs with scallop dredgers (France) and offshore beam trawlers (UK). Competition for grounds occurs with mainly offshore potting (France, UK and Channel Islands), offshore longlining (France), and fixed netting for bass (UK). In the Irish Sea competition for grounds with king scallop (*Pecten maximus),* and offshore beaming (Dutch).

Markets

The traditional markets for both species are export of live, fresh and frozen meats to the continent (mainly France).

Trends and comments

In south west England, before 1974, scallops were a small by-catch from trawling. More recently scallop dredging has become a 'traditional' metier for many small boats and an opportunistic activity for many large beam trawlers in VIIe. Vessel numbers have fluctuated without trend, (during mid '70s and '80s approximately 80 boats were involved), but the number of full time scallop dredgers has increased. In south-east England scallop dredging has been an intermittent activity for small and medium sized vessels since 1970. Effort in VIId fell sharply after 1980s due to declining stocks, with recent effort concentrating between Selsey Bill and Dungeness out to the mid-Channel.

Summer closed seasons, which exist in the Irish Sea and in part of the Devon Sea Fishery Committee district, are designed to prevent the marketing of poor quality scallops .

Over the last ten years the geographical extent of the fisheries has increased, as has vessel size, power and fishing capacity; with the more powerful vessels opening up offshore grounds to year round fishing.

Dredge design has altered little since the industry quickly settled on the spring-toothed Newhaven dredge (to reduce catching of stones) and the larger fixed tooth-bar French dredge. However, the trend to more powerful vessels in the offshore fishery has seen a corresponding increase in the weight of both the dredge and the towing bar to allow faster towing speeds.

Large scale fisheries for *A. opercularis* have existed from 1969/70 until 1993/94-1996. Subsequently, fisheries in the Channel, Cardigan Bay, Kish Bank and outer Silver Pits have disappeared, whereas those around the Isle of Man and the Firth of Clyde are still exploited. In 1996 a fishery developed off the Yorkshire coast. Gear for catching *A. opercularis* evolved from lightweight triangular dredges fitted with tooth bars to heavier dredges (Blake) which caught animals that swam up from the seabed. Current designs are based on the 'Newhaven' king scallop sprung dredge fitted with narrowly spaced teeth and small diameter rings.

Small vessels have been replaced with larger, more powerful vessels towing more dredges. Four vessels (20m) operate from the West coast and six vessels (15m, 250hp, 5 dredges per side) from the East coast.

The fishery off the Yorkshire coast is regulated by bye-laws (NESFC), which include close season, dredge specification (85cm mouth width, sprung tooth bar, ring size (75mm), mesh size (100mm), dredge number (max 10), and restricted zones.

4.1.2 Oyster Fishery

Target species and by-catch

The target species is *Ostrea edulis*, known as the European, native or flat oyster, with a negligible by-catch of flatfish; sole (*Solea solea*) and plaice (*Pleuronectes platessa*).

Gear

O. edulis is caught using the fixed blade 'Oyster' dredge, Figure 3-10.

Fishing areas (and ports)

The main fishing area is southern England, mainly in the Solent, which occurs between the mainland and the Isle of Wight, and the river Fal. Main ports are Lymington, Portsmouth and Cowes. Essex and River Fal.

Resource characteristics

Self-regenerating fishery based on wild spat settlement that is variable but regular. Harvesting occurs at 70mm shell length at age 4 in the Solent and age 5 in the Fal. Species is vulnerable to infestation by the parasite *Bonamia,* which is present in the Fal and causes mortality and marketing problems. Currently *Bonamia* is present at a low level in parts of the Solent and its associated estuaries.

Fishing strategy

Dredging is conducted mainly within the Solent, particularly on shallow banks (less than 10m depth). Fishing is restricted seasonally (November to mid-December and mid-January to mid-March), dependant on stock availability.

Interactions

Conflict for grounds with recreational vessels (yachts), and with sewage outlets.

Markets

Traditionally, live exports to France and Spain, mainly for ongrowing/fattening. Annual production: 500-1000 tons.

Trends and comments

From 1972 onwards a substantial fishery for *O. edulis* developed in the Solent and adjoining harbours, increasing the small fishing boat fleet in this area to approximately 90 vessels (8-12m at 100hp) - current fleet profile is similar. In addition, 20 sail powered vessels still operate in the Fal estuary.

The main modification to the dredge has been the addition of a bar across the ends of the teeth, which occurred in response to a ban on toothed dredges. Current production is low but stable. Controls include MLLS, closed seasons, restrictions on dredge specifications, and a Regulating order, implemented in response to high catch rates in the 1980s.

Regulation measures

Regulated fishery for much of the main area with restricted season and licence entry. Exclusive rights (Several orders) and on areas of private ownership. There are movement restrictions due *Bonamia* infection.

4.1.3 Clam fisheries

Target species and by-catch

The target species are the introduced American clam (*Mercenaria mercenaria),* with negligible bycatch of sole (*Solea solea),* plaice (*Pleuronectes platessa),* manilla clam, (*Tapes phillipinun*), carpet shell (*Tapes decussata*) and the cockle (*Cerastoderma edule).* No bycatch.

Gear

M. mercenaria is caught with a mechanical clam dredge, whereas *T. phillipinun* and *C. edule* are caught with hydraulic equipment, Figure 3-40 shows a hydraulic cockle dredge.

Fishing areas

M. mercenaria, T. phillipinum and *T. decussata* are caught in southern England; the former mainly in the Solent, which occurs between the mainland and the Isle of Wight, whereas the two latter species are caught in Poole Harbour. *C. edule* is caught mainly in south east England (Thames estuary), eastern England (The Wash), south Wales (Burry inlet), Menaii straits and Morecambe Bay and also Menai Straits.

Resource characteristics

The fishery for *M. mercenaria* and *C. edule* are self-regenerating, based on wild spat settlement that occurs on littoral and sub-littoral beds. Recruitment of *M. mercenaria* is occasional and *C. edule* can be highly variable. *M. Mercenaria* recruit to the fishery at about 63mm shell length when 7 years old wheras cockles recruit at 16mm shell length and 2-3 years old.

The fishery for *T. phillipinum* and *T. decussata* is husbanded (farmed), based on cultivation of hatchery grown spat. Animals are planted when one year old (20mm shell length) and recruit to the fishery when 3-4 years old at about 35mm shell length.

Fishing strategy

Mechanical dredging for *M. mercenaria* is conducted within the Solent, mainly in Southampton waters and particularly on shallow banks (less than 10m depth), and in limited areas within the harbours. Clams are taken intermittently in a year round fishery.

T. phillipinun and *T. decussata* are harvested by hydraulic dredges all year round on specific areas (several order fisheries) within the confines of Poole harbour, particularly on shallow banks (less than 3m depth). Hydraulic dredging for *C. edule* is conducted mainly within the confines of the Wash and Thames estuary, particularly on shallow banks (less than 5m depth).

Interactions

Many of these fisheries occur within the intertidal zones covered by Special Protection Areas (SPA) and Special Areas of Conservation under the EU Wild Birds and Habitat Directives respectively, described collectively as European Marine Sites in the Habitat Regulations 1994.

For example on the NW Coast of England and Wales (Haverigg point in Cumbria to Cardigan Bay) 50% of the intertidal zone including all of the cockle fisheries, are designated European Marine Sites. This has required the local managers of the fishery (North Western and North Wales Sea Fisheries Committee) to bring about 'favourable conservation status' their management of these locations. In one location, Treath Lavan, an area of sand and mudflat at the eastern end of the Menai Strait (designated an SPA), there has been a conflict of interests between Fishers who wished to harvest cockles using suction dredges in the area and Conservationists who considered this a threat to bird habitat. Many arguments were produced by both sides concerning ways in which the fishery should be regulated to take account of the designation; they both cited the 'Precautionary Approach'.

An important difficulty experienced in designing a management plan for this site was a lack of detailed knowledge of the interaction between the Fishers and the bird population. Previous surveys and models were of very little use in designing a management strategy within the definition of 'favourable conservation status'. Eventually, a management scheme was worked out under which the cockle stocks are surveyed annually and fishing is only allowed in relatively small, designated areas that are considered to avoid conflict with the conservation of bird populations.

However, there remains minimal hard evidence of the any detriment to the bird populations from the effects of cockle dredging in this area. Cockle stocks are highly variable in size from year to year in this area and the birds find food when cockle stocks are low as well as when they are at high levels. Thus there may not be a direct relationship between cockle population levels and favourable conservation status for the birds.

Conflict for grounds also occurs with gill and drift netters (Bass and Mullet), recreational vessels (yachts) and sewage outlets.

Markets

M. mercenaria traditionally exported to the continent, but some consumed within UK. Annual production is 0–200 tons. Annual production of *Tapes* spp is approxamately 40 tons. *C. edule* is marketed within in each of the main fishing areas, but most product is exported abroad (Holland, Belgium) as cooked meats. Annual production is extremely variable (0-9000 tons annually), but is typically 3-4000 tons.

Trends and comments

The introduced American hard shell clam (*M. mercenaria*) became established in Southampton waters in early1980s, attracting the attention of a new fleet of oyster dredgers (40 vessels up to 12m). Output increased rapidly with peak production from mid 1980s to 1993. However, stocks have been reduced greatly over the past decade but the fishery still supports a small number of boats (approx 6) throughout the year. Neither gear nor vessel specification has changed over the last decade. Access controls comprise restricted areas of public fishery and an MLLS that was introduced in1991 in response to the high catch rate, especially of small animals.

From 1987 onwards a hydraulic fishery for clams developed in Poole Harbour utilising equipment developed to minimise damage to the target species and substrate. Undersized animals fall through conveyor belt and dig back into the ground. Current production is stable.

A hydraulic fishery for *C. edule* developed in the Thames (1970) and, later, in the Wash (1980). Fleets in both areas were initially small, comprising approx 8 vessels about 10-12m in length. Capacity increased rapidly; currently, the Thames fleet comprises 10-14 large and powerful purpose built steel vessels (10-12m) though, in recent years, up to 20 'stranger' vessels fish the outer beds. Approximately 25-35 similarly sized vessels operate in the Wash.

The harvesting system evolved from a 30cm water-jet with a flexible suction pipe arrangement towed slowly (1.0 knot) to a solids handling pump system using a 76cm dredge head attached to a rigid pipe. Towing speeds increased from 1.0 knot to 4.5 knots greatly increasing catch rate. Recent dredge modifications include a grill set up at an upward gradient behind the bar to improve selection and an elevated gathering cage that which improves selection by rejecting a greater proportion of undersized cockles (Thames fishery). Some dredges incorporate the pump on the dredge head instead of the vessel (Wash fishery).

Since the introduction of the hydraulic dredge offshore grounds and sub littoral beds grounds have been opened up in the Thames estuary. However, they do not receive such consistent spatfalls as the traditional grounds and are fished infrequently. Fishing grounds in the Wash have remained unchanged, though some areas have become unproductive recently. Current annual production from the Wash is 2000 tons. Access controls include limitations on length and beam of vessel, engine power, dredge size, MLLS, riddle size, approval of fishing gear, a permit scheme and bed closure, and a Fishery order. The fundamental reason for controlling access is that catching capacity is considerably greater than carrying capacity.

4.1.4 Mussel Fisheries

Target species and by-catch

The target species is *Mytilus edulis*, the common mussel. There is no bycatch.

Gear

M. edulis is caught using the Baird dredge, Figure 3-17 and the Dutch dredge, Figure 3-11.

Fishing areas

Main areas are North Wales (Menai Straits), Northwest England (Morecambe Bay) and eastern England (The Wash).

Resource characteristics

The Wash fishery is based upon variable natural settlement, both littoral and sub-littoral. Part of stock is relayed onto private ground for on-growing, also relaying of wild spat dredged from elsewhere in UK (South Wales and Solway Firth). Animals are harvested during the winter at either 45mm or 50mm (MLLS), when 3-4 years old. Stock is vulnerable to adverse weather.

The North Wales fishery is based on the relaying of wild spat dredged locally or from elsewhere in UK (South Wales and Solway Firth). Stock is harvested at 45mm MLLS when 3 years old.

Fishing strategy

Within The Wash dredging is conducted mainly on managed areas (shallow banks, less than 10m depth, called 'lays'), from 31 August to 30 April. Seed is relayed from August–December and harvested from January-May.

In North Wales dredging is conducted mainly within the confines of the Menai Straits particularly on managed areas (shallow banks, less than 10m depth, called 'lays'), from 31 August to 30 April. Seed relayed August–December and harvested January-May.

Interactions

Conflict with hand-gatherers for grounds, and sewage outlets ('B' classification).

Markets

Live export to mainly France, with some domestic (UK) consumption. Annual production from North Wales is 3000 tons and 500-2000 tons from The Wash. Current production from Menai is stable, whereas resource in The Wash has declined over recent years, reportedly due to spatfall and recruitment failure.

Trends and comments

From 1986, The Wash has suffered poor spat-fall and recruitment. The 'Gat' sand is the only remaining wild fishery, reserved currently as a parent stock. Future production will be based on good 1998, and subsequent, spat-falls. Fishery is progressing towards husbanded operations conducted on 'private'(Several order) lays. Fleet size decreased from 110 vessels at peak in mid-80's to present 35 vessels approx. Vessel size has increased from 10m to 12m and power has increased from 100hp to approx 300hp. The main modifications to the dredge are a diving plate to ensure better ground contact and additional weight to accelerate descent to seabed. Also, the mesh collecting bag has been elongated to allow increased tow length. Access controls are based on a MLLS, restrictions on dredge specification and number, closed seasons, licensing system, a quota system and Fishery Order. The fundamental reason for controlling access is that catching capacity is considerably greater than stock availability.

The fishery in Menai started in 1960's with two low powered (80hp) vessels each using two dredges. Capacity increased greatly during the mid '70s to the current fleet, which comprises three large and powerful purpose built fishing vessels (17-24m, 500-600hp), each using four dredges (2 on each beam) and two large supply vessels (27-32m, 500hp). The main modification to the dredge includes the addition of a blade on the cutting bar for use on harder grounds. Areas for harvesting seed are becoming more extensive; in addition to existing grounds (Morecambe Bay, Caenarvon and Conwyn Bay) areas around South Wales (Burry inlet) and off Cumbria are being investigated.

4.1.5 Management measures UK dredge fisheries

Measures used to manage dredge fisheries in English and Welsh waters are summarised in **Table 4-1**

Table 4-1. Management measures for 'mechanical' dredge fisheries

Fishery	Species	Dredge	Location	Input controls	Output controls: e.g. Quota
King scallop	*Pecten maximus*	Newhaven Spring Dredge	Irish Sea (ICES VIIa excluding Isle of Man)	Close season June to October inclusive (Northern Irish Sea) and July to October inclusive (Southern Irish Sea), and vessel licence requirement (N). Vessel length restriction and maximum beam length of 12.19m in 3-12 mile area (7.62m in 0-3 mile area) (L). Dredge specification: maximum width of 85mm, 9 teeth on the bar with spaces between teeth not less than 75mm, metal belly ring size no less than 75mm internal diameter and back mesh size of 100mm. Not more than 8 dredges aside (L).	No more than 10% of protected species may be landed and only whole scallops may be landed (EC). Carriage size and MLLS of 100mm (EC). MLLS of 110mm (N and L).
King scallop	*Pectem maximus*	Newhaven Spring Dredge	Channel (ICES VIIe)	Vessel licence requirement (N). Effort restriction of 12 dredges per vessel (L). Close season July-September inclusive (L-Devon). Dredge specification: maximum width of 85mm, metal ring size no less than 75mm internal diameter and back mesh size of 100mm (L).	No more than 10% of protected species may be landed (EC) and only whole scallops may be landed (EC and L). Carriage size and MLLS of 100mm (EC).
King scallop	*Pecten maximus*	Newhaven Spring Dredge	Channel (ICES VIId)	No more than 10% of protected species may be landed and only whole scallops may be landed (EC). Vessel licence requirement (N). Vessel size and dredge number (L).	Carriage size and MLLS of 110mm (EC).
Queen Scallop	*Aequipecten opercularis*	Queenie Dredge	Irish Sea (ICES VIIa)	None.	None
Queen Scallop	*Aequipecten opercularis*	Queenie Dredge	Yorkshire coast (ICES IV b)	Close season October-June inclusive. Gear specification: only sprung toothbars, dredge aperture restricted to 85cm, metal ring size no less than 75mm internal diameter and mesh size of 100mm; 10 dredges per vessel, and zonal restriction (no vessel inside 3 mile limit) (L).	
Mussel	*Mytilus edulis*	Baird Dredge	East coast (ICES IVc)	Regulated fishery; close season May-August inclusive; gear restriction of 2 dredges per vessel; vessel length restricted to 14m and restricted licence entry (L). Dredge width restricted to 1m.	Daily quota of 4 tons per vessel. MLLS of 50mm (L).
Mussel	*Mytilus edulis*	Dutch Dredge	West coast (ICES VIIa)	Regulated fishery; exclusive rights via a Several order (L).	None
Oyster	*Ostrea edulis*	Oyster Dredge	South coast (ICES VIId)	Regulated fishery; close season mid March-October inclusive and mid December-mid Jan (L). No teeth allowed on blade of dredge	MLLS of 70mm (L).
Clam	*Mercenaia mercenaria*	Clam Dredge	South coast (ICES VIId)	Restricted areas of public fishery (L).	MLLS of 63mm (L).
Clam (Poole)	*Mercenaia mercenaria*	Clam Dredge	South coast (ICES VIId)	Restricted areas of public fishery (L).	MLLS of 63mm (L).
Cockle (Thames)	*Cerastoderma edule*	Hydraulic dredge	South coast (ICES IVc)	Regulated fishery; gear restriction of 1 dredge per vessel; vessel length restricted to 14m and beam width to 5m. Permit and restricted licence entry (L). Dredge head aperture and max blade width of 76cm.	Riddle length of 1.75m and parallel bar spacings of16mm, Certificate of approval (<10% damage).

MLLS: Minimum Legal Landing Size — EC: EC legislation
N: National legislation — L: Local legislation (within 6 miles of coastal baseline)

4.1.6 Dredge Fishing Effort for *Pecten maximus* in England and Wales

P. maximus are taken throughout the Channel and parts of the Irish Sea. However, the pattern of recent fishing, Figure 4-1, shows that dredge fisheries have been concentrated in three areas: south west and south east England and around the Isle of Man. Between the main fishing areas scallops are reported to be dispersed widely but at low densities. They are rare or absent from the central section, south of the Isle of Wight, which comprises very coarse gravel, pebbles and rock due to the action of strong tidal forces.

Seasonal pattern of fishing

The movement and timing of effort in the Channel is influenced by the different reproductive patterns of stocks in the eastern and western fisheries. Large vessels work in the eastern Channel from December to April when scallop roes are ripe and from spring to summer in the western Channel. Small vessels fish western Channel stocks on a year round basis. Effort in the Irish Sea occurs from November to May due the operation of a close season during the rest of the year.

The principal strategy is to fish an area until catch per effort (CPE) becomes uneconomical and then move to different grounds. In the Channel fisheries small vessels (<10m) tend to work inshore, targeting small dense aggregations due to their high manoeuvrability, but limited size, speed and dredge capacity. In contrast, large vessels (>20m) usually operate off-shore; they ignore density considerations and tow numerous dredges quickly in straight lines, often using grid plans to reduce non fished areas. Medium sized vessels suit neither strategy due to limitations of speed, manoeuvrability and dredge capacity. Though they employ both techniques, their low CPE and the patchy nature of scallop distribution make them increasingly uneconomical. Consequently, the number of vessels in this category is reported to be decreasing.

Fleet profile

For the last 20 years most effort in the western Channel (ICES Area VII Divisions e, f, g and h), Figure 4-2, has been expended by vessels greater than 20m and, over the last decade, increasingly so. In contrast, the effort increases in the under 10m and 10-20m sectors has been much smaller.

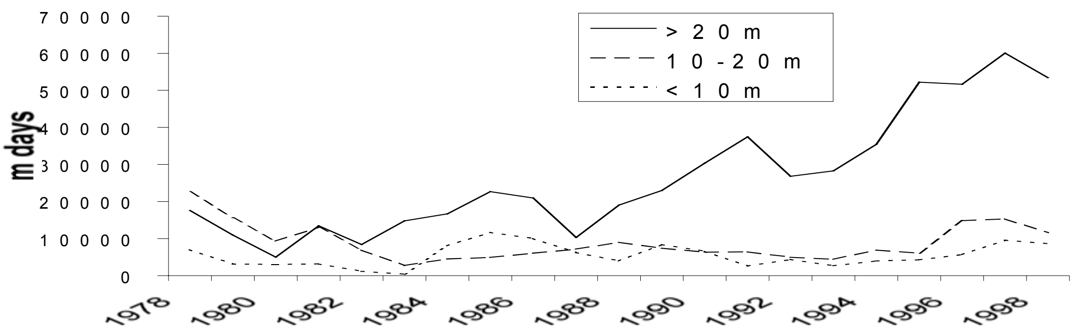


Figure 4-2. Effort in m days by vessel category in ICES Areas e, f, g and h.

Effort

Effort data is presented as m-days (metres of dredge number of days) by ICES Division. Over the last twenty years most annual effort has occurred in the western Channel (ICES Division VII e-h), and has increased greatly since 1988, Figure 4-3. However, recent effort increases (since 1995) have been small.

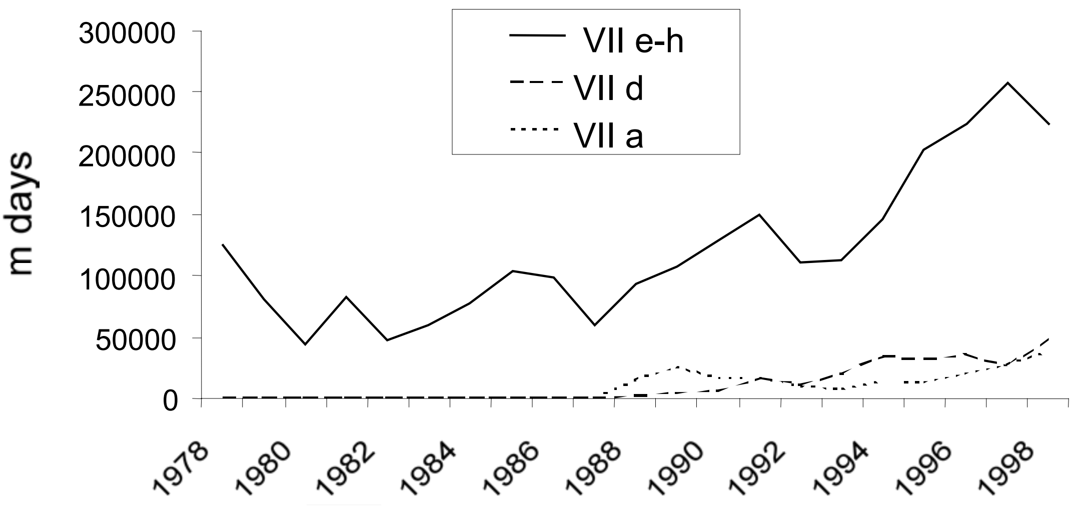


Figure 4-3 Annual scallop effort (all vessel categories) in m days by ICES division.

Effort in the Irish Sea (ICES division VIIa), and the eastern Channel (ICES division VIId), is much less but shows the same increasing trend. Although effort data prior to 1987 is unavailable landing data for the same period suggests that effort levels before1987 would not have differed greatly from those recorded subsequently. Effort increases have not been gradual and show considerable annual variation, mainly due to size variation in recruiting year classes and variable fuel prices. Recently, additional effort has resulted from existing members attempting to build up track records to help secure entitlements in the eventuality of a licensing regime, and an influx of new entrants.

Catch per effort

Though total annual effort shows considerable variation the catch per effort (CPE) has remained relatively constant over recent years, Figure 4-4. CPE is measured in tonnes live weight per metre dredge width per day. Areas tend to return similar mean CPEs due to the cyclical fishing pattern whereby effort is switched to a new patch when the CPE of a fished patch becomes uneconomical. Also, variations in CPE levels are often attenuated by inexperienced entrants whose activity reduces the initial levels, which, after a gradual decline, tend to increase when they leave the area.

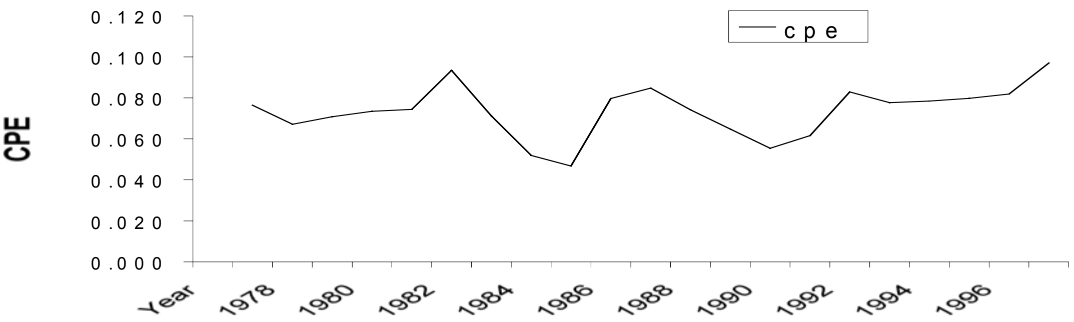


Figure 4-4. Annual CPE (tonnes per metre of dredge per day) of all vessel categories in ICES Areas VII e, f, g and h

This trend is likely to increase as more new entrants enter the fishery due to reduced whitefish opportunities. A situation of constant CPE and increasing effort suggests that the fishery is expanding spatially as new grounds are targeted.

Landings

The pattern of recent landings, Figure 4-5, shows that most scallops are landed from the western Channel (ICES Areas VII e, f, g, and h) and that landings have increased nearly fourfold since 1993.

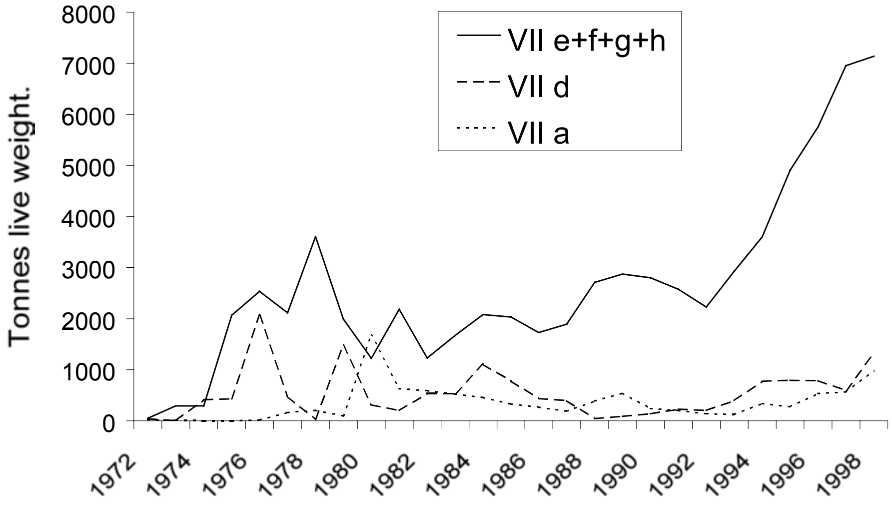


Figure 4-5. Annual scallop landings from the English Channel and Irish Sea, by ICES Areas – UK vessels landing in England and Wales

Landings from the Irish Sea (ICES Area VIIa) and the eastern Channel (ICES Area VIId) show a similar but lesser trend.

Accuracy of Data

Data for the over 20m sectors is reliable as it is derived from EC log-books, which are submitted annually. Data for 10-20m sector may be regarded as reliable since it is derived from MAFF landing returns from the five main ports, which are considered to be policed effectively. Returns for the under 10m sector will be less accurate than for the larger vessels since under 10m vessels are not obliged to submit effort information.

The effort descriptor ‘m days’ (metre of dredge $\times$ number of days fishing) is not ideal since it takes no account of differences in the length of a fishing day, which can vary greatly between sectors. Correction factors have been applied to the data to increase clarity, although no account has been taken of differences in towing speed whereby faster vessels cover more ground per hour.

Other sources of possible inaccuracies include overestimated catch effort data, due to existing members attempting to build up a track record (to help secure entitlements in the eventuality of a licensing regime), and misallocation between Areas VIId and VIIe due to incorrect reporting of different minimum landing sizes.

4.2 Scotland

4.2.1 Pectinid Group

Areas around Scotland from where *P. maximus* are taken are shown in Figure 4-6.

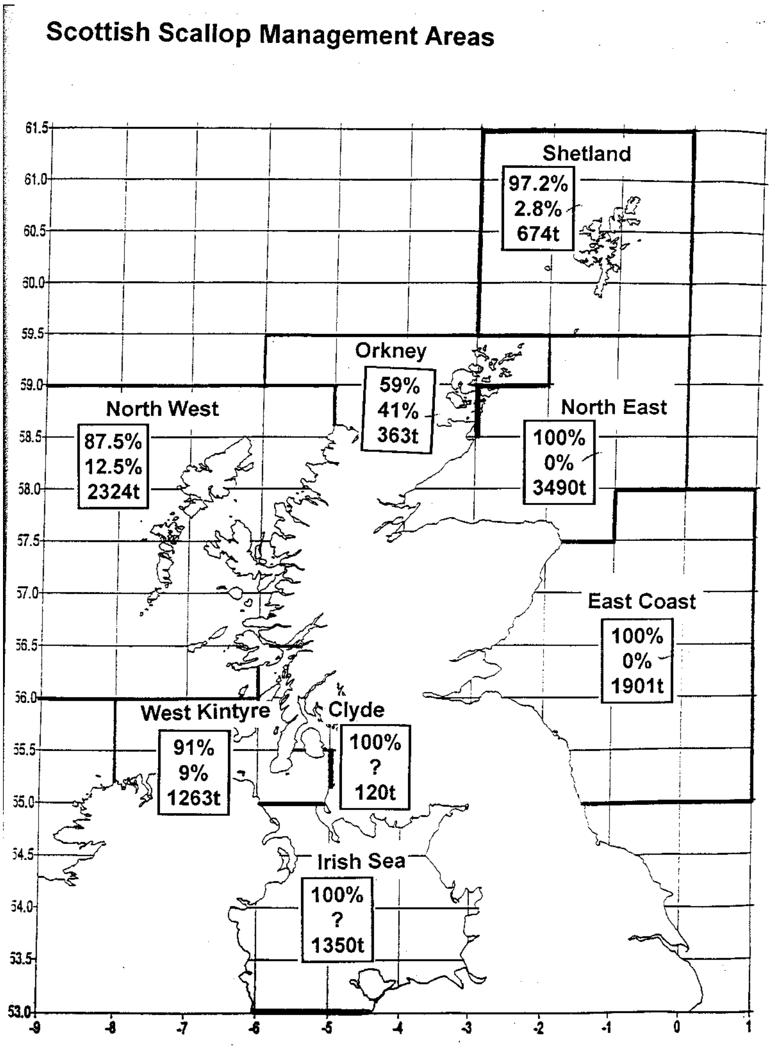


Figure 4-6 Management areas boundaries shown in bold areas around Scotland from which *P. maximus* is taken. Quantities landed shown from each area in 1998 in tonnes with the percentage dredged (top) and diver caught (below).

Target species and by-catch

The main target species is *P. maximus;* queen scallops *(A. opercularis)* are taken as a by-catch or targeted as a separate fishery with similar gear, where smaller ring and mesh sizes are used. By-catch of crabs *(Cancer pagarus)* and angler fish *(Lophius spp.)* are taken. Divers also target scallops: about 590 tonnes, 7% of total landings.

Fishing areas (and ports)

Scallop dredging is a significant fishery (4-5% of all Scottish landings by value) around almost the entire coast of Scotland, including the Western and Northern Isles, as well as up to 200+ km offshore in the North Sea. Recent total Scottish landings have averaged 8,000 tonnes valued at £13million (21.7million Euros). The Scottish scallop grounds (as opposed to the elective management areas described below) can be separated conveniently into three regions:

- **North East (Moray Firth, Orkney and Shetland)** This area accounts for around a third of Scottish scallop catches, dominated by landings from the Moray Firth.

- **West Coast of Scotland.** Total scallop landings from the West Coast slightly exceed those from the North East, though the landing figures are augmented by catches from the Irish Sea landed into Scottish ports bordering the Irish Sea.

- **East Coast.** The importance of these grounds has been increasing since the early 1990s as larger more capable vessels have exploited the offshore grounds in the North Sea (up to 200+ kilometres offshore).

Landing Ports

Most major fishing ports receive significant scallop landings: Campeltown, Oban, Stornoway and Mallaig on the West Coast, Wick and the Orkney and Shetland ports in the North East, and Aberdeen, Fraserburgh and Buckle in the North Sea.

Resource characteristics

The Scottish scallop fisheries are characterised by 8 management areas, rather than by discrete stocks. However, over these management areas there are significant differences in annual recruitment patterns and spawning stock biomass, and age profiles of the exploited stock. The boundaries of the eight management areas are elected to coincide with those of the relevant ICES statistical rectangles. [Landings data, 1998: landings figures distorted by ASP area closures in 1999.]

Irish Sea Management Area

Landings 1350 tonnes. Comprises 6.5 ICES statistical statistical rectangles covering the north Irish Sea and the south west of Scotland including the Solway Firth.

Much of this area lies within the Irish Sea, though landings into Scotland are taken mainly from north of 54º.30’N. Historically, landings were composed largely of 3 to 6 years old scallops, but since 1996 the proportion of animals of 7 years and older has increased.

Clyde Management Area
Landings 120 tonnes. Based on split ICES square data for this local fishery. This small, more or less discrete and localised area yields 120 tonnes per annum. Catches and recruitment have been relatively stable; 3 to 5 year old scallops predominate in the landings.

West Kintyre
Landings 1149 tonnes. 6.5 ICES statistical rectangles from the west Clyde to south Islay, including the north Irish coast west to 008-W. Recruitment, and age structure, vary significantly between statistical rectangles within this relatively small management area. In some statistical rectangles the stock consists of mostly young scallops (3 to 5 years), while in others there is a broader range of ages.

North West Management Area
Landings 2021 tonnes. This is the second largest management area in the Scottish scallop fishery (23 ICES statistical rectangles): only the East Coast area is larger, but in the North West area scalloping is generally confined to coastal margins and shallow banks; much of the rest of this area is deep muddy substrate more associated with *Nephrops* fishing. Recruitment over this area is regular though variable. Recruitment in the early 1990's was above recent averages though spawning stock biomass appears to be declining, perhaps due to increased effort.

Orkney Management Area
Landings 214 tonnes**.** 6 ICES statistical rectangles to the west and north of Orkney. Significant diver caught landings from inshore shallow beds; 50%, up to 100% in some years. Data for this fishery is limited; local dived and marketed catch has dominated the fishery, with 4 to 8 year old animals predominating. The predominance of 4 year old scallops in 1994 is consistent with the generally above average recruitment in the early 1990's, borne out by the importance of 5 and 6 year olds in subsequent years.

North East Management Area
Landings 3490 tonnes. 13 ICES statistical rectangles to the north-east of Scotland representing the largest landings from any of the individual Scottish management areas. This relatively recent dredge fishery, which started in the mid 1970s compared with the early 1960s for some other areas, was originally dominated by landings of older animals (8+ years). Landings are now composed mainly of scallops aged 4 to 7 years, consistent with fairly regular recruitment though, as with many other areas, recruitment did peak in the early 1990s.

Shetland Management Area
Landings 653 tonnes. Although this area comprises 12 ICES statistical rectangles landings are 600 - 800 tonnes, less than 10% of all Scottish landings. Over time the proportion of older scallops in the catches has fallen. Landings are currently dominated by 4 to 8 year old scallops; this is consistent with the good recruitment experienced by most, but not all, of the other areas in the early 1990's.

East Coast Management Area
Landings 1901 tonnes. This is the largest management area, 27 ICES statistical rectangles. It is unusual amongst the Scottish management areas as it includes important and extensive scallop grounds well offshore, up to 200+km east of the Scottish mainland in the central northern North

Sea. Recruitment across this area may be more irregular than in other areas; recent catches appear to rely on just two or three-year classes, e.g. in 1995 and 1996 four to six year old animals predominate.

Fishing Strategy

There are no area closures in the Scottish scallop fishery based on scallop stock management, or quality or marketing strategies, though in the Clyde there is effort limitation - a statutory weekend ban on mobile gear - with a voluntary weekend ban to the west of the Mull of Kintyre. Seasonal closures, instigated to resolve gear conflict, and sporadic closures due to build up of various algal toxins in the scallop tissue, are treated under the appropriate separate headings below. A seasonal winter ban (October to March) that exists in a number of West Coast sea lochs and adjacent waters was introduced to protect nursery grounds for herring and plaice.

Since the beginnings of the Scottish scallop fisheries (early 1960's on the West Coast, 1970s in the North Sea) the fishery has been dominated by dedicated scallop dredgers. However, *Nephrops* vessels have, particularly in the last decade, opted to diversify into scallop dredging as a more economic alternative in the winter months, primarily on the West Coast.

On the West Coast the most productive scallop grounds occur often as patches amongst rough ground close inshore. Smaller, more manoeuvrable vessels (up to 16 metres), which tow 2 to 10 dredges per side, are best suited for these grounds, and so dominate the West Coast fleet; this includes the dual purpose *Nephrops*/scallop vessels.

Scallop grounds on the Scottish east coast, notably the Moray Firth and the North Sea, are more extensive and generally offshore, up to 200+ km east of the Scottish mainland. These grounds are exploited mainly by larger vessels of 300 to 400 hp towing 10-14 dredges per side. Many of these vessels are nomadic; operating on the open water east coast grounds in the summer (April -September) and moving to the Scottish West Coast or other scallop grounds for the winter months.

Interactions

Significant interactions or conflicts are reported from mainly the West Coast of Scotland. There is a conflict of access between scallop divers and dredgers, particularly on inshore grounds (0-30m depth) close to the home ports of small diving vessels (up to 9 metres).

Significant creel fishing (potting) occurs on, or closely adjacent to, many of the West Coast scallop beds: crabbing *(Cancer)* on the same grounds as the scallops; prawn creeling *(Nephrops)* on the deeper margins; and velvet crab (N. *puber)* and lobster (*H. gammarus)* creeling close inshore. Conflict with these static gear fisheries is reported from most areas. There is a statutory six-month closure to scallop dredgers east of the Hebrides to resolve conflict with the local crab fishery; further areas are proposed, notably around the Shlant Islands to the North of Skye.

Markets

Most Scottish caught scallops are handled and/or processed at dedicated scallop factories around Scotland, for live, fresh or frozen export to continental Europe. The local hotel and restaurant outlets are steadily becoming more significant, as is a small but growing trade with the Far East.

Trends and Comments

The three most significant trends are:

1. A steady increase in effort represented by increases in the number, size and engine capacity of the dedicated scallop fleet in all Scottish waters;
2. an increase in the last decade in the number of *Nephrops* trawlers converting to dual purpose trawler/scallopers, particularly for the winter scallop fishing; and
3. algal toxins, most significantly since 1990, have increasingly affected the Scottish fishery resulting in area closures, primarily in the most productive summer months.

Algal Toxins, which concern the Scottish shellfish industry are: PSP (paralytic shellfish poisoning) and ASP (amnesiac shellfish poisoning), which have had the most significant effect on the scallop fishery, and DSP (diarrhoeic shellfish poisoning), which is more significant in the cultured mussel industry.

PSP area closures have become a regular feature of the scallop fishery since the 1980s, but increasingly in the 1990s, on both East and West coasts. Closures have generally ranged from one to three months. The most commonly affected areas have been Orkney and the Moray Firth, though in 1995 much of the eastern North Sea, including the Moray Firth, was closed for over two months in mid-summer (the usual peak of the scallop fishery in this area). Lost revenue has been estimated at approximately £1 million (1.6 million Euros).

Statutory testing for ASP commenced in 1998, when there were no significant outbreaks. This was also the case in 1996 and 1997 under the previous non-statutory regime. However, in 1999 levels of ASP toxin (domoic acid) in routine samples from the fishery resulted in large scale closures over almost the entire West Coast grounds, as well as Orkney and the Moray Firth, for several months. Significant areas of the West Coast, closed in June 1999, remain closed to scallop and queen fishing in January 2000. Losses have been estimated at approximately £2million (3.2 million Euros).

Management measurers

Scallop entitlement introduced to vessel shellfish licences for the first time in April 1999. Proposed technical measures:

Industry proposals for management of the scallop fishery are currently under discussion and include minimum belly ring and top mesh sizes, maximum beam length and maximum number of dredges within six miles.

Landings

The total Scottish scallop landings from1993 to1999 have ranged between 6000 and 9000 tons, Figure 4-7

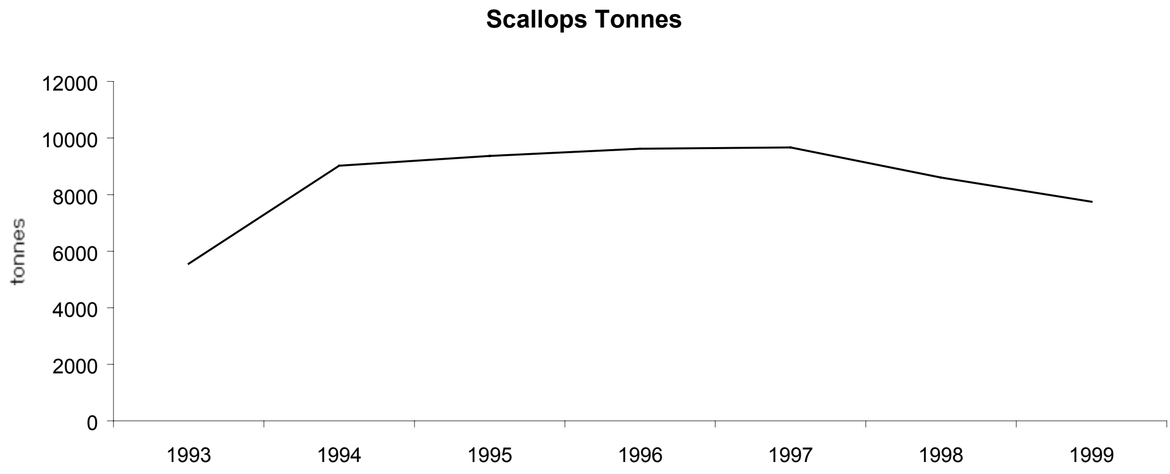


Figure 4-7 Total Scottish *P. maximus* landings from 1993- 1999

Value

The annual value of scallops landed in Scotland from 1993 to 1999 has ranged from approximately £M 8.0 to £M 15.0 Figure 4-8.

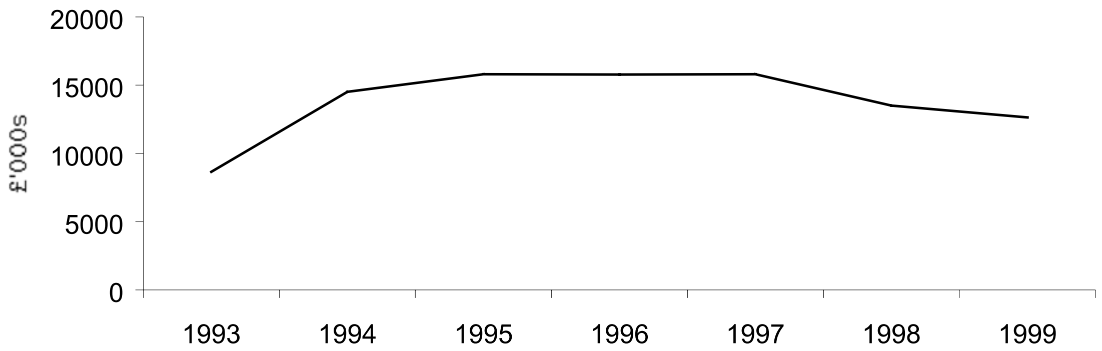


Figure 4-8 Annual value of *P. maximus* landed in Scotland 1993-1999

4.2.2 *Aequipecten opercularis*

Target species and by-catch

Target species is the queen scallop, *A. opercularis.* There is a variable, though generally small, by-catch of *P. maximus* in the directed 'queenie' fishery; however, in some areas the proportion of *P. maximus* in the catch is significant and economically important and, in effect, represents a mixed fishery. Otherwise the by-catch is not significant, though may comprise a small proportion of commercial flat fish species (e.g. *Solea).*

Fishing areas (and ports)

The Scottish queen scallop fishery is dominated almost entirely by landings into the Ayr Fisheries District (South West Scotland) mainly into the port of Kirkcudbright; catches are from the Clyde, Solway and northern Irish Sea grounds.

Resource characteristics

Recruitment, though more significantly from a commercial point of view "catchability", is variable; both factors, coupled with market demand, affect the volume of landings from the important south west district. Localised queen scallop beds outwith the south west have been sporadically exploited, notably in various west coast sea lochs (Loch Nevis, Loch Dulch, and the Kyles) and the Sound of Mull. No regular, sustained fishery has developed.

Fishing strategy

Dredging for queens employs spring tooth dredges of the Scottish scallop with small meshes, rings, and tooth spacing. Most vessels in the directed fishery employ deck mounted, hydraulically driven, 'riddles' for catch sorting; discarded small queens (less than about 45mm) are returned to the sea. In the mid 1980's there were sporadic attempts to establish trawl fisheries for queens on the Scottish west coast beds, using very heavily constructed otter trawls. This trawl method for queens is relatively efficient but these fisheries have not been sustained; economic returns were generally disappointing particularly when compared with the alternative option of *Nephrops* trawling, despite a number of vessels investing in heavy queenie nets and hydraulic sorting riddles.

Markets

The main markets are for fresh or frozen processed queen scallop meat on the continent. Yields per shell are small and there is little economic incentive for 'live' (i.e. in shell) sales. Processing large numbers of these small bivalves involves complex mechanical factory systems of which there are very few in Scotland; processing has been concentrated in Glasgow and the south west.

Trends and comments

The comparatively low value of the queen scallop product, relative to the king scallop *(Pecten),* and the more localised grounds means that effort has not grown to the same extent as effort for *P. maximus*

Algal Toxins

PSP outbreaks over the last decade have generally not affected the South West district from where most *A. opercularis* are taken. However, the ban on catching *P. maximus* due to ASP toxin extending over most of the West Coast in 1999 also included *A. opercularis*. Although significant *A. opercularis* grounds remained open to the south of Islay and Kintyre in 1999, overall catches were down 30%, but it is unclear how much of this reduction, in a historically unpredictable fishery, can be attributed to ASP area closures.

Landings

Landings over the period 1993 – 1999 have varied from approximately 2000 tons to 6500 tons Figure 4-9.

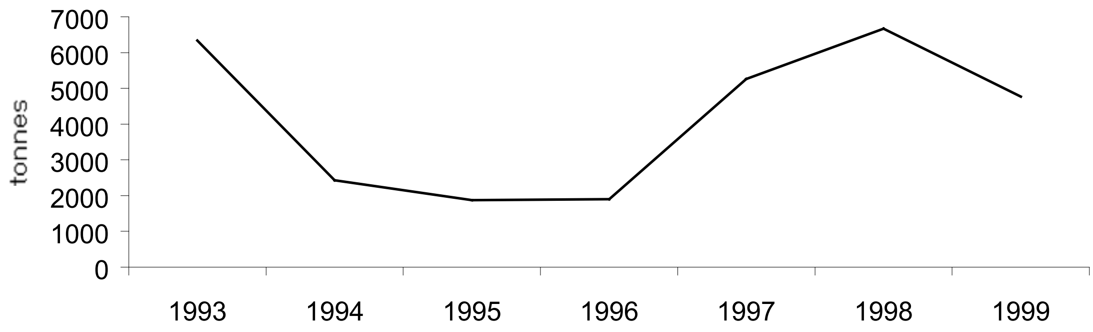


Figure 4-9 ***A.opercularis* landings in Scotland 1993-1999.**

Value

The annual value of *A. opercularis* landed in Scotland 1993-1999 has ranged from approximately £M 1.0 to £M2.5, Figure 4-10.

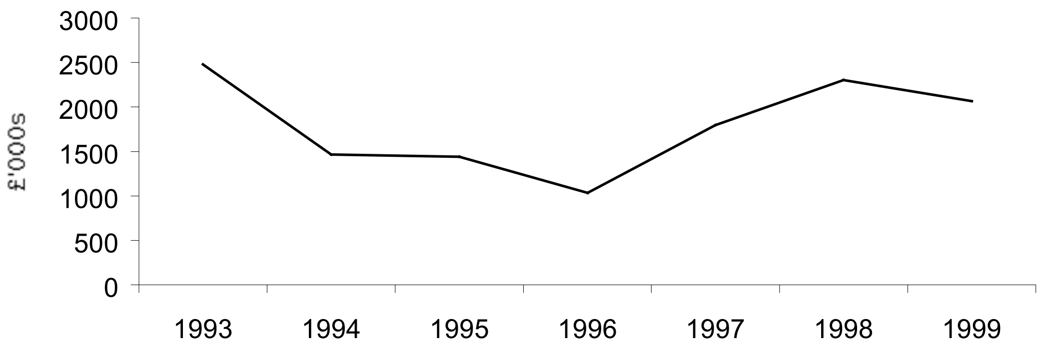


Figure 4-10 Annual value of *A. opercularis* landed in Scotland

4.2.3 Other local novel bivalve dredge fisheries

There is a wide variety of suction, hydraulic, airlift, and towed dredges employed in mainly local, often small scale, shellfish fisheries targeting a range of species. The variety of dredges, many being experimental amateur builds, is such that all dredges in this group (barring towed fixed gear) are, for the meantime, in Scotland classified as suction dredges in terms of their perceived or potential environmental impact.

Target species and by-catch

Target species include mussels *(Mytilus edulis),* razor-shells *(Ensis and Solan spp.)* and the trough shell, marketed as 'surf clam', (*Spisula solida*). By-catch in these totally targeted, gear specific fisheries is insignificant. Cockles *(Cerastoderma edule)* are hand raked on a small scale.

Fishing areas (and ports)

Virtually all wild caught mussels in Scotland are landed into Wick Fishery District from the Dornoch Firth mussel beds. Landings of razor shells are significant in three areas: Mallaig, Orkney and the island ports of the Outer Hebrides. Surf clams have been targeted sporadically in the shallow waters of Mallaig District, and landed into the port of Mallaig and adjacent creeks.

Resource characteristics

The mussel fishery of the Dornoch Firth is administered by the regional council (Highland Council). Razor shell and surf clam dredging are recent, often sporadic, fisheries employing a variety of ad hoc gear from small vessels, often the result of attempts to diversify from diving operations or other small boat fishing. In the relatively few instances where catching operations have been successful the effort has tended to be concentrated on a very small area (one to ten hectares) with consistent returns. These two species may represent a significant potential resource as further productive beds are identified, and methods improved.

Fishing strategy

Mussel dredging in the Dornoch Firth is carried out by single vessel that deploys a Dutch type, fixed bar, towed mussel dredge, and harvests about 200 - 250 tonnes per annum.

The variety of dredges employed in the razor shell and surf clam fisheries is almost as large as the number of vessels taking part. Many have been designed and developed by fishermen themselves. They range from towed French type diving plate dredges through suction dredges, airlift dredges, hydraulic with airlift dredges, to hydraulic only where the shell is gathered by divers from the dredge track by hand. The small number of vessels involved, often a single vessel, has resulted in effort being confined to a very few small and discreet and productive beds; there has been little pressure to search for more widespread resources.

Regulations

The Dornoch Firth mussel fishery is managed and regulated by Highland Council.

There are no management regulations for the razor shell and surf clam fisheries. However, most of the dredges employed are classified as suction dredges and their use is discouraged in conservation areas and may be banned in these areas in the future.

Markets

The Dornoch Firth mussels, which are landed seasonally in bulk, are destined for processing/live export (1999 - £200 - £250 per tonne). The price is depressed by high transport costs, despite animals coming from Class A waters and requiring no purification. (Cultured mussels are harvested in alignment with market demand, where the in-shell restaurant and export trade, which is becoming increasingly important, can achieve £500 - £ 1000 per tonne).

The market for razor shell and surf clams is largely continental, but has proved difficult to sustain due to the small number of vessels, which often use unreliable gear and are unable to generate a consistent supply.

Trends and comments

Dornoch Firth mussel fishery is likely to continue without trend given adequate annual settlement. Razor shells and surf clams may have significant potential for increased exploitation, particularly if suitable vessels could be equipped with modem efficient hydraulic dredges which have been well proven elsewhere, promoting more regular supply to the market.

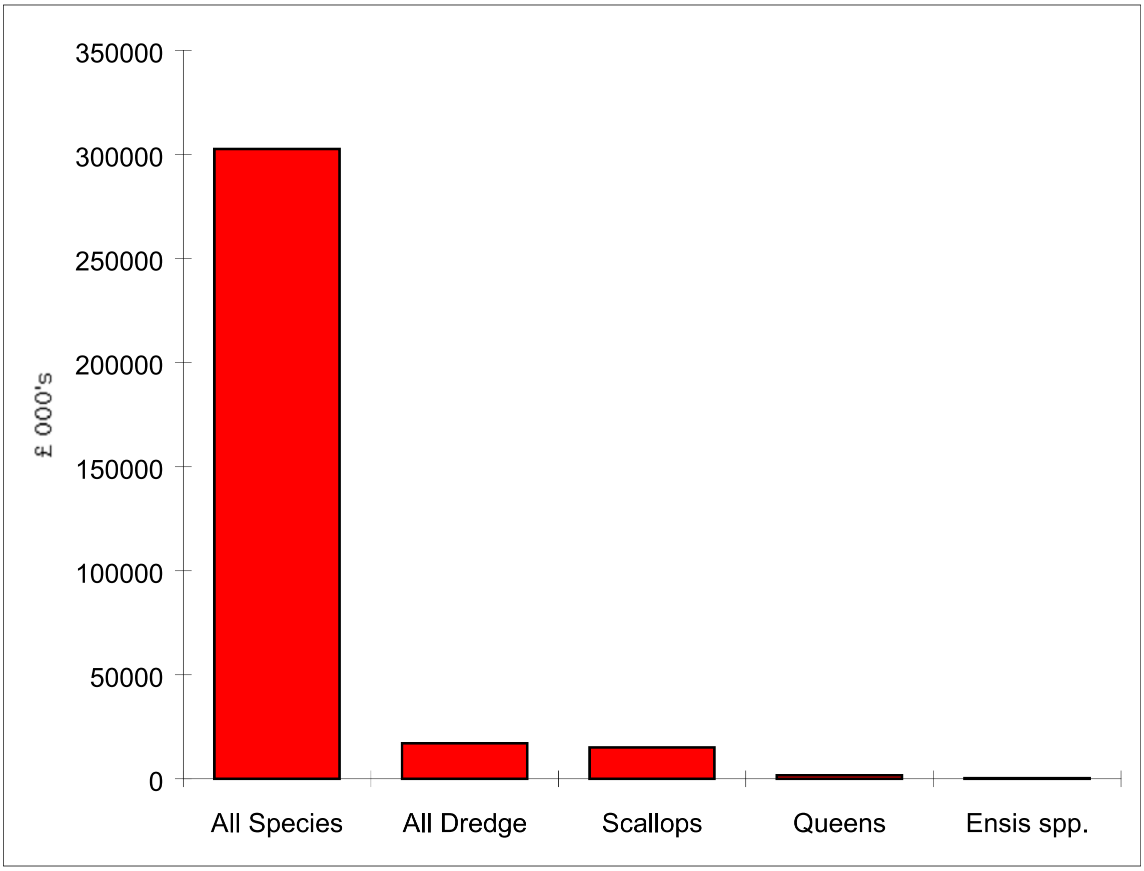


Figure 4-11 Dredge fisheries as a component of all Scottish Landing (1996-1998 average)

4.3 Isle of Man

4.3.1 Pectinid group

Fishing Areas

The development of *P. maximus* and *A.opercularis*the fisheries in the Irish Sea has been accompanied by a gradual expansion of the area exploited, Figure 4-12.

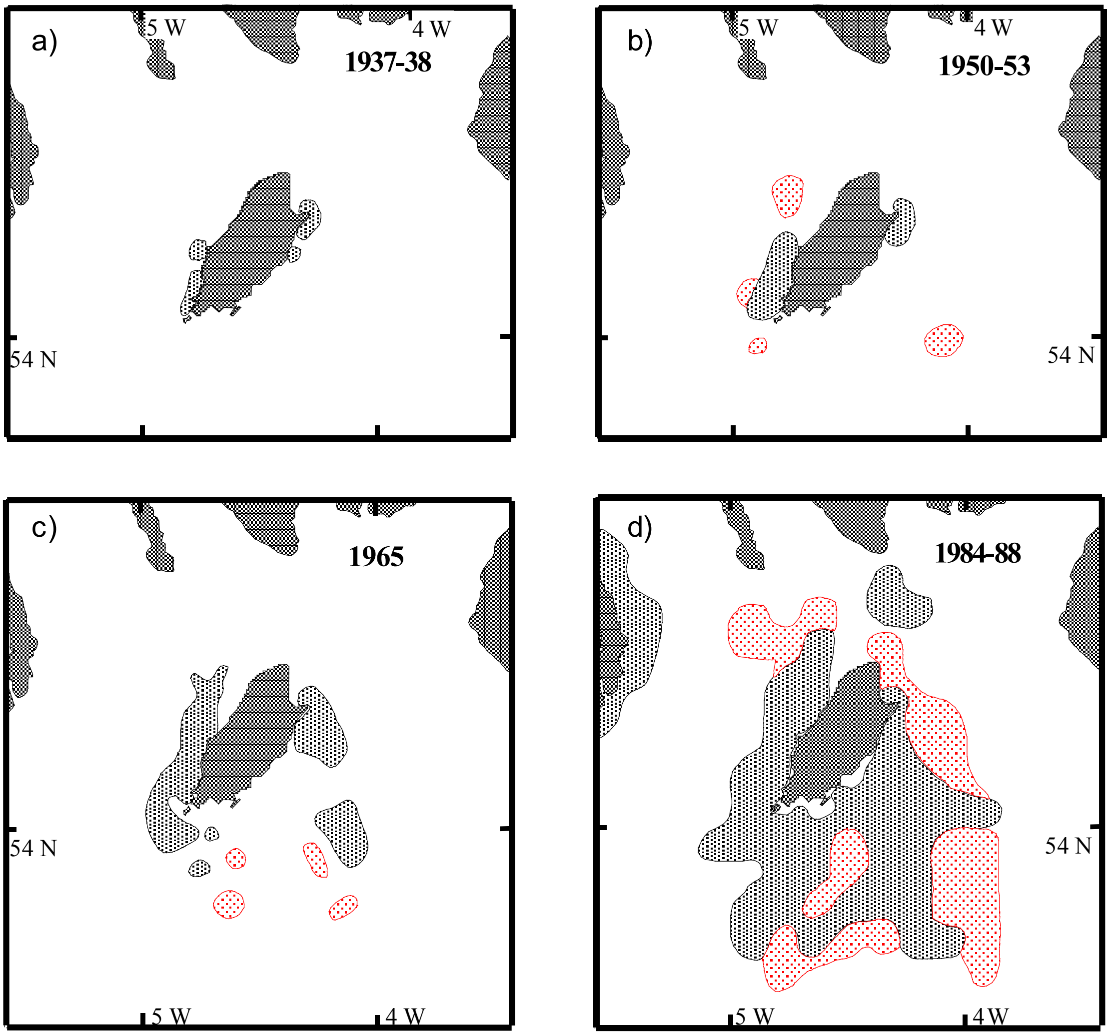


Figure 4-12. Areas fished for scallops (*Pecten maximus*) by commercial fishing boats in the Irish Sea: a) 1937-38; b) 1950-53; c) 1965 and d) 1984-88. (Dark shaded areas are regularly exploited, light shaded areas occasionally exploited).

The introduction of spring tooth-bar dredges in 1972 and smaller individual dredges in 1980/81 ((Murphy 1986)), allowed the fishing fleet to exploit rougher grounds without damaging the gear, and possibly with greater efficiency than with larger fixed tooth bar dredges. The start of the *A. opercularis* fishery in 1969 also influenced the exploitation of new *P. maximus* grounds. The two species coexist in many areas, so, subsequently, *P. maximus* have been fished on grounds where they occur in densities that would not be viable, were not for the lucrative queen by-catch, or vice versa.

Manx boats currently fish for scallops extensively around the Isle of Man. Areas can be divided into a number of semi-discreet fishing grounds where the substratum is suitable for scallops and fishing gear, separated by unsuitable zones, Figure 4-13. *A. opercularis* is fished over a more limited area; with grounds mainly off the Point of Ayre, east and south east of Douglas, south of Port St. Mary and on the Targets (Brand and Allison 1987). Apart from the Targets fishing ground there are no commercial *A. opercularis* grounds to the west of the Isle of Man.

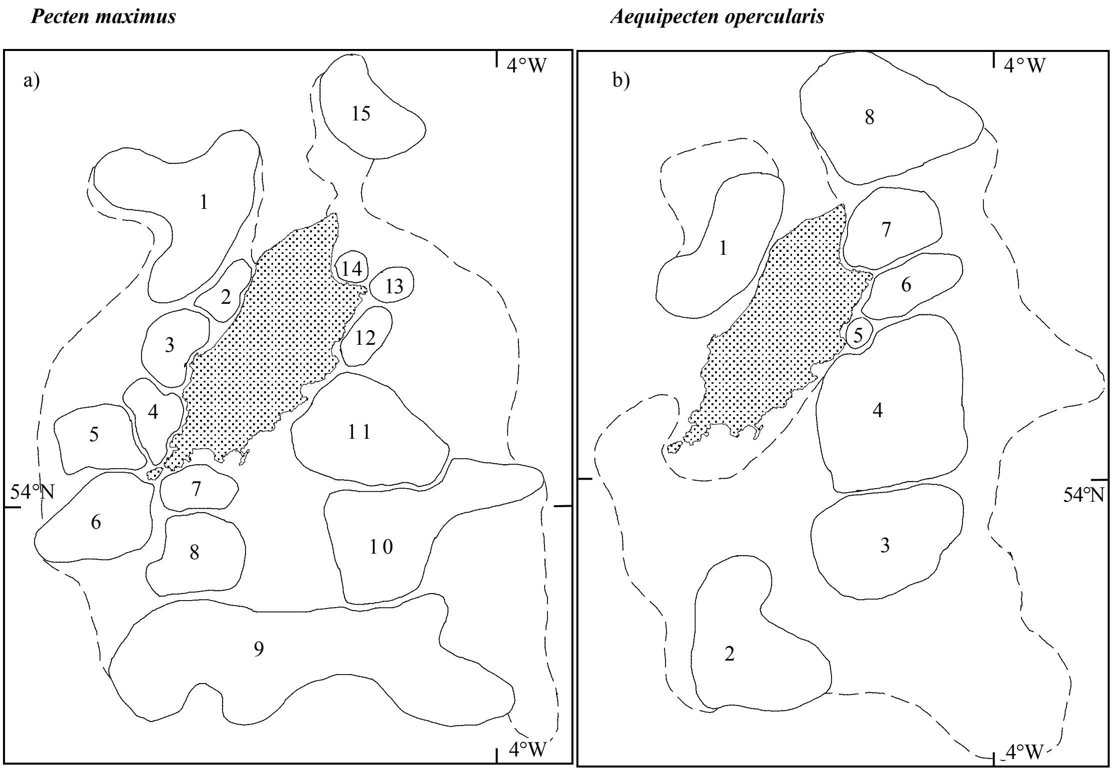


Figure 4-13 North Irish Sea scallop (*Pecten maximus*) and queen (*Aequipecten opercularis*) fishing grounds around the Isle of Man, currently fished.

Major fishing grounds bounded by solid lines; a dotted outline indicates areas where scallops occur and are occasionally fished. All boundaries are approximate and many fishing grounds are contiguous.

a) *P.maximus* fishing grounds: 1, The Targets; 2, Kirkmichael Bank; 3, Peel Head; 4, Bradda Inshore; 5, Offshore Bradda/West Calf; 6, The Chickens; 7, Port St. Mary; 8, Port St Mary Offshore; 9, H/I Sector & Offshore South; 10, Southeast Douglas; 11, East Douglas; 12, Laxey; 13, Maughold Head; 14, Ramsey; 15, Point of Ayre.

b) *A.opercularis* fishing grounds: 1, The Targets; 2, H/I Sector; 3, Southeast Douglas; 4, East Douglas; 5, Laxey Bay; 6, Maughold Head; 7, Ramsey Bay; 8, Point of Ayre.

Several small *P.maximus* fishing grounds around the coast of Northern Ireland are exploited regularly by Northern Irish boats and, occasionally, by the Manx (Briggs 1991, 1995). Similarly, off the east coast of Ireland, a number of small grounds are fished regularly for *P. maximus*, particularly around the Saltee islands, and the Kish Bank, which occasionally, have supported a large *A. opercularis* fishery (Duff 1976).

Scottish boats, which show the most widespread searching and fishing activity, now fish both scallops and queens over extensive areas of the north and eastern Irish Sea, as far as Liverpool bay and up into the Solway Firth.

Fishing strategy

On some fishing grounds bottom trawls can be very efficient at catching *A. opercularis* in the summer months, when the animals are most active. Trawls resemble groundfish nets with heavier bobbin wheels or rock-hoppers on the groundline (Chapman et al. 1979; Brand et al. 1991). The doors are attached usually to the mouth of the net, though bridles are sometimes used to increase by-catch of fish. Some boats use only one type of gear while others change according to the area fished and the season.

Queen dredgers use mechanical riddles on deck to sort marketable-sized queens from the large quantities of fish, invertebrate by-catch, dead shell and bottom debris. This sorting process performs a valuable conservation function by returning young, unmarketable queens quickly to the sea. It does, however, increase damage to the by-catch before discarding. Most boats use rotary sorters but some modern vessels use a more efficient vibrating flatbed system as part of their automated deck-handling equipment.

Vessel profile

Changes in the Manx dredging fleet, are shown in Figure 4-14. The fleet increased from 9 vessels in 1937 to a maximum of 70 boats in 1983-84. Subsequently, numbers decreased and now comprises 45 boats.

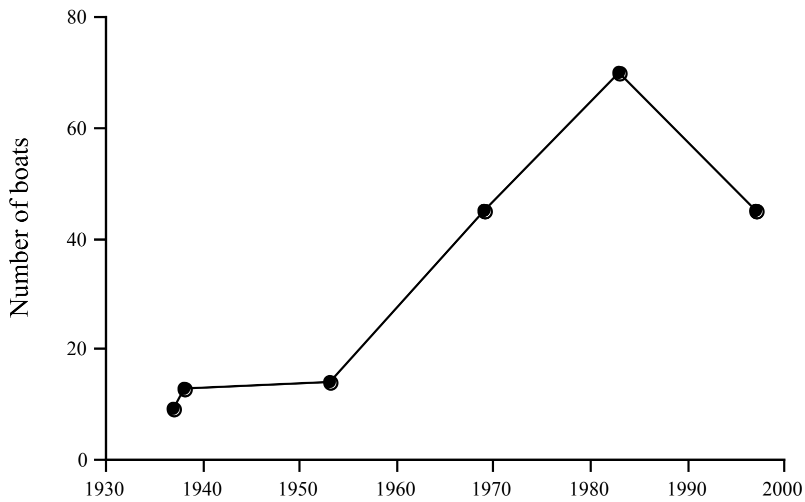


Figure 4-14 Number of vessels in the Manx dredging fleet

The main trend throughout this period has been one of increasing boat size and power in order to pull more gear and exploit grounds farther off shore. Vessels bought in the 70s were mainly second-hand Dutch beam-trawlers (18-25m), capable of towing a wide spread of gear. Though some new multi-purpose vessels have been purchased recently many old vessels in the Manx fleet (27%) are more than 30 years old. Currently, 57% of active vessels are now greater than 16m in length, which disqualifies them from fishing inside the Isle of Man 3-mile territorial limit.

In addition, UK boats fish *P. maximus* and *A. opercularis* in the north Irish Sea every year. A fleet of some 15 vessels, which includes several purpose-built dredgers, operate from Kirkudbright, and a smaller number of boats operate from ports in England (Maryport, Whitehaven), Wales (Conwy) and Northern Ireland. Scottish vessels from the Clyde or farther north also fish occasionally in the Irish Sea, particularly on the northern grounds.

The Irish Sea *P. maximus* and *A. opercularis* stocks are fished predominantly by the same vessels, which can fish preferentially for *P. maximus* when legally allowed (November-May inclusive), turning to *A. opercularis* for the rest of the year. However, the number of vessels fishing at any time can vary enormously, both within and between fishing seasons, as an increasing proportion of vessels (Manx and probably most of the UK boats) would leave the Irish Sea to fish elsewhere if it were economically favourable. During the Irish Sea closed season for scallop fishing, Manx boats may therefore be fishing for *P.maximus* , or for *A. opercularis*, on grounds off the west coast of Scotland, east coast of Scotland or in the Channel.

Dredge fishing effort

Data on annual fishing effort for the Irish Sea scallop fisheries, as a whole, is unavailable. However, detailed data from 1981 are available for a proportion (approximately 30%) of the Manx fleet from voluntarily completed fishermen's logbooks. These estimates of fishing effort are probably generally representative of the Manx fleet but less so of the UK boats.

The areas fished are reported for 5 x 5 nautical mile grid squares, which gives sufficient spatial resolution to calculate the catch, effort and stock abundance for individual fishing grounds, without making the logbook difficult to complete.

Catch per unit effort – (P. maximus)

Discontinuous series of catch per unit effort data (CPUE), expressed as numbers of animals per metre dredge width per hour’s fishing, are available for a number of fishing grounds around the Isle of Man since 1950. These grounds differ considerably in environmental conditions and in the length of time, the regularity and the intensity with which they have been fished. For all grounds the CPUE has declined, Figure 4-15. Although numerous factors can affect CPUE values (such as changes in gear efficiency), these changes undoubtedly reflect large decreases in stock abundance.

Each year since 1981, annual CPUE values for individual grid squares throughout the northern Irish Sea show that areas of highest abundance vary from year to year and generally occur on grounds further offshore. These grid squares of high CPUE are not necessarily the most heavily exploited for they may contain small high density patches of scallops that are fished out quickly, resulting in high catch rates with low fishing effort but a low total seasonal catch.

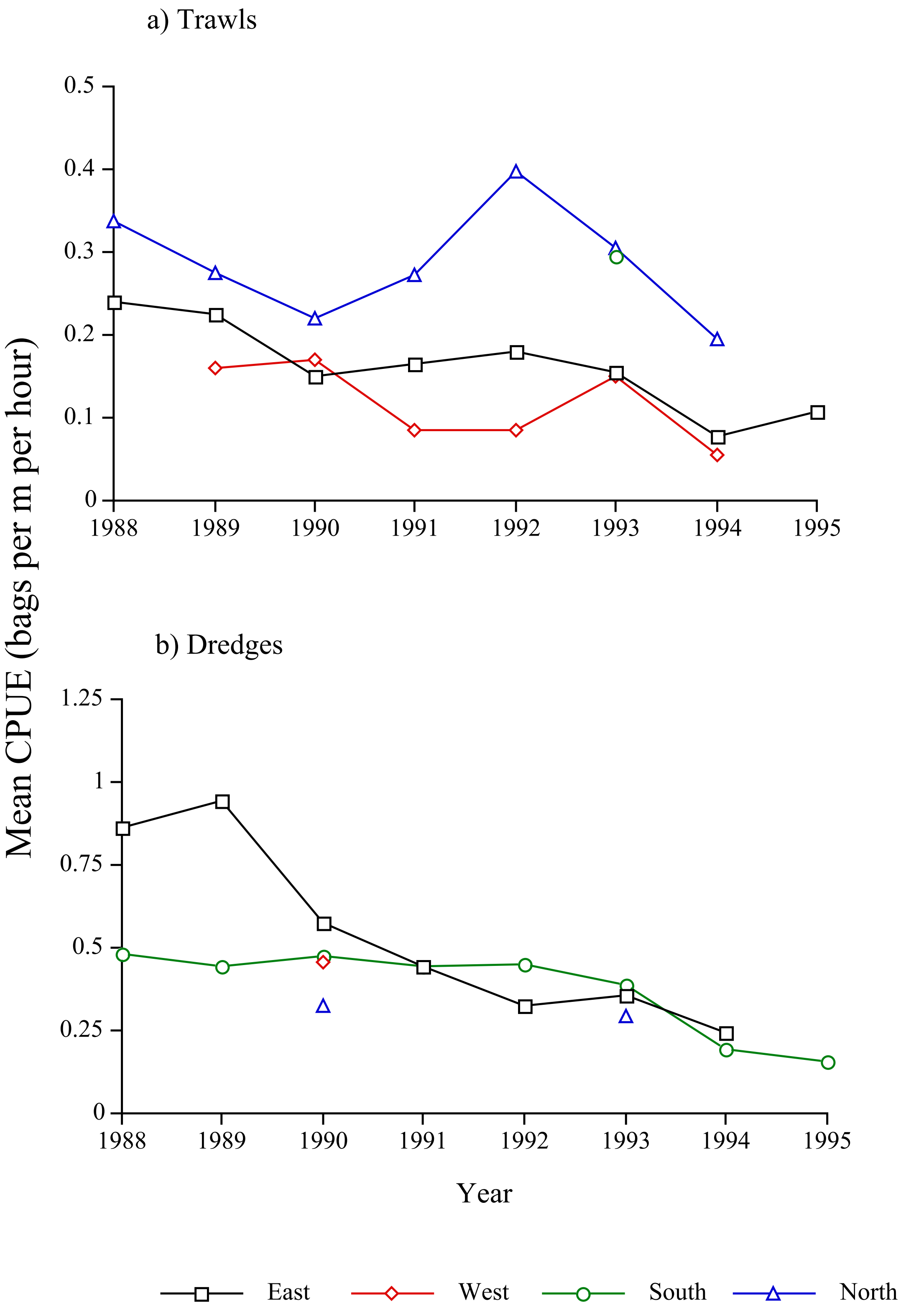


Figure 4-15 Mean CPUE for *P. maximus* in different areas around the Isle of Man

Estimates of scallop densities on different fishing grounds, as calculated from commercial CPUE values, show a long-term decline; from 9-20 scallops $100m^{-2}$ in the 1950-60s to <7 scallops $100m^{-2}$ between 1981-84, <4 scallops $100m^{-2}$ in 1986-90 and currently <3 scallops $100m^{-2}$. For the most heavily exploited fishing grounds, where the populations are dominated by young scallops, there are large seasonal variations in density. Pre-season (October) estimates of density are now all around 3 scallops.$100m^{-2}$, a level dependent largely on the strength of summer recruitment. The post-season (June) densities of around 1.5 scallops $10m^{-2}$, probably approximate to the density that the fishermen currently consider to be uneconomical; when density falls to this level they move off to fish elsewhere.

Catch per unit effort (A. opercularis)

Mean annual CPUE for dredgers and trawlers over the period 1988-1995, has varied annually on all grounds, but with a general downward trend. Dredging has shown little change in CPUE on the southern grounds but catches on the important eastern grounds off Douglas have declined greatly since 1989. CPUE for trawls has always been considerably higher on northern grounds, but has fallen steadily over the last 3-4 years on all grounds where this gear is used.

Catches (P. maximus)

P. maximus landings in the Isle of Man declined from 1,369t in 1969 to less than 500t in 1972 as many Manx boats diverted to the lucrative new *A. opercularis* fishery. Thereafter, as the initially very high queen catch rates fell, boats returned to *P. maximus* fishing and there was a generally rising trend in catches to a maximum of 2,162t in 1985. Since then the annual Manx *P. maximus* catch has declined fairly rapidly and for the last six years has been under 1,000t.

Compared with the Manx landings, Irish Sea *P. maximus* landings in Ireland, Scotland, England & Wales and N. Ireland have generally been very much lower but have followed a broadly similar trend, Figure 4-16. Overall, the total annual catch of *P. maximus* from the Irish Sea (ICES Area VIIa) increased from about 1,000 – 4,000 t through the 1970s, remained fairly stable through the 1980s and declined steadily through the 1990s. For most of this period, the Manx share of the catch has been greater than 50% but since 1987 it has declined to about 35%.

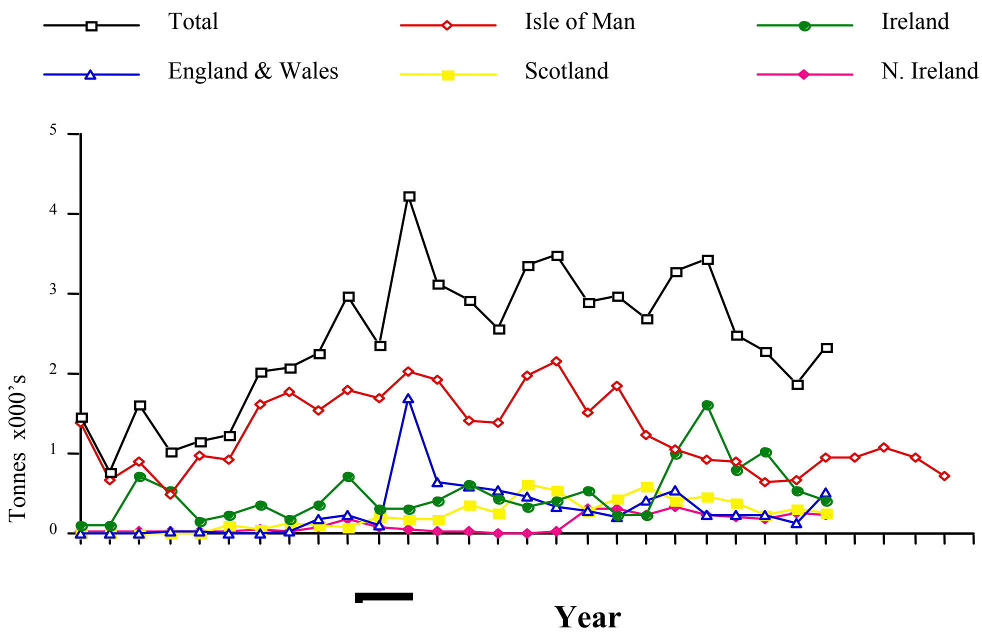


Figure 4-16: Annual landings of *P. maximus* from the Irish Sea (ICES Area VIIa) by country, 1969-98. (Data from various government sources).

Catches (A. opercularis)

With very high catch rates from previously unfished stocks, the Isle of Man fishery developed rapidly and annual catches reached a maximum of 7,627t in 1972, Figure 4-17. Subsequently, catch rates declined to 2,193t in 1977, whereas scallop catches increased. Since then, catches have been variable, but since 1983, in general decline.

The Scottish fishery in the Irish Sea started in 1974 with the opening of a processing factory in Kirkudbright and since 1976 has generally had the highest catches. However, with their more mobile fleet, Scottish landings from the Irish Sea fell particularly sharply during the very poor 1994 fishery, to a level similar to the Isle of Man. Substantial quantities (1,000 - 4,000t) were also landed in England and Wales between 1976 and 1987 but, since then, catches have been highly variable. Apart from some large landings in the early years of the fishery, annual catches in Ireland and N. Ireland have been less than 250t.

The total Irish Sea catch by all nations varied annually within the range of 5,000 - 13,000 t up until 1993, but with no apparent trend. In 1994, however, the catch slumped to 3,379 tonnes. Variation in annual catch is therefore considerably greater than for the *P. maximus* fishery.

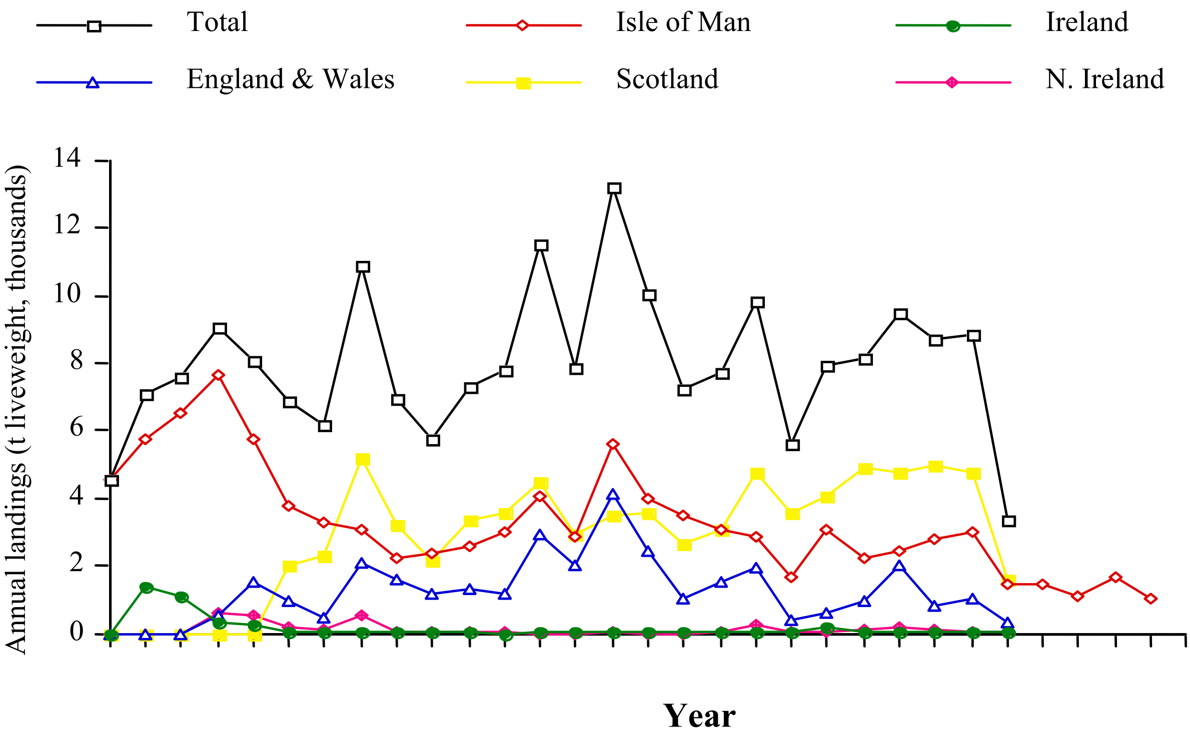


Figure 4-17: Annual landings of *A. opercularis* from the Irish Sea, by country, 1969-98. (Data from various government sources).

Other European P. maximus and A. opercularis catches

To put the Irish Sea (ICES Area VIIa) fisheries into perspective, annual catches can be compared with those reported from other ICES Areas. The Irish Sea ranks fourth (after the east and west Channel (Area VIId and VIIe) and the west of Scotland (Area VIa) accounting for about 12% of the annual scallop landings within the ICES region (the western European Continental Shelf). From 1994 scallop catches from the east and west Channel declined so that, by 1989, the north east Scotland (Area IVa) returns the largest catches. Taken together, there has been a steady and marked decline in the total European scallop catch over the last 20 years.

The Irish Sea (Area VIIa) is the most important fishery for *A. opercularis*, accounting for about 70% of the total annual landings within the ICES region. Since 1980, the second most important area for *A. opercularis* fishing has been the Faroes (Area Vb), where annual catches have increased steadily (apart from one massive fishery in 1990). Other areas that support an *A. opercularis* fishery each year, in decreasing order of significance, are the west of Scotland (Area VIa), south east Scotland/north east England (Area IVb), west Channel (Area VIIe) and north east Scotland (Area IVa). In addition, there are also recordings of *A. opercularis* landings from seven other ICES areas, indicating the wide distribution of fishable concentrations of this species. Until about 1990 the fisheries for *A. opercularis* in many of these areas were sporadic but over the last four years they have become more regular as increasing effort is turning to both scallop species as an alternative to whitefish.

Marketing and processing

Various markets have been developed for scallop meats. In 1960/61, markets were developed for fresh *P. maximus* meat (including the roe) in Belgium and in France. In the

1970s a market for frozen *A. opercularis* adductor muscle meat was found in the USA although the strength of this market was not maintained. After a period of low demand in the late 1970s and early 1980s the market for *A. opercularis* recovered somewhat in the late 1980s with the establishment of new outlets for fresh roe-on product in Europe .

Value

On the Isle of Man the first sale value of the *P. maximus* fishery rose to a maximum of just under £2.5million in 1987 but has since declined to £1.25million in 1995. The annual first sale value of the Isle of Man *A. opercularis* fishery has been more variable, peaking in 1972, 1983 and 1993 (£1.75million). In 1994 the value fell to £0.5 million before rising to £0.8million in 1995.

4.3.2 Management measures Isle of Man fisheries

Management measures applied to the *P. maximus* and *A. opercularis* fisheries are summarised in Table 4-2.

Table 4-2 Management measures for *P. maximus* and *A. opercularis* fisheries in Manx coastal waters.

Fishery	Species	Location	Input controls	Output controls
King Scallop	*Pecten maximus*	Isle of Man coastal waters (3 mile limit)	Closed season June to October inclusive Vessel licence (L) Vessel length restriction 16m. Only whole scallops may be landed Dredge specification: maximum aggregate width 8m French dredges not allowed Landings with greater than 20% spawned individuals not allowed	MLLS of 110 mm (L)
King scallop	*Pecten maximus*	Isle of Man coastal waters (3-12 mile limit)	Closed season June to October inclusive Vessel licence (L) Only whole scallops may be landed Dredge specification: maximum aggregate width 12m French dredges not allowed Landings with greater than 20% spawned individuals not allowed	MLLS of 110 mm (L)
Queen scallop	*Aequipecten opercularis*	Isle of Man coastal waters (3 mile limit)	Vessel length restriction 16m	None
Queen scallop	*Aequipecten opercularis*	Isle of Man coastal waters (3-12 mile limit)	None	None

MLLS - Miminum legal landing size (L) Local legislation

4.4 Ireland

4.4.1 Pectinid group

Fishing Areas

The main commercial fishing areas in Irish waters where commercial scallop dredging is ongoing are those indicated in Figure 4-18.

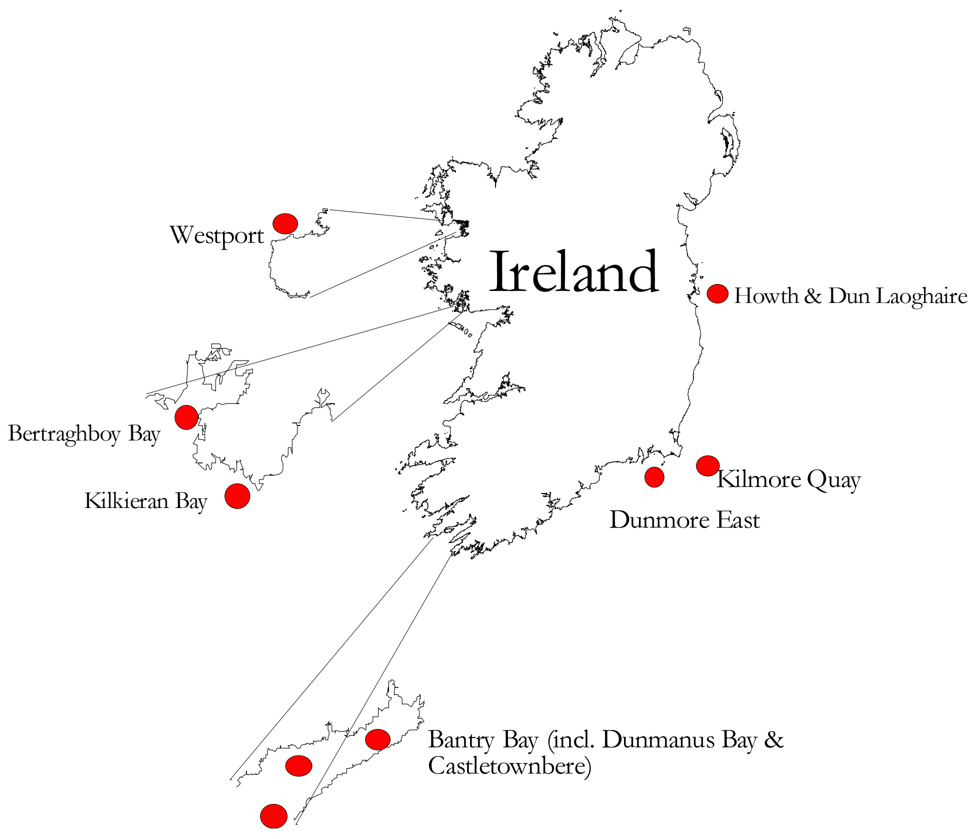


Figure 4-18. Location of commercial *P. maximus* fishing ground in Irish Waters.

Target Species and By-Catch:

The target species of this fishery is the King Scallop, *P. maximus*.

Gear

P. maximus is caught using a 'Newhaven' spring scallop dredge Figure 3-25.

Resource Characteristics

The main *P. maximus* fishery in Irish waters occurs on the south east coast (Kilmore Quay and Dunmore East), where very old animals are found. There is also a fishery close to the Saltee Islands, east of Hook Head. Fifteen to twenty miles offshore of this area, animals are dredged on open ground and these beds have supported the fishery over the last number of years. Inshore populations, found off the south east coast tend to be pulse fished and are exhausted fairly quickly. Some recruitment occurs in these areas and some evidence exists that storm events may effect the presence / absence of some year classes found in these areas (Minchin, *pers comm.*). Scallop fishermen have previously exploited a bed in Cork Harbour, near Whitegate. This population declined in the early 1980s and it has been suggested that TBT contamination and dredging activities going on the harbour at that time were the causative agents for this decline. Recently, the population recovered but was fished out immediately. A large bed exists in Roaringwater Bay, on the south east coast of Ireland where animals have been fished commercially for a number of years.

Between Cape Clear and Sherkin Island there has been a commercial scallop fishery for some years using the traditional spring toothed dredge. However, this area is difficult to fish due to strong tides, which lift the gear off the bottom. Off the southwest coast of Ireland in Dunmanus Bay, Bantry Bay, Berehaven Sound, Whiddy Island, Glengariff, there is an extensive fishery, which was exploited heavily by dredges and divers. However, these beds have yielded very low numbers of scallops over the last 5 years. Other small scallop beds exist further around the western coast. A number of the scallop populations in these areas were affected by the bad frost in 1962 – 1963 and have been slow to recover. Other large scallop beds exist near Roassaveal, Kilkieran Bay and Betraghboy Bay, near Galway.

Fishing Strategy

Dredging for scallops in Irish waters is mainly on inshore beds to a maximum depth of approximately 40m.

Interactions

Conflict exists with recreational vessels, beam trawlers and boats fishing for lobster, especially in the Kilmore Quay area (Radford, *pers. comm.*). The high percentage of adult whelk and whelk egg case by-catch whilst dredging for scallops is cause for concern as it might impact on recruitment to this developing fishery. In recent years, conflict has arisen between conservation groups and commercial fishing interest in Strangford Lough, Northern Ireland, over perceived damage caused to the Lough bed by trawling, principally of the diverse communities associated with the trawl fishery for the queen scallop, *Aequipecten opercularis* (L.) (Magorrigan et al. 1995).

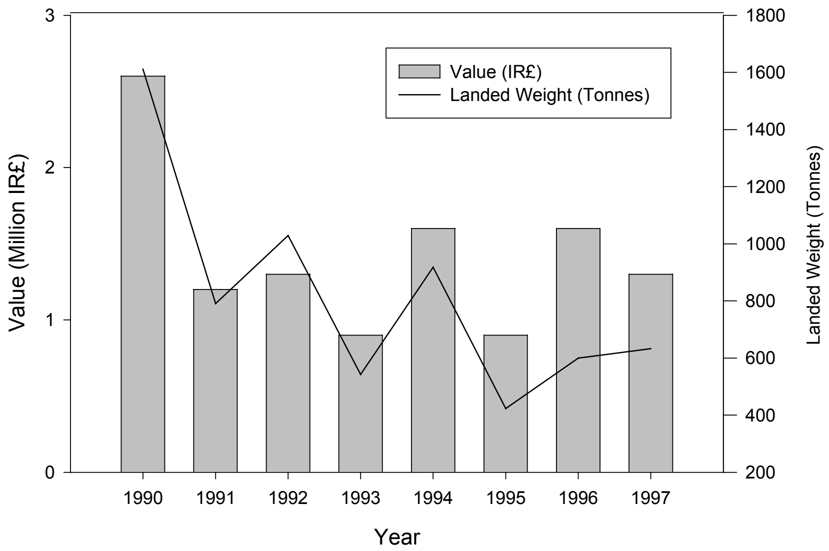


Figure 4-19. The Value (IR£) and Landed Weight (Tonnes) of Scallop, *P. maximus*, landed in Irish Ports between 1990 and 1997 (Data from Dept. of Marine Natural Resources, Dublin, Ireland).

Landings

Many of *P. maximus* fishing grounds in Irish waters are small and do not support a commercial fishery. Scallops fished in these areas are generally by local fishermen who may not report scallop landings. Therefore, the landings reported by the Dept. of Marine & Natural Resources may be severely underestimated.

Markets

Over the last 10 years, the export market for *P. maximus* has expanded to include France, Spain, Italy and Germany. Exports of Irish shellfish to the French market amounted to 13,800 tonnes in the first nine months of 1997 with this figure increasing in 1998 (exact figures unavailable). In 1997, total shellfish exports from Ireland were worth £52.7m and accounted for 23.1% of the total fish production from Irish waters (Bord Iascaigh Mhaire 1998). Scallops accounted for approximately 10% of the total shellfish exported from Ireland in 1997.

Trends and Comments

From Figure 4-19 it should be noted that there has been a decline in the landed weight and value of *P. maximus*, between 1990 and 1997. Comparable data is currently unavailable for 1998. Some of the decline may be attributed to reduced recruitment to the fishery in 1993.

4.4.2 Oyster group

Target Species and By-Catch

The target species of this fishery in Irish waters is *Ostrea edulis* with a negligible by-catch of flatfish; sole, *Solea solea*, and plaice, *Pleuronectes platessa*.

Gear

O. edulis is caught using a wire mesh oyster dredge Figure 3-10.

Fishing Areas and Port

The main commercial fishing areas for oysters in Irish waters are on the South East coast, Co. Wexford, on the West Coast in Kilkieran and Bertraghboy Bays, Co. Galway and on the North West Coast in Moville, Co. Donegal.

Fishing Strategy

Fishing for oysters in Irish waters is mainly on inshore beds to a maximum depth of approximately 30m.

Interactions

While fishing for oysters in Fenit, Tralee Bay on the West coast of Ireland, there is a bycatch of spider crab, *Maria squinado*.

Markets

The export market for oysters is the United Kingdom, France, Italy, Germany and Spain. The annual exports to these countries is approximately 10.5% of the total fish production from Irish waters (Bord Iascaigh Mhaire 1998).

Landings and value

Figure 4-20. shows the oyster landings by Value (Millions IR£) and landed weight (tonnes) for Irish ports between 1990 and 1997. Data is currently unavailable for 1998 (Data from the Dept. of Marine & Natural Resources, Dublin, Ireland).

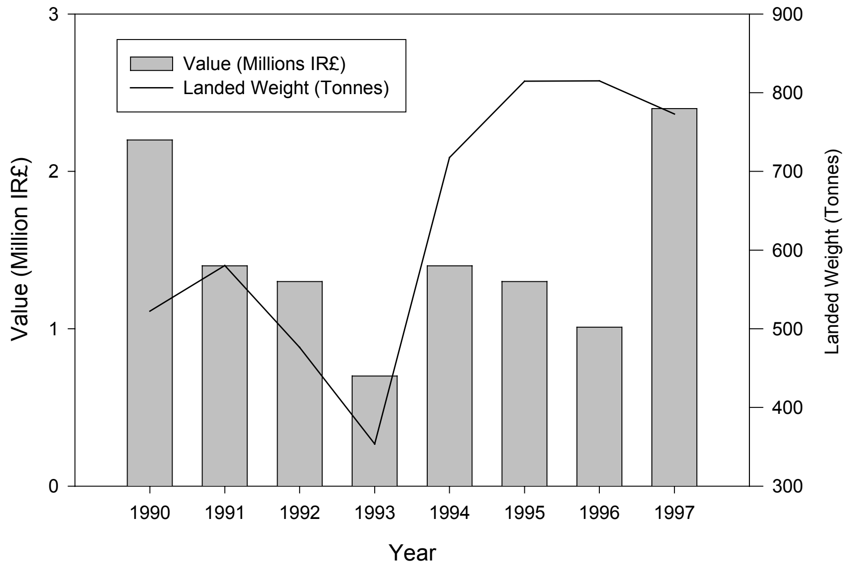


Figure 4-20. The Value (Millions) IR£ and the Landed Weight (Tonnes) of Oyster, *Ostrea edulis* from Irish boats between 1990 and 1997 (Data from Dept. of Marine & Natural Resources, Dublin, Ireland).

4.4.3 Management measures

Management measures applied to the dredge fisheries are summarised in Table 4-3

.

Table 4-3 Management measures for traditional mechanical dredge fisheries.

Fishery	Species	Location	Input Controls	Output Controls
Oyster	*Ostrea edulis*	South East Coast (ICES Area VIIa)	Regulated fishery between Wicklow and Carnsore Point; closed season from April 30 to September 1 each year (L) .	MLLS of 76mm (N)
Oyster	*Ostrea edulis*	South East Coast (ICES Area VIIa)	Regulated fishery in the common estuary of the Rivers Suir, Nore and Barrow; closed season from January 1 to September 30 every year (L).	MLLS of 76mm (N)
Oyster	*Ostrea edulis*	South Coast (ICES Area VIIg)	Regulated fishery in Cork Harbour or the estuaries of the rivers flowing thereinto; closed fishery from May 1 to September 1 every year (L); dredging for or taking oysters between sunset and sunrise; Dredging allowed between May 1 and June 14 inclusive; prohibits dredging between September 1 and October 14	
Oyster	*Ostrea edulis*	South West Coast (ICES Area VIIj)	Regulated fishery; prohibits, between October 19 to November 12, every year the taking of oysters by any means except between 9am and 2.30 pm on Tuesday, Wednesday & Thursday of each week; prohibits between November 13 and December 10, the taking of oysters by any means except between 9am and 2.30pm Monday to Thursday each week; prohibits, between December 11 and February 22, the taking of oysters by any means except between 9am and 2,30pm from Monday to Friday of each week (L) MLLS of 76mm (N)	None
Oyster	*Ostrea edulis*	South West Coast (ICES Area VIIj)	Closed fishery in Tralee Bay or the Bays or inlets thereof between February 23 and October 18 (L) MLLS of 76mm (N) MLLS of 76mm (N)	None
Oyster	*Ostrea edulis*	West Coast (ICES Area VIIb)	Prohibits dredging for oysters in the River Shannon or any of the bays or inlets thereof (L)	None
Oyster	*Ostrea edulis*	West Coast (ICES Area VIIb)	Regulated fishery; closed seasons for different areas of the bay (L) MLLS of 76mm (N)	None
Oyster	*Ostrea edulis*	North West Coast (ICES Area VIa)	Regulated fishery; closed season in parts of Kilkieran and Bertraghboy Bays between December 21 and the following November 30 inclusive; dredging for oysters from December 1 and December 20 inclusive on a Saturday or Sunday between 4pm and the following 9am (L) MLLS of 76mm (N); Dredge with spring loaded bar prohibited or dredge which measures more than 120cm on its longest side (L)	None

Table 4-3: Management measures for traditional mechanical dredge fisheries (cont'd).

Fishery	Species	Location	Input Controls	Output Controls
Mussel	*Mytilus edulis*	South West Coast (ICES Area VIIj)	Regulated fishery; closed season in Castlemaine Haven, Co. Kerry between April1 and May 31 inclusive (L). Prohibited to take any mussel that passes freely through a ring 2.54cm in diameter	None
Mussel	*Mytilus edulis*	South West Coast (ICES Area VIIj)	Regulated fishery; closed season in Castlemaine Harbour between October 1 and March 31 inclusive (L). Prohibited to take any mussel that passes freely through a ring 2.54cm in diameter	None
Mussel	*Mytilus edulis*	West Coast (ICES Area VIIb)	Prohibits keeping, placing, laying or storing, or washing or culling mussels in any watercourse or in any part of the tide way liable to be covered by any tide within a distance of 2.41 km from the seaward extremity of Nimmos Pier in Galway (L).	None
Mussel	*Mytilus edulis*	East Coast (ICES Area VIIa)	Regulated fishery in Carlingford Lough; closed fishery between March 1 and September 30 and January 16 to October 31 inclusive (L).	None
King Scallop	*Pecten maximus*	South West Coast (ICES Area VIIj)	Regulated fishery; closed season between April 1 and October 31 and between November 1 and the following March 31 except between 9am and 6pm, Monday to Friday inclusive (L).	MLLS of 100mm (EC)
King Scallop	*Pecten maximus*	West Coast (ICES Area VIIb)	Regulated fisher; closed season between February 28 and November 20; restricted fishery between December 1 and February 27, Monday to Friday and between 9am and 4pm (L).	MLLS of 100mm (EC)
King Scallop	*Pecten maximus*	North West Coast (ICES Area VIa)	Prohibits dredging for scallops in the North Water and the Moross Channel and the tidal creeks and inlets thereof (L).	MLLS of 100mm (EC)

4.5 France

4.5.1 Pectinid group

The locations of Pectinid fisheries around France are shown in Figure 4-21.

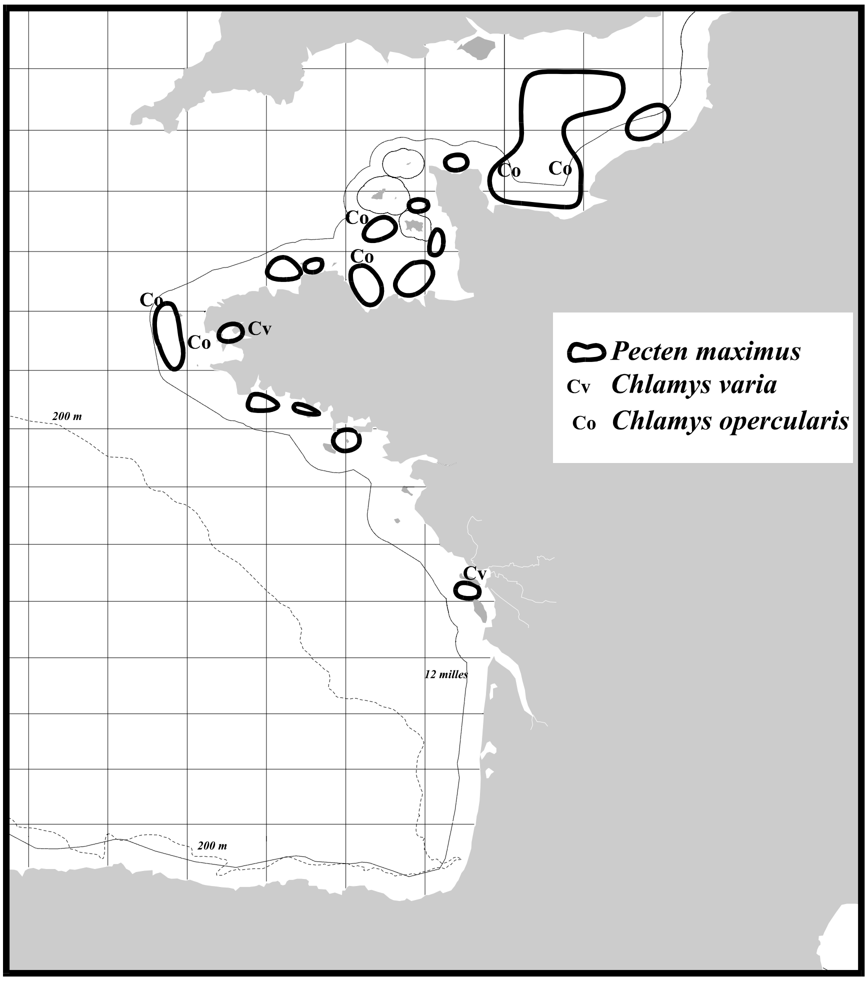


Figure 4-21. Location of Pectinid fisheries in France

4.5.2 King scallops (*Pecten maximus*)

Target species and by-catch

The target species is *Pecten maximus,* with by-catch of flatfish in Bay of Seine (plaice, sole, brill).

Fishing areas and ports

Dredging for *P. maximus* is the main métier: 80% of the dredge fleet are involved from Boulogne to La Rochelle. The main regions are:

Region	**ICES Division**
Saint-Brieuc	VIIe
Seine	VII
Saint-Malo/Granville	VIIe
Brest	VIIe
Morlaix – Lannion	VIIe
Ar Men – Iroise	VIIa,h,e
Belle-Ile	VIIIa
Concarneau	VIIIa

Fishing strategy

Prior to the implementation of the current regulations the variability of resource abundance was the most important influence on annual fishing effort. Current fishing strategies and deployment of fishing effort are influenced mainly by management rules. Management systems were initiated the main scallop fisheries in the middle of 1970s when signs of resource depletion were first observed.

Fishing strategies in Bay of Saint-Brieuc

In response to reduced allowable fishing effort fishing strategies have attempted to increase catch per unit of effort causing increased fishing capacities. The increase of fishing capacities has been distinguished by different stages (Fifas 1991, 1993). Firstly, the introduction of depressor plates on dredges in 1968 caused a high increase of fishing yield per hour (Piboubes 1974). Secondly, the introduction of fishing licences (1973) and a management system (1974) caused effort to concentrate on the areas of the highest density of recruiting year classes. In optimising their activities, skippers have taken account of information about distribution of year classes determined by annual stock assessment information.

Thirdly, increases in vessel size and power, which allows large vessels to tow quickly many dredges. Increase of the engine power of fishing vessels has also made a contribution in fishing strategies; it became easier because:

1. Efficient use of dredges with depressor plate requires powerful boats at the aim of moving quickly on the flat sea bottom and towing dredges at high speed. Foucher (1986) cited some examples of skippers who have adopted towing speed of 5 knots instead of previous speed of 3 knots (weight of dredges is not limited); at present, towing speed can be sometimes equal to 6 knots.
2. Use of powerful engines allows diversification to other fishing activities; Foucher (1986) wrote that entries in scallop fishery of Bay of Saint-Brieuc in the middle of 1980s (period of high development of coastal otter trawling) affected only powerful ships.

Three stages have defined a particular dredging strategy of targeting sedentary species. Fifas (1993) showed that catchability coefficient on scallops (*i.e.* the probability of catching an individual, which includes the components accessibility and vulnerability) depends on mean engine power and abundance of the mainly targeted age groups. These age groups are the age group 2 (the age group of first recruitment) and 3 (on average, this age group is the most abundant of the remainder of population) Figure 4-22. Over the historic period of the scallop stock in the Bay of Saint-Brieuc, age group 3 has become the dominent year group in the fishery due to depletion of older year groups.

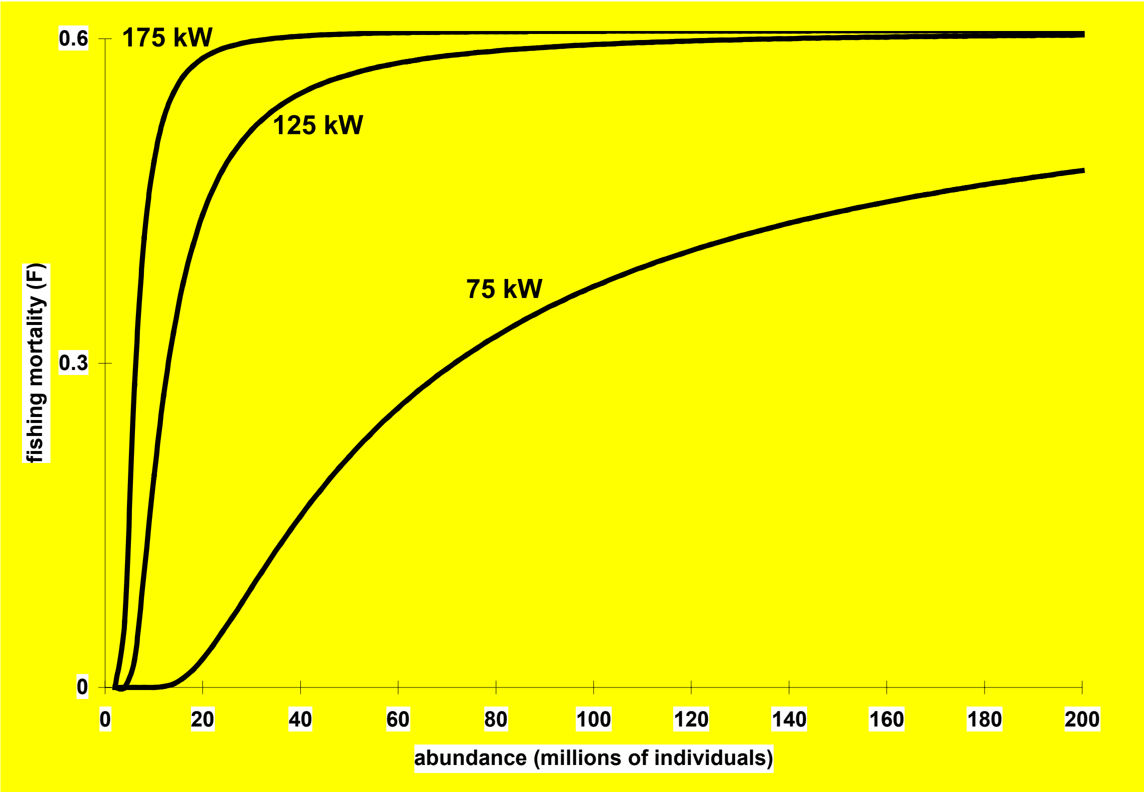


Figure 4-22: Bay of Saint-Brieuc. Theoretical catchability coefficient (from S. Fifas IFREMER unpublised data) for age group 2 the most abundant year group in the catches.

Limitation of maximum allowed engine power

Modification of the access criteria related to characteristics of fishing vessels (in 1990, the maximum allowed engine power was limited at 185kW instead of 294kW and the maximum allowed length was fixed at 13m instead of 16m) affected fishing strategies. At present, it has not been useful to maximise engine power, at least above a level lower than previously. Bioeconomic simulations were realised by Guyader and Fifas (1999) who stratified the fishing fleet of Bay of Saint-Brieuc at four groups of vessels:

1. engine power below 60kW;
2. between 60 and 120kW;
3. between 120 and 185kW; and
4. above 185kW (this group consists of fishing boats which are still allowed to dredge scallops in spite of regulation of 1990 ; no further vessels of this size can enter the fishery).

The number of fishing vessels of each stratum is variable from year to year. The main trend is an increase of the number of the third group (120 to 185kW). An increase of the number of vessels close to the presently allowed limit leads to higher fishing capacity; furthermore, it makes easier diversification to otter trawling.

Figure 4-23 shows the evolution of catchability (expressed by standardised fishing mortality for fishing effort equal to 10000 hours) by stratum of vessels against abundance of the age group 2. Similar evolution of all curves is obvious except for the stratum below 60kW. The decrease of the maximum allowed vessel power in 1990 did not significantly reduce the fishing effort on the fishery (the curves corresponding to the strata 120 to 185kW and above 185kW are very close).

Figure 4-23 shows catchability expressed as fishing mortality for fishing effort of 10000 hours versus abundance of year class (in this example age group 2) for different levels of mean engine power of the fishing fleet. The mean engine power per stratum is calculated according to mean patterns of the fleet for the years 1993 to 1997.

Table 4-4 Bay of Saint-Brieuc. Characteristics of fishing fleet by stratum based on engine power. Years 1993 to 1997 (S. Fifas IFREMER)

Stratum kW	Number					Mean Engine power (kW)					% trawling(1)
Year	*93*	*94*	*95*	*96*	*97*	*93*	*94*	*95*	*96*	*97*	
0-60	26	28	28	25	25	42	44	45	43	46	3.8
60-120	102	103	100	100	101	92	92	91	91	92	44.3
120-185	86	94	95	102	100	150	151	151	151	151	58.7
> 185	34	32	31	26	23	242	244	244	241	242	76.0

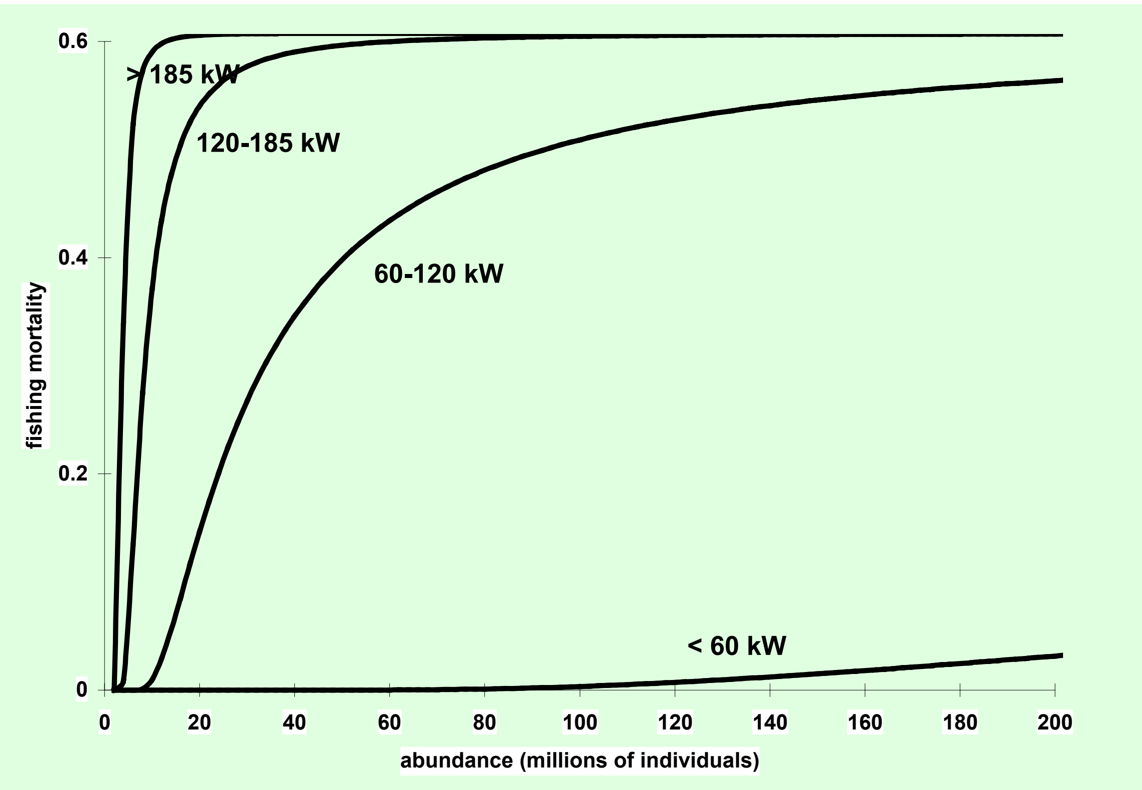


Figure 4-23: Bay of Saint-Brieuc. Theoretical catchability coefficient (from S. Fifas IFREMER).

Acquired Technological knowledge.

Trends in mean engine power of the dredger fleet of are not enough to explain the evolution of fishing capacities. At present, the mean engine power is not significantly higher than in the beginning of the 90s, but for a given status of scallop resource, catches per unit effort are greater than ten years ago. The catch rate calculated for a given administrative fishing effort (expressed by fishing hours x engine power) has increased spectacularly for ten years. Thus the catchability coefficient per age group must be examined in relation components other than engine power and scallop abundance.

Skippers are constantly learning more efficient method of fishing and optimising deployment of fishing effort as a continuous process because of the low turnover of crew and vessels in these scallop fisheries. Technological progress is integrated in the fishing effort deployment in two ways. Firstly, for a standardised duration of daily dredging activities, it is possible to cover a larger area than in the past. Knowledge of optimum locations to concentrate dredging effort because of technological development of navigation and positioning equipment of (PC, GPS, plotter, etc.). Secondly, after arrival on a fishing area with high potentiality, it is possible to dredge at higher speed with increasing wieghts of dredge gears (no regulation of dredge weight of dredges except Bay of Brest).

Catchability models describing dredging strategies can take into account those ways of optimisation of fishing strategies. The asymptotic levels of curves Figure 4-22 and Figure 4-23 may be higher because the vessels cover larger areas. At the medium levels catchability may be higher, that is they may correspond to lower levels of abundance.

Fishing strategy for other fisheries

The particular case of Bay of Saint-Brieuc can be extrapolated on other scallop fisheries with two main differences:

- The use of dredges with depressor plate requires an increase in engine power because of the increased drag of this gear.
- The limitation in the daily duration of dredging is more drastic in Bay of Saint-Brieuc than on other fisheries.

However, the main trends described above are valid.

Bay of Seine: The fishing power is based on deployment of effort on larger areas with lower scallop densities than in Bay of Saint-Brieuc and longer duration of daily activities. These factors mean that the effect of engine power (combined with weight of dredges) and technological progress of navigation and positioning may be less obvious than on the Western fisheries. However, in targeting always the firstly recruited year class fishing strategies are close to Saint-Brieuc. Spring toothed dredges are used in this fishery; more information is required on the characteristics of these dredges.

Bay of Brest: An analysis of statistical data on for the period 1983 to 1995 showed that Skippers concentrate their effort on the same areas with no modification depending on yearly level of resource (Boucher and Fifas 1995). The calculated Robson index of concentration of in this fishery was not significantly different to 1. However, opening of dredging activities on previously closed areas (there is an evolving extensive scallop farming operation) may affect fishing strategies.

Interactions

Historic conflict, which concerned mainly the use of different gears on different grounds, was resolved by power limitations in Bay of Saint-Brieuc and banning the use of dredges with depressor plates in the Bay of Seine. Current conflicts involve differences between the aims of management and exploitation options on different grounds, the use of non standard scallop gear (e.g. otter trawl with tickler chain), and scuba-diving.

Market

Most production is consumed nationally.

Trends and comments

Evolution of Exploitation: French Atlantic and Channel

Bay of Saint-Brieuc: The stock of Bay of Saint-Brieuc has sustained a productive dredge fishery since the 1960s, Figure 4-24. The severe winter of 1962-1963 caused a collapse of *Octopus sp*. populations, which were considered to be the main predators on scallops during 1950s (Piboubes 1974). Scallop catches in the Bay of Saint-Brieuc peaked in productivity in the middle of 1970s. This was the result of highly abundant year classes produced between 1968 and 1973; 12500 tons were caught in the fishing season 1972-1973 and 10500 tons in 1975-1976. Since then there has been a slow decline in catches minimum level of 1300 tons in 1989-1990. Favourable climate conditions caused an increase of production in 1990s.

Figure 4-25, which describes the variation in estimated stock size and age structure of the population over time, shows how the good year classes generate increased abundance and ultimately landings. These conditions generated self-sustaining stocks in the Normand-Briton Gulf (Saint-Malo, Granville, Minquiers) even though the abundance of these stocks was sporadic in the past. A decreasing phase has been re-occurred recently considered to be due to over fishing in this fishery.

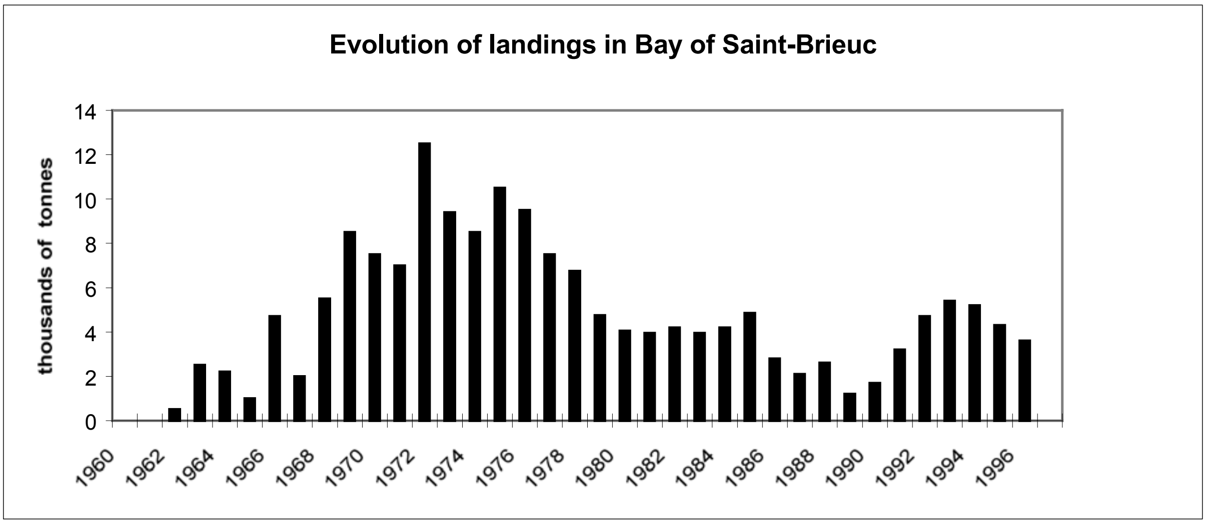


Figure 4-24 Landings in Bay of St. Bruic 1962-1998

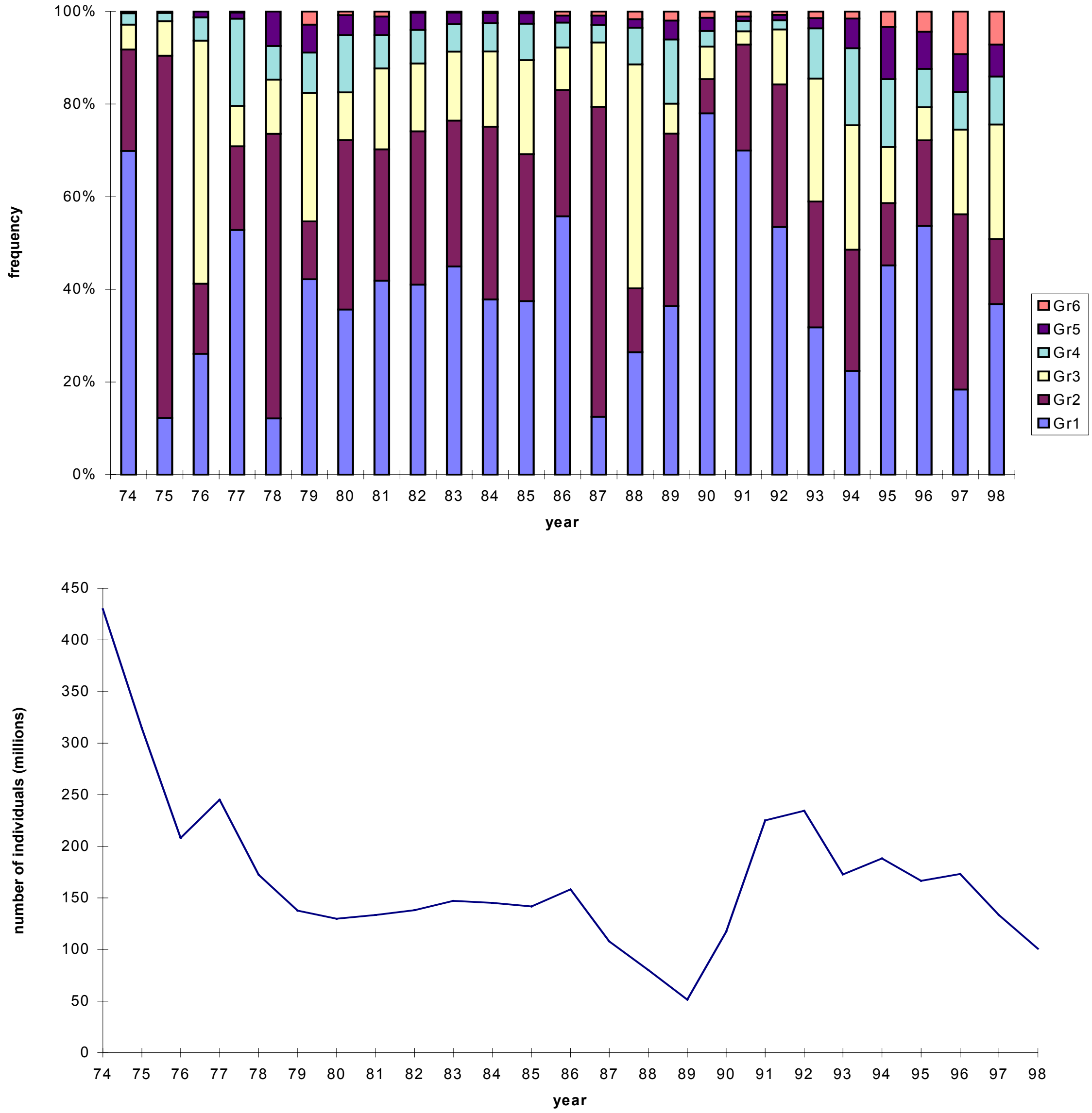


Figure 4-25 Evolution of scallop abundance and composition per age (age group 1 to 6; Gr1 to Gr6) in Bay of St. Brieuc.

Eastern Channel

Stocks in the eastern English Channel are spread over a large area and have followed broadly similar trends to the Bay of San Brieuc. The only fishery where detailed knowledge is available is the Bay of Seine. High productivity in the 1960s and 70s with variable but increasing catches in the 1990s; the fishery has targeted the larger recruiting year classes.

Bay of Brest and Atlantic

In contrast, in the Bay of Brest scallop fishery, which had been productive in the 1950s, the extreme climatic conditions of the severe 1962/3 winter resulted in poor recruitment, Figure 4-26. This, together with over-fishing, meant that low stocks in the Bay of Brest did not recover until the 1990s with a period of improved year classes, which are being augmented by extensive farming activities.

However catches are still low compared with historic levels. There is a similar pattern of evolution in the other French Atlantic scallop beds off Quiberon and Belle Isle, Concarneau Iroise and Ar Men.

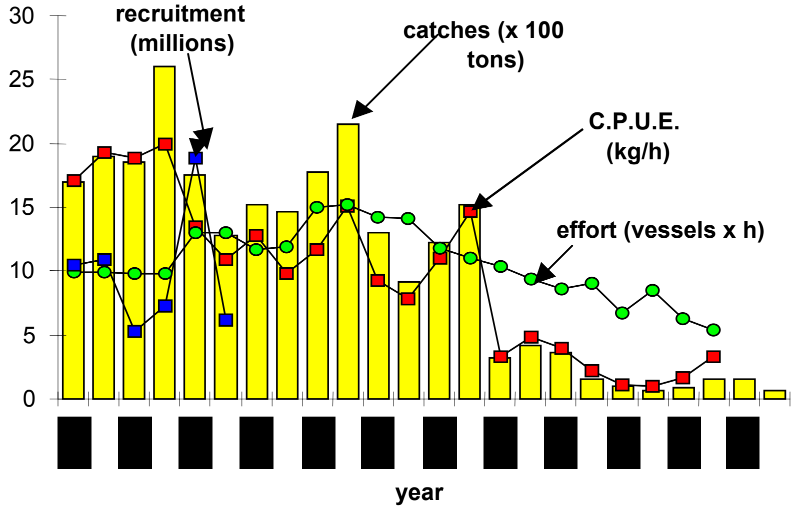


Figure 4-26 Evolution of several parameters of the scallop stock in Bay of Brest. Years 1950 to 1973 (from S. Fifas IFREMER).

4.5.3 Queen scallops (*Chlamys varia* and *Aequipecten opercularis*).

Target species and by-catch

Target species are Queen scallops (*Chlamys. varia),* and *Aequipecten opercularis*; with by-catch of Sea urchins.

Fishing areas (and ports)

Bay of Brest and Camaret: 50 boats for the ports of Brest and Camaret.
East part of the Bay of Brest for *C. varia* (black Queen scallop); West part of the Bay of Brest and Bay of Camaret for *A. opercularis* (white Queen scallop).

Perthuis Charentais: *C. varia*.

English Channel*: A. opercularis*.
Estimated total activity in ICES division VIIe: 160 months in 1995 (Tétard 1995).

Resource characteristics

The common size of *C. varia* is 45-55mm, with a maximum size of 80mm. The colour varies and is not always black. The common size of *A. opercularis* is 40-60mm, with maximum size of 110mm. Species longevity is about 4 to 5 years. Aggregations of animals are not stable; they appear suddenly and stay only few years.

Fishing strategy

For *C. varia* the season extends from November to February. For *A. opercularis*, fishing starts when an aggregation is detected.

Interactions

P. maximus and *Venus verrucosa*.

Market

C. varia is consumed locally in Perthuis Charentes. *C. opercularis* is delivered to firms of Saint Quay Portrieuc for shelling (Noix de Saint Jacques). Market is live/ fresh product.

Trends and comments

C. varia production in the Bay of Brest fluctuates between 200 and 400 tons/year; presently the stock is decreasing. Perthuis Charentes produced historically 800 tons/years, but collapsed from 1969 and 1991. Since 1992 production increased to 200 tons in 1996-1997. *A. opercularis* is targeted when an aggregation is located.

4.5.4 Clam group

The location of clam fisheries is described in Figure 4-27.

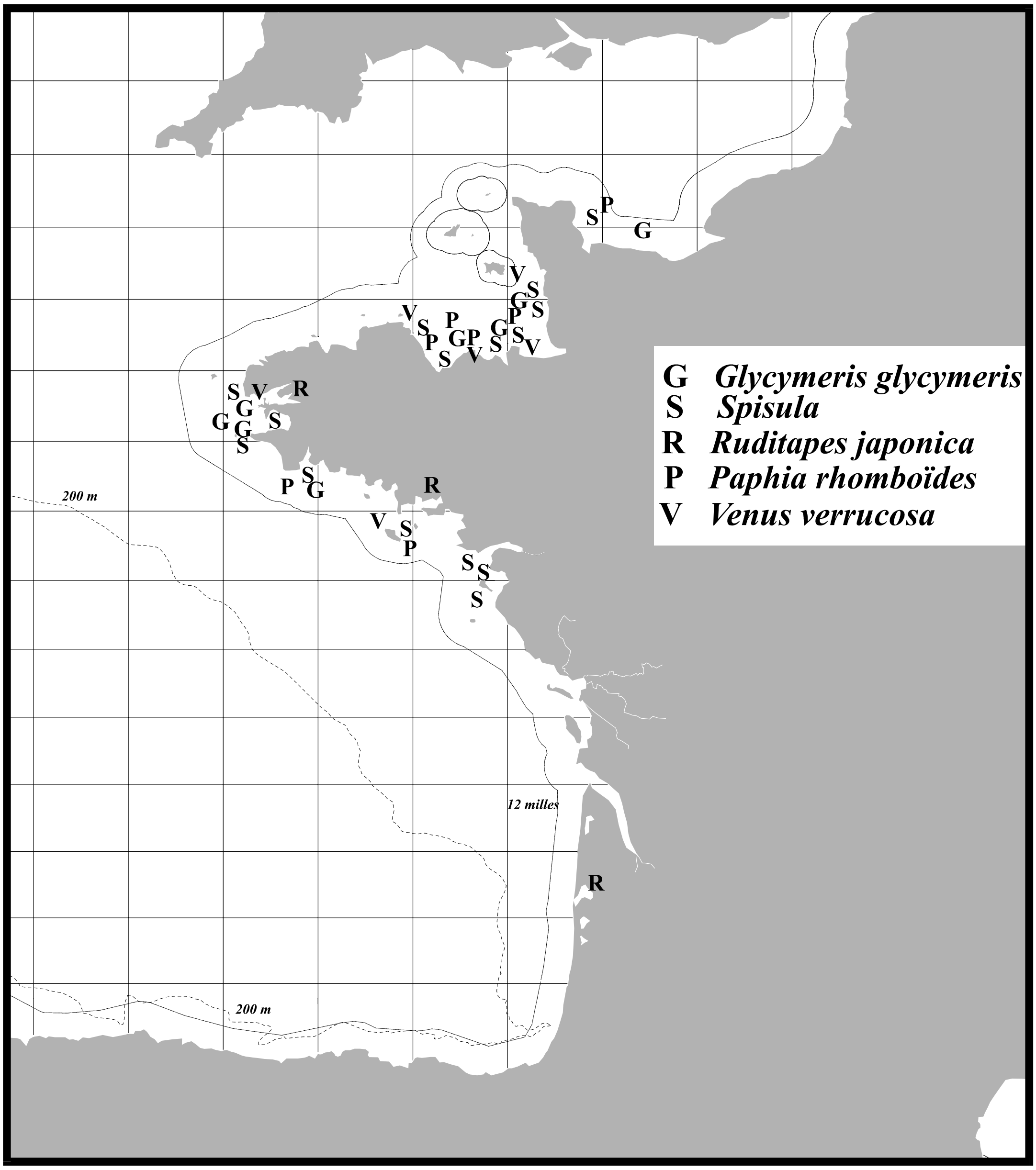


Figure 4-27 Location of clam fisheries (from IFREMER DRV/RH).

4.5.5 Warty venus (*Venus verrucosa*)

Target species and by-catch

The target species is *V. verrucosa.* By-catch of queen scallops and *Pecten maximus* occur within the Bay of Brest, and within the Norman-Breton gulf by-catch of *G. glycymeris* and *B. undatum*.

Fishing areas (and ports)

Dredging for *V. verrucosa* occurs only on the French coast of VIIe from Bay of Granville to Paimpol and Bay of Brest.128 boats in 1996 catch Warty venus, mainly in the Norman-breton gulf and in the Bay of Brest. The main ports are: Saint Brieuc, Granville, Saint Malo, Paimpol and Brest. Estimated total activity in ICES division VIIe: 704 boats in 1996.

Resource characteristics

Self-regenerating fishery based on wild spat settlement that fluctuates annually. Animals recruit to the fishery when 7 - 8 years old at about 40mm shell length.

Fishing strategy

The season is September to April.

Interactions

This métier has few interactions in resource terms. In activity terms it is complementary to inshore trawl, scallop dredge, crustacean métiers and bass longline.
French V. verrucosa

Markets

These are mainly regional and national markets for fresh product. More than 95% of French catches originate from Norman-Breton Gulf; the rest are caught in the waters of South Brittany and the Bay of Brest.

Trends and comments

Bay of Brest:

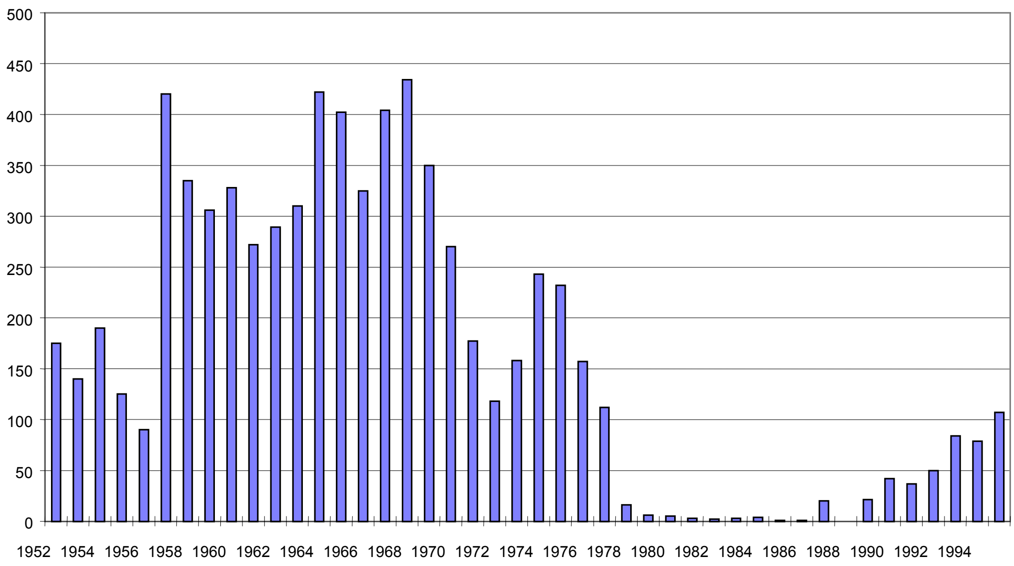


Figure 4-28: Evolution of Warty venus production in the Bay of Brest (production (tons) / year) (from IFREMER DRV/RH).

This fishery dates back further than the fisheries at Saint Brieuc and Granville. The fleet reached 280 units, but after the hard winter of 1963, when annual production decreased from 1500 to less than 100 tons, vessel numbers decreased. Since 1973, the number of dredging boats has halved, whereas engine power has almost tripled.

Norman-breton gulf

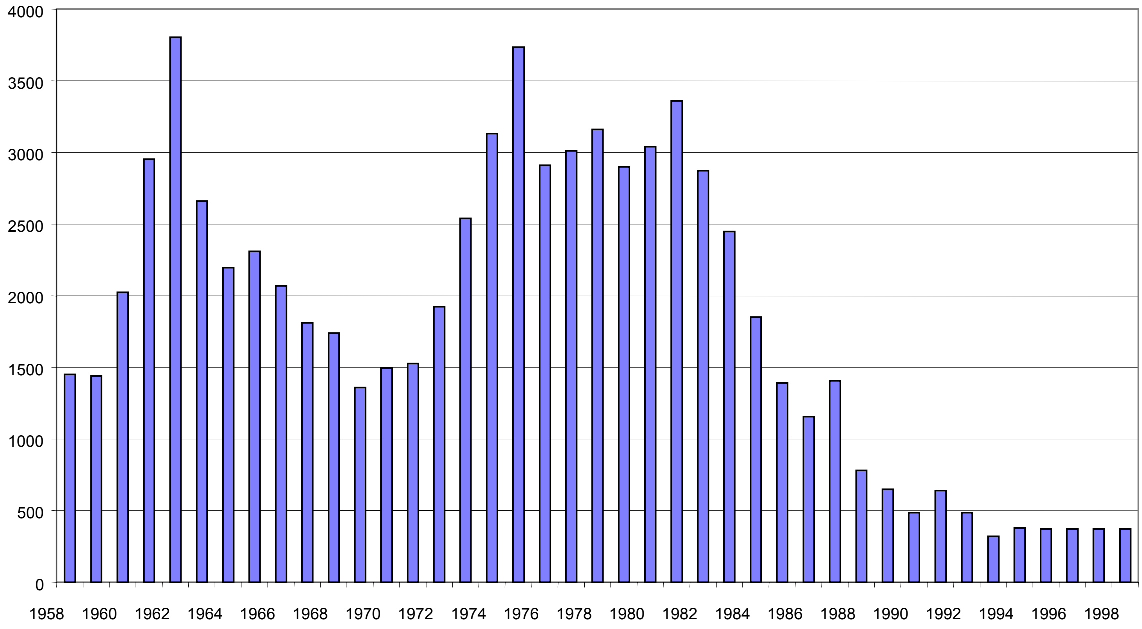


Figure 4-29 Evolution of Warty venus production at Granville (production (tons/year) (graph IFREMER DRV/RH).

The fishery for *V. verrucosa* at Granville has developed since 1958 with peak production of 3500 tons in 1962, 1975 and 1982. From 1982, production had declined and since 1993 has been less than 400 tons/annum. Up to 1963 the fleet comprised 30 to 60 small dredgers of 7-8 meters, about 3 tons with an of engine power of 18-30kW. By 1974, the fleet comprised of 10-12 vessels ranging from 5-25 tons, whereas by 1981 the fleet comprised 74 units. Since 1958, the number of boats has tripled and dredgers of Granville as doubled their tonnage and tripled their engine power. The characteristics of the *V. verrucosa* dredge Figure 3-6 used in Norman Breton Gulf are have been regulated at a maximum weight of 90kg, without any change since 1975 (Berthou 1984). Most of the dredges exceed the regulation rules and the biggest ones reached a width of 80-90cm and a weight of one ton.

Then, the fleet is decreasing because of a separation into two blocks with small boats (about 10 tons burden, 110kW), and bigger boats (14-15m long, 30 tons burden). The number of bigger boats increases at the end of 1980s and small boats disappear from the fleet or change their fishery. Then, with innovation, the depressor plate Figure 3-7 installed on the dredge helps to increase the tow speed for most powerful boats.

4.5.6 Small bivalves: Palourd, Bittersweet and Thick trough shell

Target species and by-catch

Target species are palourd *V. rhomboïdes*; Bittersweet, (*G. glycymeris*), thick trough shell (*Spisula sp*), with a by-catch of Warty venus (*V. verrucosa*).

Fishing areas (and ports)

Tapes: Saint-Brieuc, Paimpol, Granville;
Bittersweet: Granville, Saint-Brieuc, Camaret;
Spisula sp: Granville, Camaret, Douarnenez, Le Guilvinec, Concarneau

Resource characteristics

Self-regenerating fishery based on wild spat settlement that fluctuates annually.

Fishing strategy

Vessels work day trips, using gear as illustrated in Figure 3-8 and Figure 3-9mainly within 6 miles, either part-time or full-time. Most of the year the target is *Spisula sp*, palourid and bittersweet. When it is part-time activity, these boats switch to scallop or *V. verucosa* dredging in summertime.

Interactions

In resource terms, this métier has few interactions. In sea activity terms it is complementary to inshore trawl, scallop dredge, crustacean métiers and bass longline.

Markets

V. rhomboïdes is commercialised fresh in bays of Saint-Brieuc and Granville. A market for frozen product is being developed. *G. glycymeris*: 50% of captures are from the Norman-breton gulf, the rest from South Brittany. Product is commercialised fresh or frozen. *Spisula sp* : Catches are from South brittany, Iroise, Vendée and Norman-Breton gulf. Historic market for fresh product, but recent market for frozen product has been developed in southern Europe.

Trends and comments

Spisula sp, palourd and bittersweet are mainly under-exploited in the Channel according to the market's or recruitment's fluctuations.

V. rhomboïdes: Catches Before 1983 were almost negligible but the last years have increased from about ten to more than three thousand tons. They are still above the biological potential of the stock. In South Brittany the production is stable (300 tons).

G. glycymeris: Production is stable due to poor market. Production was between 2000 and 2500 tons in 1988, increasing during the 90s to 4000- 5000 tons. Potential is still strong

Spisula sp: Stock fluctuates greatly. In 1987, production was about 5000 tons and did not exceed 1000 tons in 1995. At the end of 90s French production was near zero due to strong recruitment fluctuations. As stocks are mono-cohort, fishermen have to wait for the next recruitment.

4.5.7 Mussels

Target species and by-catch

Target species is *M. edulis*.; no bycatch.

Fishing areas (and ports)

Main ports: Barfleur, Saint Vaast La Hougue, Grandcamp (Cotentin, Normandie).
Number of boats: 19 units (this number varies between 10 and 40 according to mussel abundance and trade conditions). Estimated total activity in ICES division VIId: 117 months (Tétard A., 1995).

Resource characteristics

Animals recruit to the fishery at about 50mm shell length, 60 – 70mm in Mediterranean Sea.

Fishing strategy

Mussel dredging is carried out along the east coast of Cotentin, between 0.5 and 5 miles offshore, according to the location of the mussel beds. The working season generally begins in June and continues for about 6 months, according to the mussel abundance that depends on annual recruitment.

Interactions

Boats mainly alternate this métier with inshore bottom trawling for 12 units and 46 months, beam trawling for 8 units and 37 months, and scallop dredging for 16 units and 37 months.

Regulation measures

- MLLS of mussels: 4cm,
- Gears: only one dredge (120kg maximum weight, and 2 blades maximum (order number 33 of the 3rd of May 1977) per boat,
- Licences to fish mussels are issued each month. In recent years, licence numbers were limited, but in 1991 a limit of 40 was set, without restriction of maximum length or power of boats,
- Daily quota: 600kg/fisherman/day and limit of 3000kg/boat/day,
- Mussel landings are allowed into only 3 ports: Barfleur, Saint-Vaast-La-Hougue and Grandcamp,
- Fishing is allowed only 5 days per week, during daylight.

Markets

Cultivation accounts for most production though wild stock contributes to national production. 30 – 45% of production is exported, the remainder being consumed nationally.

Trends and comments:

Table 4-5 Evolution of the fleet (number of boats and months per year) (from IFREMER DRV/RH)

	1990	1991	1992	1993	1994
Boats	43	39	58	62	51
Months	221	236	336	440	453
% boats	3	2.7	4	4.3	3.5
% months	1.3	1.6	2.3	2.9	2.9

Mussel dredging has been carried out for about 25 years in east Cotentin. The management of this resource, which depends on annual recruitment, is based on immediate recommendations given to the fishermen after a short assessment cruise. This resource is important locally because of its landings value and because it allows fishing effort to transfer from other métiers.

Management measures

Table 4-6 Management measures for French 'traditional mechanical' dredge fisheries (from IFREMER DRV/RH).

Fishery	Species	Location	Input Controls	Technical controls	Output controls: e.g. Quota
King scallop	*Pecten maximus*	East Channel (ICES AreaVIId)	No more than 10% of protected species may be landed and only whole scallops may be landed (EC). Close season 15 May to Sept inclusive (N), and restricted licence entry (L); Vessel length restriction and maximum beam length (L).	Carriage size and MLLS of 100mm (EC). MLLS of 110mm (EC). Dredge specification: metal belly ring size of 82mm (L), diving plate prohibited on French dredges.	Daily quota of 200kg per fisherman (L)
King scallop	*Pecten maximus*	Channel and Bay of Biscay (ICES Area VIIe and VIII)	No more than 10% of protected species may be landed (EC) and only whole scallops may be landed (EC and L). Close season 15 May to September inclusive (N) locally longer (L), and restricted licence entry (L); Vessel length restriction and maximum beam length depending on the beds (L).	Carriage size and MLLS of 100mm (EC), increased to 102mm in Bay of Saint-Brieuc and 105mm in the Bay of Brest. French dredge specification: maximum width of 2m, metal ring size of 85mm every where and 92mm in the Bay of Saint-Brieuc and Bay of Brest (L). diving plate locally prohibited on French dredges.	Seasonal quota only in the Bay of Saint-Brieuc (L)

MLLS - Minimum Legal Landing Size. (EC) - EC legislation. (N) – National legislation. . (L) - Local legislation

Table 4-7 Management measures for French 'traditional mechanical' dredge fisheries (continued) (from IFREMER DRV/RH).

Fishery	Species	Location	Input Controls	Technical controls	Output controls: e.g. Quota
Mussel	*Mytilus edulis*	East coast Cotentin (ICES Area IVd)	Regulated fishery; listed beds, close season October-May inclusive; gear restriction of 1 dredge per vessel; restricted licence entry (L).	Dredge weight restricted to 120 kg, only two blades allowed, and MLLS of 50mm (L).	Daily quota of 3 tons per vessel
Warty venus	*Venus verrucosa*	Norman-breton gulf (ICES Area VIIe)	Regulated fishery; listed beds, close season May-August inclusive (N); gear restriction of 2 dredges per vessel; ; vessel length locally restricted to 13m, restricted licence entry (L). Days and hours at sea.	Dredge width and weight restricted (N), and MLLS of 40mm (N).	Daily quota per vessel (L)
Warty venus	*Venus verrucosa*	Bay of Brest (ICES Area VIIe)	Regulated fishery; listed bed, close season April-October inclusive (L); gear restriction of 1 dredge per vessel; Days and hours at sea.; vessel length restricted to 12m restricted licence entry (L).	Dredge width and weight restricted (L), and MLLS of 42mm (L).	
Various Clams	*Spisula sp* *Tapes rhomboïdes* *G. glycymeris*	Channel and Bay of Biscay (ICES Area VIIe and VIII)	Regulated fisheries; listed beds, close season; gear restriction of 1 or 2 dredges per vessel; Days at sea.; vessel length restricted; restricted licence entry (L).	Dredge width and weight restricted (L), and MLLS per specie (N)	Locally Daily quota
Queen Scallops	*Aequipecten Opercularis*	East coast Cotentin (ICES Area VIId)	None	None	None
Queen Scallops	*Aequipecten Opercularis,* and *Chlamys varia*	Bay de Brest, Bay of Camaret (ICES Area VIIe)	Regulated fishery; listed beds, close season October-May inclusive; gear restriction of 1 dredge per vessel; Days and hours at sea.; vessel length restricted to 12m; restricted licence entry (L).	Dredge width and weight restricted (L), and MLLS	None

MLLS - Minimum Legal Landing Size. (EC) - EC legislation. (N) – National legislation. . (L) - Local legislation

4.6 Italy

4.6.1 Chamelea gallina fishery

Fisheries for C*hamelea gallina* occur along all Adriatic coasts, Figure 4-30 especially those characterised by sandy beaches. Almost all Adriatic Maritime Districts are involved: Monfalcone, Ravenna, Rimini, Ancona, S. Benedetto del Tronto, Pescara, Manfredonia and Molfetta with a fleet of about 700 vessels (Froglia 1989).

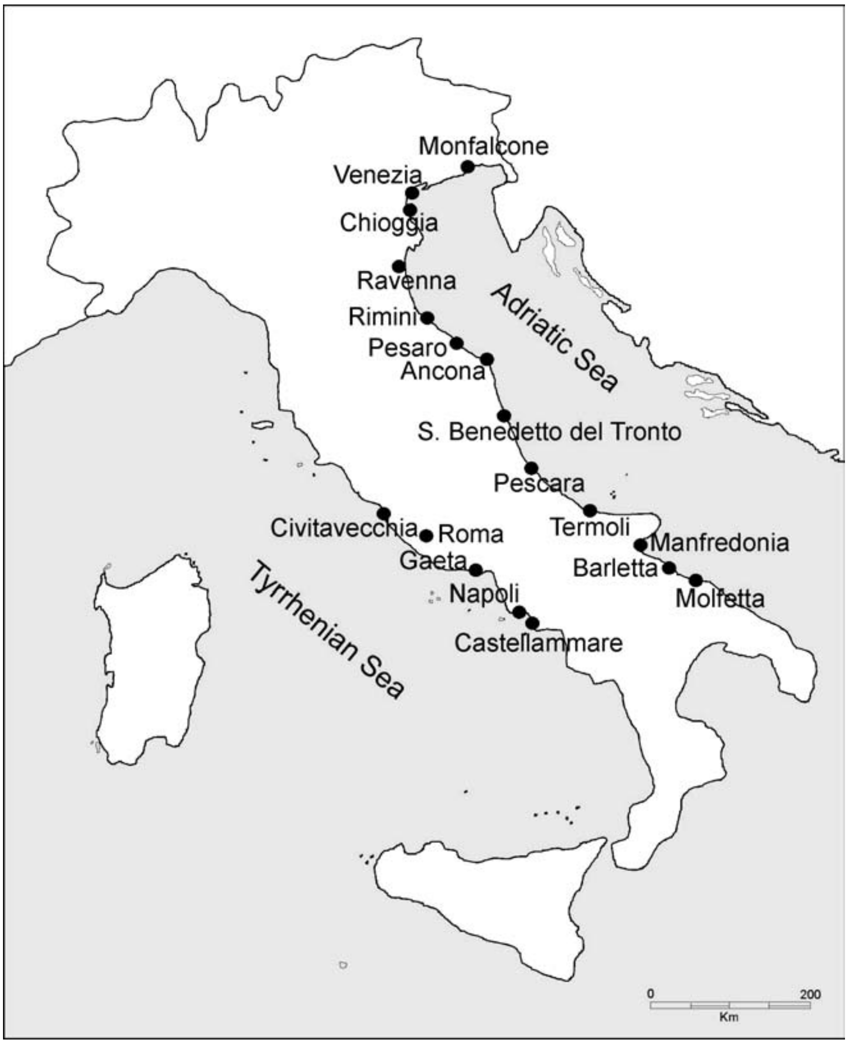


Figure 4-30 Main Italian districts involved in dredge fisheries

Within the study area, the main districts where fishing occurs are Chioggia, Venezia and Monfalcone, Figure 4-31.

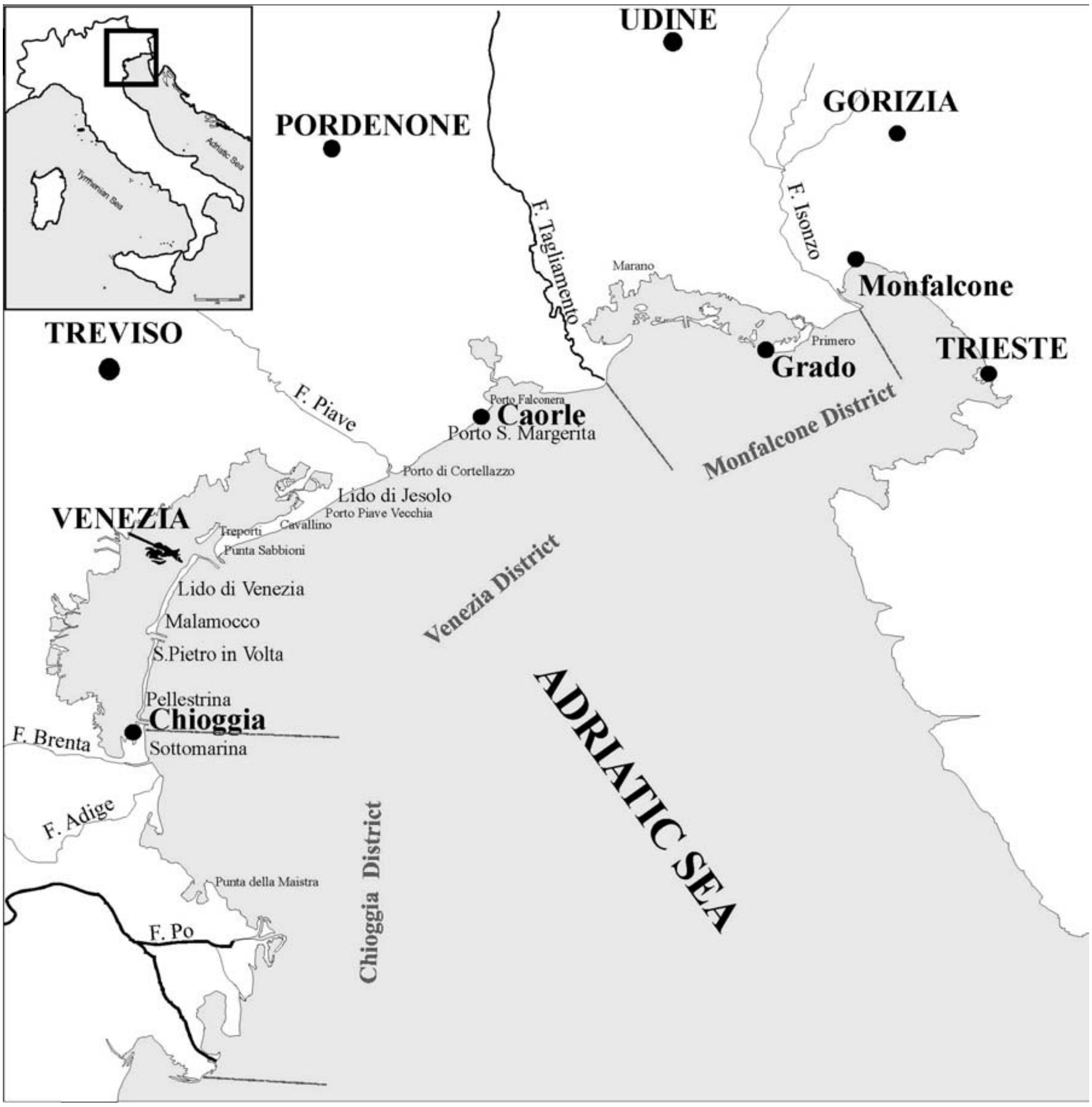


Figure 4-31. ***C. gallina*** **fishering areas and management districts in North Adriatic Sea**

Target species and by-catch

The target species of this fishery is the venus clam *(Chamela gallina*). By-catches include crabs *(Carcinus mediterraneus, Macropipus sp., Corystes sp.),* hermit crabs *(Pagurus sp.),* gastropods *(Murex brandaris, Naticarius millepuntatus),* bivalves *(Paphia aurea),* and plaice *(Pleuronectes flesus).*

Resource characteristics

Chamela gallina grows to 16 - 18mm in about 1 year, and reaches the minimal legal size of 25mm in 2 years. The reproductive period peaks at the end of the spring, though individuals with ripe gonads occur in August. Growth decreases and stops when the water temperature is below 10°C. A clam is sexually mature at 16mm, or 12 months.

Target species and principal associated fauna

The target species are *C. gallina,* the razor clam (*Ensis* sp. and *Solen* sp.), the wedge shell clam (*D. trunculus)*, and the brown venus clam (*C. chione).* By-catch species include *M. corallina*, *G. glycimeris*, *G. pilosa*, *C. edule*, *P. aurea*, *V. verrucosa*, *L. oblungum*, Cardiidae, *A. tuberculata, A. aculeata, A. echinata, A. spinosa* and the Pectinidae *P. jacobaeus, F. glaber, F. proteus, A. opercularis* and *C. varia* (Marano et al. 1998a).

Fishing strategies

The Management Consortiums influence fishing patterns by controlling fishing duration and vessel movement. From 1st October to 31st March fishing is not allowed on Saturdays, Sundays or public holidays, and from 1st April to 30th September Saturdays, Sundays, public holidays and another day determined by the Management Consortium. From 1st July to 15th September, the maximum daily duration of hydraulic razor clam dredging in the Tyrrhenian Sea is 4 hours.

Interactions

Hydraulic dredging, which occurs within 1.5 miles from the coast, conflicts with set nets or drift nets or traps at certain specific periods of the year; for example in the Adriatic Sea between March and June when cuttle fish is targeted with traps and nets. In the Gulf of Trieste the sediment texture and granulometry has been altered such that the settlement of *Callista chione* is favoured over *V. verrucosa***.** Fishing conflicts also with sewage disposal, and fresh water runoff (river Po) can produce large variations of salinity and input polluting substances. Abundant input of fine material can modify substrates and cause anoxia.

Landings

In the Mediterranean, *Chamelea gallina* is the most important of five commercially exploited species. Officially reported catches increased from 1960, peaked in 1983 but have varied since, **Figure 4-32**.

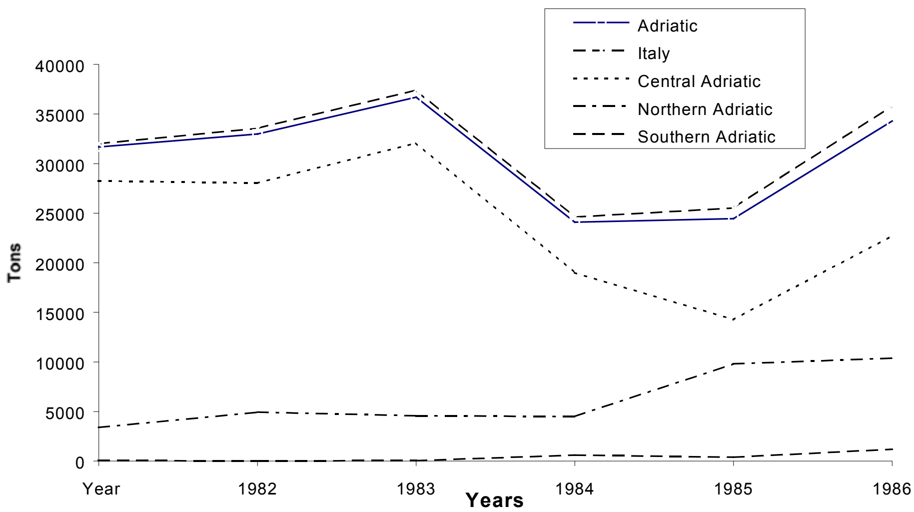


Figure 4-32. Catches of *Chamelea gallina* in Italy and regions 1982-1986. Official statistical data (from: Bombace 1991).

However, official data probably underestimated commercial catches since landing estimates derived from Export, Processing, and National Marketing Data (from: Froglia 1989), Figure 4-33, suggests annual landings in the order of 80000 – 100000 tons.

Figure 4-33. Estimated *C. gallina* landings from from Export, Processing, and National Marketing Data (from: Froglia, 1989)

Within the study area (Northern Adriatic), which comprises the regions of Molfalcone, Venezia and Choggia, annual landings of *C. gallina* are much less, Figure 4-34.

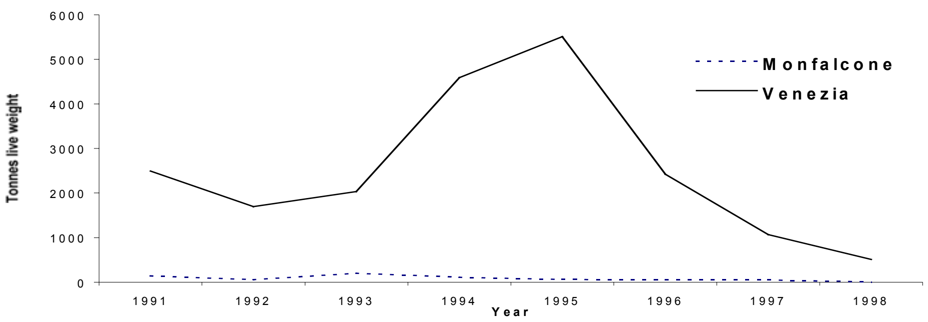


Figure 4-34. *C. gallina* landings 1991-1998 in Molfalcone and Venezia. Data for Choggia is unavailable.

Markets

National and export markets (especially Spain), Figure 4-35, for fresh clams absorb most production. In 1989, 45,000 people were involved directly in clam fishing in Italy, with an additional 8500 people in processing and 16,500 people in the distribution and marketing sectors. The total value of this sector was US$4.944 billions or Euro5.283 billions (Mattei and Pellizzato 1997).

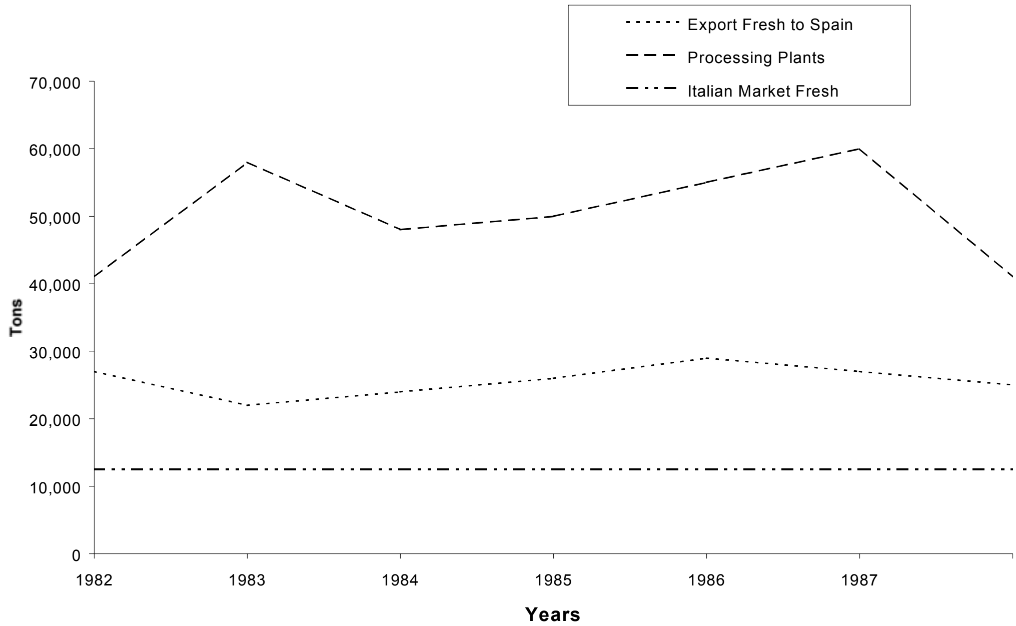


Figure 4-35. Markets for *Chamellea* landed in Italy 1974-1985

Export Fresh to Spain (1974): (Froglia 1975a)
Export Fresh to Spain (1980-84):Asociacion Nacional de Empresarios Exportadores e Importadores de Moluscos - Spain
Export Fresh to Spain (1985) and Processing Plants (1980-85):Associazione Nazionale Conservieri Ittici e delle Tonnare – Italia

Trends and comments

The coastal zone should be managed from an ecological and biological perspective to resolve certain fishing problems and facilitate resource regeneration. Fishing effort should be regulated with respect to the resources, and, if necessary, stopped (Bombace 1991). Clam surveys should continue and spat relaying encouraged. Technological mechanisms capable of reducing fishing mortality during the pre-recruitment phase (gear selectivity, protection of the juvenile organisms, anti-predation, etc.) should be improved and adopted (Agri.te.co. 1998).

Diversification of fishing activity should be promoted. Over recent years, many fishermen have modified their vessels and equipment to permit use of multiple fishing techniques, due to frequent and widespread fluctuations in certain Italian marine resources. In 1997, about 7000 boats had combined gears for fin-fish and molluscs (Mattei and Pellizzato 1997).

Finally, it would be important to utilise the biochemical energy which accumulates inshore by means of recycling systems. Eutrophication should be channelled towards halieutic production.

One approach to achieving these aims would be to introduce artificial reefs for multiple purposes and for marine culture in the open sea. In 1991, 16 experimental artificial reefs existed in Italy: 8 in the Adriatic Sea, 4 in the Ligurian Sea, 2 in the Tyrrhenian Sea and 2 at Sicily (Bombace, 1991).

As previously mentioned, production has decreased greatly since 1984. For many years, the various adopted clam fishing management measures have proved to be inadequate, due to non compliance and high fishing effort, which has lowered the mean age of the natural population. It is evident that current fishing depends on a single age class; specimens aged more than three years are rare. Absent or poor year classes can compromise fishing activity for approximately two years.

Vessel profile

Currently, about 700 vessels operate along the Northern and Central Adriatic coasts, targeting mainly *Chamalea gallina*. Between 1991-1998, 274-280 vessels with licences have operated within the study area (Monafalcone,Venice and Chioggia).

Accuracy of data

The reported data, which have been supplied by the harbour offices of the 3 Districts, probably underestimate commercial catches. Theoretical catch estimates from the Chioggia District differ greatly from official statistical data.

4.6.2 Razor clam fishery

Fisheries for razor shell clams, *Ensis* sp. and *Solen* sp., and wedge shell clams, *Donax trunculus,* occur mostly along the Tyrrhenian coasts of Tuscany, Latium and Campania, and along the southern Adriatic Sea (Lesina e Manfredonia). In central and southern Tyrrhenian Sea about 80 vessels operate, whereas activity in the Tyrrhenian Sea can be considered incidental (Mariani et al. 1998).

Target species and by-catch

The target speciesare *Ensis* sp. and *Solen* sp. with a bycatch of *Donax trunculus*.

Fishing areas and ports

Ensis sp., *Solen* sp. and *D. trunculus* are targeted along mainly the Tyrrhenian coasts of Tuscany, Latium and Campania, and along the southern Adriatic Sea (Lesina e Manfredonia). Figure 4-36. Particularly important is the central and southern Tyrrhenian Sea where about 80 vessels are involved in this type of activity.

Figure 4-36. Distribution of *Ensis* sp., *Solen* sp., and *Donax trunculus* in the Italian and Corsican Seas all Italian and Corsican coasts highlighted

Vessel profile

About 80 operate along the Tyrhenian coasts of Tuscany, Latium and Campania, and the southern Tyrhenian sea targeting *Ensis* and *Solen* sp.,

Resource characteristics

The razor shell clam species, *Ensis minor,* requires 16 months to reach the minimum fishing size of 80mm. Reproduction occurs in late spring and the growth stops when the water temperature is below 7-8°C. The fishery targets 2 years old animals (Froglia 1975b); (Costa et al. 1987)).

Over the last few years, severe mortality rates and high fishing effort have resulted in reduced biomass in many areas, Table 4-8.

Table 4-8. Estimated commercial biomass of *Ensis siliqua minor* (tons) along the Tyrrenian coasts (mean values for area 1985 - 1987) (from: Ministero delle Risorse Agricole Alimentari e Forestali 1996) .

Areas	Magra River - Serchio River	T.re di S. Severa - T.re Caldara	Anzio - Capo Circeo	Sud di S. Felice Circeo - P.ta S. Agostino	Scauri - Lago Fusaro
Abundance (tons)	88.331	156.398	168.926	168.426	37.225
Surface (Km^2)	4.1	5.2	4.4	4.1	5.6

D. trunculus has suffered similarly, exhibiting reduced biomass (Table 4-9). Possible causes influencing the depletion of this resource along the Latium coasts. Changes in the sediment granulometry is considered to be the most likely cause, and confirms the importance of the 0.5 - 0.25mm granulometric fraction for the presence of *D. trunculus*, which appears to be unable to survive in fractions measuring less than 0.25mm (Costa *et al*., 1987).

Table 4-9. Estimated commercial biomass of *D. trunculus* (tons) along the Tyrrenian coasts (mean values for area 1985 - 1987) (from: Ministero delle Risorse Agricole Alimentari e Forestali, 1996).

Areas	Marina di Massa	Viareggio - Livorno	Mondragone - Pozzuoli
Abundance (tons)	6.21	28.96	11.10

4.6.3 *Callista chione* fishery

The Venus clam (*Callista chione)* fishery occurs along the northern Adriatic coasts; it represents an alternative to clam fishing with hydraulic dredges, especially after the reduced clam resources during the last few years. The Maritime Districts involved are: Chioggia, Venice and Monfalcone, Figure 4-37, with a fleet of about 60 vessels (Marano et al. 1998b). *Callista chione* occur in patches (200-300m. diameter), situated 6-12 miles offshore, at a maximum depth of 18-21m.

Figure 4-37. Distribution of *C. chione* in the Italian and Corsican Seas all Italian and Corsican coasts highlighted

Target species and by-catch

The target species is *Callista chione*, which is always associated with *Laevicardium oblungum*. Other associated species are the Cardiidae *Acanthocardia tuberculata, A. aculeata, A. echinata, A. spinosa* and the Pectinidae *Pecten jacobaeus, Flexopecten glaber, F. proteus, Aequipecten opercularis* and *Chlamys varia* (Marano et al. 1998b).

Fishing strategy

C. chione is targeted only along the northern Adriatic coasts; it represents an alternative to clam fishing with hydraulic dredges, especially after the impoverishment of the clam beds during the last few years. Ports are: Chioggia, Venice and Monfalcone with a fleet of 60 vessels. *C. chione* are found in small banks, 2-3m high, having a diameter of 200-300m. Normally these are situated 6-8 miles, but sometimes 12 miles, away from the coastline and at a maximum depth of 18-21m.

Recently, the increased exploitation of *C. chione* (Table 4-10), has resulted in a daily quota of 350 kg per boat (Marano *et al*., 1998).

Table 4-10. Estimated commercial biomass of *C. chione* (tons) along the Northern Adriatic (mean value for area 1992 - 1994) (from: Marano et al., 1998)

Areas	Monfalcone	Venice	Chioggia
Abundance (tons)	7000	6000	1500
Surface (Km^2)	526	1060	254

Resource characteristics

C. chione requires 1 year to reach the size of 18mm and 5 years to reach the size of 60mm. Fishing targets individuals 4-7 years old (Marano *et al*, 1998a).

Vessel profile

Approximately 60 vessels target *Callista chione* along the northern Adriatic coast.

4.6.4 Management measures

Measures used to manage the Italian dredg fisheries are summarised in Table 4-11 below.

Table 4-11 Management measures for Italian dredge fisheries

Fishery	Species	Location	Input controls	Output controls e.g. quota/mlls
Clam	*Chamelea gallina*	Adriatic and Tyrrhenian coasts	Regulated fishery: close season for at least two months from April to September according with each Management Consortium's decision; from October to March every Saturday, Sunday and holidays; from April to September every Saturday, Sunday and holidays, plus one more day determined by the Management Consortium; restricted license entry. The maximum dredge mouth width (blade length) must be 3m; the maximum pressure from the jets must be 1.8 bar; the maximum dredge weight must be 600Kg. The minimum spacing in cage must be at least 12 mm for bars; the catch must be separated by sieves having bars distant at least 12mm, it is allowed a tolerance of 1mm.	Daily quota of 600Kg per vessel. The minimum legal landing size is 25mm.
Razor clam	*Solen sp., Ensis sp.*	Southern Adriatic and Tyrrhenian coasts	Regulated fishery: close season in April along the Adriatic coasts and from 1st April to 31st May along the Tyrrhenian coasts. The maximum dredge mouth width (blade length) must be 3 m; the maximum pressure from the jets must be 1.8 bar; the maximum dredge weight must be 600Kg. The minimum spacing in the lower part of the cage must be at least 7mm for bars; metal meshes are not allowed in substitution of bars; it is forbidden to keep on board and to use the sieve.	Daily quota of 300 Kg per vessel. The minimum legal landing size is 80mm.
Brown Venus clam	*Callista chione*	Northern Adriatic coasts	The maximum dredge mouth width (blade length) must be 3m; the maximum pressure from the jets must be 1.8 bar; the maximum dredge weight must be 600Kg. The minimum spacing for bars in the lower part of the cage must be at least 25mm; it is forbidden to keep on board and to use any type of sieve.	Daily quota of 350Kg per vessel.
Warty Venus-shell clam	*Venus verrucosa*	Southern Adriatic and Tyrrhenian coasts	Regulated fishery: close season from 1st June to 31st July.	Daily quota of 100Kg per vessel.
Wedge shell clam	*Donax trunculus*	Southern Adriatic and Tyrrhenian coasts	Regulated fishery: close season in April.	Daily quota of 100Kg per vessel.
Bearded horse mussel	*Modiolus barbatus*	Southern Adriatic and Tyrrhenian coasts	None	Daily quota of 300Kg (together with *Aequipecten opercularis*) per vessel.
King scallop	*Pecten jacobaeus*	Northern Adriatic coasts	None The maximum gear mouth width must be 1.6m. The minimum mesh size of the bag must be 50mm. The minimum legal landing size is 10cm	None

4.7 Portugal

Fishing areas and ports

Along the Portuguese coast three bivalve fishing grounds exist (Figure 4-38):off the Northwest coast (between Caminha and Figueira da Foz), off the Southwest coast (between Nazaré and Sines) and off the South coast (between Sagres and Vila Real de Santo António).

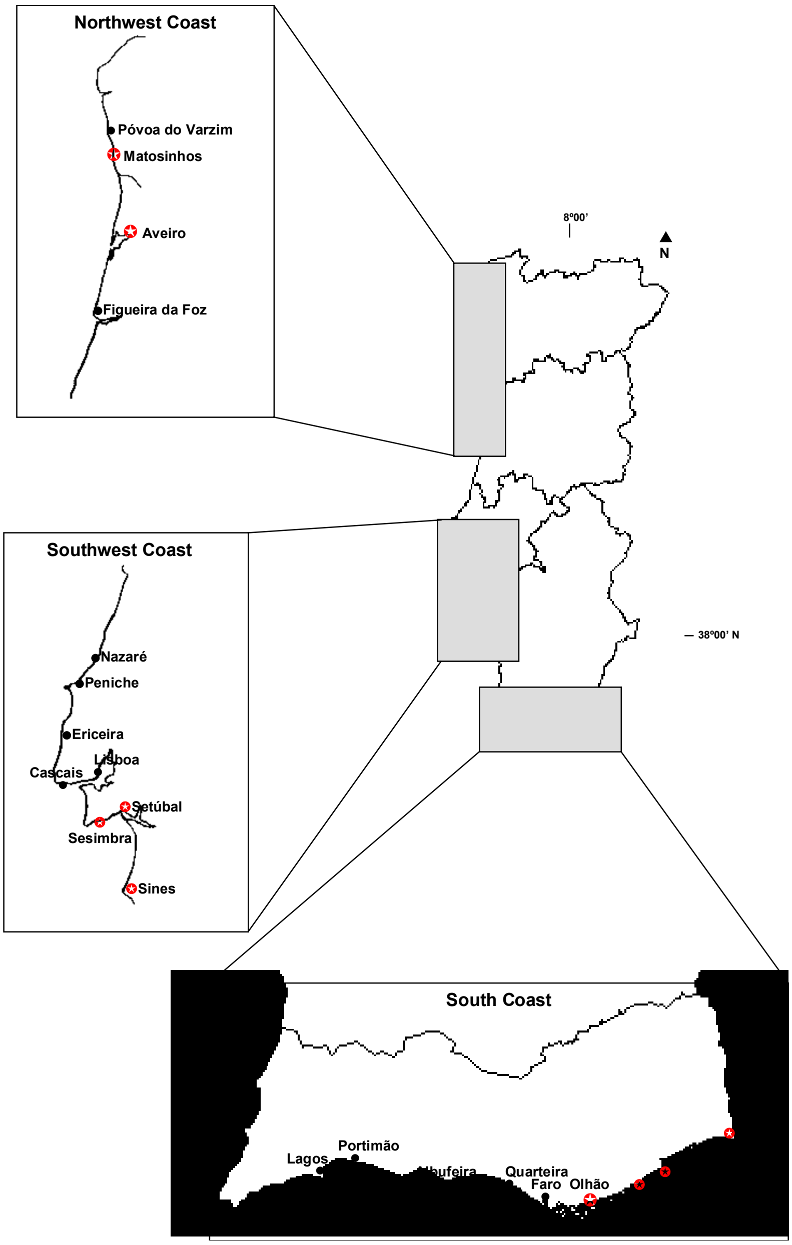


Figure 4-38: Bivalve fishing grounds and location of main ports of the Portuguese coast.

The main ports are Figueira da Foz and Aveiro (north west coast), Setúbal, Sesimbra and Sines (south west coast) and Olhão, Fuzeta, Tavira and V.R.S.A. (south coast).

Target species and by-catch

Currently (1999) the most important commercial species are the clams: *Spisula solida*, *Chamelea gallina*, *Donax trunculus* and *Callista chione* and the razor clam *Ensis siliqua*. On the north west coast only *Spisula solida* is targeted, whereas all the five species are exploited on the south west coast (the most important species being *Spisula solida*, *Chamelea gallina*, *Donax trunculus* and *Ensis siliqua)*.

Bycatch

Bycatch comprises other bivalve species, mainly: *Acanthocardia* sp., *Laevicardium crassum* and *Mactra* sp.

Market

Product is exported live: *Spisula solida*, *Chamelea gallina* and *Callista chione* to Spain; and *Chamelea gallina* to Italy. Some product is consumed in Portugal (*Spisula solida*, *Donax trunculus, Chamelea gallina* and Ensis *siliqua*) in fresh, frozen or canned form.

Fishing strategy

No seasonal restrictions exist in this fishery; the market regulates the pattern (species and timing) of exploitation. Clams and razor clams occur in patches, that often in different places from year to year. Hence, during the return trip to the port, fishermen make small tows in order to find new clam beds.

Interactions

There is no conflict with the *Donax* fishery, which occurs within ¼ mile off the coastline, since commercial fishing gears (except for dredges) are not allowed within this zone. However, conflict may occur with gillnets, trammel nets, pots and traps. No known conflict with nature conservation interests.

Trends and Comments

Resources are characterised by large annual fluctuations due to variable fishing effort and recruitment; the management of this fishery (in terms of daily quotas and temporal closed areas) can be adjusted annually depending on strength of recruitment and stock biomass.

Fishing effort

The description of the Portuguese dredge fleet was based on official statistics from Direcção Geral das Pescas e Aquicultura (DGPA) and describes the situation of the fleet as of May 1, 1999. The compositions by port, GT, and HP are given for the fishing boats classified in two categories: local and coastal. Table 4-12 summarises the legal requirements of these categories. However, in the case of the dredge fleet, boats can operate within the shore line and ¼ of mile.

Table 4-12 – Legal requirements for fishing boats classification.

Categories		Operating area	Size (length or GRT)	Engine power
Local	Open-deck	Within ¼ - 6 mi	Up to 9 m	< 60 HP
	Close-deck	Within 1 - 30 mi	Up to 9 m	< 100 HP
Coastal		Out-side 1 mi Out-side 6mi if GRT > 100	>9m and up to 180 GRT	> 35 HP

Vessel number

In May 1999 the Portuguese dredge fleet comprised 131 boats, of which 56 operated in the north-west coast, 19 in the south-west and the remaining 56 in the south, Table 4-13. Most vessels belong to the coastal category.

Table 4-13 – Number of boats that operate with dredges per category and zone in Portuguese main land in May 1999 (source DGPA).

Zone / Category	Local	Coastal	Total
Northwest	6	50	56
Southwest	0	19	19
South	31	25	56
Total	37	94	131

Ports

The number of boats registered and licensed by port and zone is shown in Table 4-14. At present important ports, in terms of number of boats that operates with dredges, are: Povoa de Varzim; Vila do Conde; Douro (Matosinhos); Setúbal; Olhão; and Fuzeta.

Table 4-14 – Number of boats that operate with dredges by port in the 3 bivalve fishing grounds of the Portuguese coast in May 1999 (source DGPA).

	Ports	Local	Coastal	Total
Northwest	Viana do Castelo	0	4	4
	Povoa de Varzim	2	14	16
	Vila do Conde	0	11	11
	Leixões	1	8	9
	Douro	2	10	12
	Aveiro	1	3	4
Southwest	Sesimbra	0	7	7
	Setúbal	0	12	12
South	Lagos	2	0	2
	Olhão	7	14	21
	Fuzeta	20	3	23
	Tavira	2	4	6
	V.R.S.A.	0	4	4

The composition of the Portuguese dredge fleet in terms of gross tonnage (GT) and engine power (kW) is shown in Table 4-15 and

Table 4-16, respectively. These tables shows that the mean GT and mean engine power decreases from the north to the south; this is due to a decreasing north-south gradient in the severity of sea conditions

Table 4-15 – Total and mean gross tonnage (mean in parenthesis) per category and zone in Portuguese main land, in 31st December 1998 (source DGPA).

Zone / Category	Local	Coastal	Total
North	24.84 (4.14)	764.78 (15.3)	789.62 (14.1)
Centre	0	166.78 (8.78)	166.78 (8.78)
South	84.13 (2.71)	219.49 (8.78)	303.62 (5.42)
Total	108.97 (2.95)	1151.05 (12.25)	1260.02 (9.62)

Table 4-16 – Total and mean engine power (mean in parenthesis) in kW per category and zone in Portuguese main land, in 31st December 1998 (source DGPA).

Zone / Category	Local	Coastal	Total
North	301 (50.17)	5814 (116.28)	6115 (109.2)
Centre	0	1646 (86.63)	1646 (86.63)
South	1070 (34.53)	1587 (63.48)	2657 (47.44)
Total	1371 (37.05)	9047 (96.24)	10418 (79.53)

Bivalve landings

Bivalve landings between 1992- 1997 have shown a general decline, Figure 4-39. However, the data should be analysed with caution since reliable statistical data are unavailable before 1997 because fishermen were not obliged to declare catches. Nevertheless, the decreasing trend is representative of the actual situation.

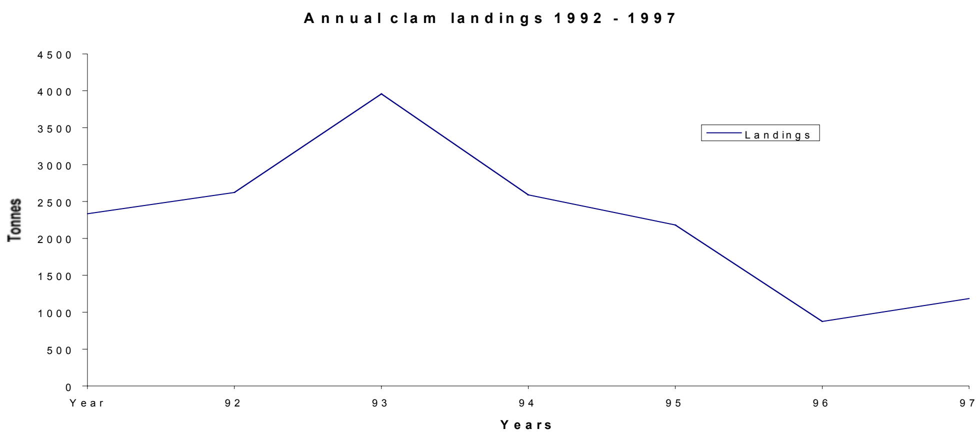


Figure 4-39 Weight of the five commercial species of clams landed in Portugal, 1992-1998 (source DGPA).

Landings peaked in 1993at 4000 tons. However, the extensive beds of one and two years class of clams that contribute to the expansion of the fishery were quickly depleted (especially on the south-west and north-west coast) and subsequent landings decreased to the extent that clam beds on the Northwest coast were closed, as were *Spisula solida* and *Ensis siliqua* beds on the south-west coast. By 1997, total landings had declined 78% from the peak in 1994 however, in1998 increased total landings indicated the recovery of clams beds along the Portuguese coast.

Value

Over the same period the value of clam landings has shown a similar decline, Figure 4-40.

Figure 4-40 – Value of the five commercial species of clams landed in Portugal, 1992-1998 (source DGPA).

4.7.1 Management measures

Measures used to manage the Portuguese clam fisheries are shown in Table 4-17

Table 4-17: **Management measures for clam fisheries in Portugal.**

INPUT CONTROLS	OUTPUT CONTROLS
Licence limitation • Northwest coast : 90 • Southwest coast: 37 • South coast: 57 **Limitation of fishing gear** • Maximum length of mouth: 100cm on the Southwest and South coast and 150cm on the Northwest coast. • Minimum tooth spacing: 1.5 cm • Maximum tooth length: 55cm • 2 dredges per boat **Vessel limitations - Engine power** **Northwest coast:** 151.3HP **Southwest coast:** 131.1HP **South coast:** 100.8 HP **Minimum mesh size** • 25mm **Closures** • Closed from May 1 to June 15 (which coincides with the most important phase of spawning) • The harvesting may also be interrupted due to episodic, natural contamination, due to red tide • Clam flat can be closed for conservation purposes **Other fishing gears** • During closures boats are allowed to use long-lines	**Size limits** • *Spisula solida*: 25mm • *Chamelea gallina*: 25mm • *Donax trunculus*: 25mm • *Callista chione*: 50mm • *Ensis siliqua*: 100mm **Daily catch quota per boat** **Northwest coast:** • 210Kg **Southwest coast:** • 800Kg (*Callista chione*) • 100Kg (*Donax trunculus*) • 200Kg (*Ensis siliqua*) **South coast (According to GRT):** • GRT< 2 ----------------- 50Kg • GRT ≥ 2 and < 3 ----- 75Kg • GRT ≥ 3 and < 4 ----- 100Kg • GRT ≥ 4 and < 5 ----- 120Kg • GRT ≥ 5 and < 6 ----- 150Kg • GRT ≥ 6 ---------------- 200Kg

References for Section 4 European dredge fisheries

Agri.te.co. (1998). Sperimentazione della gestione dei molluschi bivalvi nei compartimenti di Monfalcone, Venezia e Chioggia. Rapporto finale - Compartimenti di Monfalcone e Venezia. Ricerca Scientifica 4.A.88.

Berthou, P. (1984). Gestion rationelle des stocks de praires sur la côte Ouest du Cotentin. Comité local des pêches de Granville.

Bombace, G. (1991). Fisheries of the Adriatic Sea. In: Marine Eutrophication and Population dinamics. 25th European Marine Biology Symposium, Università di Ferrara.

Bord Iascaigh Mhaire, B. (1998). Irish Food - Seafood Edition. A publication produced by BIM.

Boucher, J. and S. Fifas (1995). Dynamique de la population de coquilles Saint-Jacques (Pecten maximus) de la rade de Brest : Hier etait-il different d'aujourd'hui? Communaute Urbaine de Brest /IFREMER, Prog. Rade, Rencontres scientifiques internationales, Brest (France), 3: 2-14.

Brand, A. R. and E. H. Allison (1987). The Isle of Man fishery for the queen scallop, Chlamys opercularis. 6th International Pectinid Workshop, Menai Bridge, Wales.

Brand, A. R., E. H. Allison and E. J. Murphy (1991). North Irish Sea scallop fisheries: a review of changes. An international compendium of scallop biology and culture. S. E. Shumway and P. A. Sandifer. Baton Rouge, World Aquaculture Society**:** 204-218.

Briggs, R. P. (1991). A study of the Northern Ireland fishery for the escallop Pecten maximus (Linnaeus 1758). In: An international compendium of scallop biology and culture, Baton Rouge.

Briggs, R. P. (1995). A review of research on the Northern Ireland scallop stocks. 10th International Pectinid Workshop, Cork, Ireland.

Chapman, C. J., J. Main, T. Howell and G. I. Sangster (1979). The swimming speed and endurance of the queen scallop *Chlamys opercularis* in relation to trawling. Progress in Underwater Science: 57-72 (new series).

Costa, C., M. Bianchini, P. Ceccarelli, P. Orecchia, E. Rambaldi and L. Volterra (1987). Indagine sui molluschi bivalvi di interesse commerciale (telline, cannolichi e vongole) delle coste della Toscana, del Lazio e della Campania, 1985 - 1987. Quad. Ist. Idrobiol. Acquacolt. Brunelli 7: 3-58.

Duff, M. (1976). Scallop fishing in Ireland. 1st International Pectinid Workshop, Baltimore, Ireland.

Fifas, S. (1991). Analyse et modélisation des paramètres d'exploitation du stock de coquilles Saint-Jacques (*Pecten maximus*, L.) en baie de Saint-Brieuc (Manche Ouest, France). Brest, d'Université, IFREMER/UBO**:** 422 p.

Fifas, S. (1993). Un modèle de capturabilité pour le stock de coquilles Saint-Jacques (*Pecten maximus*, L.) en baie de Saint-Brieuc (Manche, France). Les recherches françaises et évaluation quantitative et modélisation des ressources et des systèmes halieutiques. Halieumétrie. Rennes, Actes du colloque**:** 141-155.

Foucher, E. (1986). L'évolution de la pêcherie de coquilles Saint-Jacques en baie de Saint-Brieuc à partir des licences de pêche. Mémoire ENSAR**:** 71p.

Froglia, C. (1975a). Aspetti biologici, tecnologici e statistici della pesca alle vongole (Venus gallina). Quad. Lab. Tecnol. Pesca 9: 7-22.

Froglia, C. (1975b). Osservazioni sull'accrescimento di *Chamelea gallina* (L.) ed *Ensis minor* (Chenu) nel Medio Adriatico. Quad. Lab. Tecnol. Pesca 2(1): 37-48.

Froglia, C. (1989). Clam fisheries with hydraulic dredges in the Adriatic Sea. In: Marine Invertebrate Fisheries: their Assessment and Management., Ed. J.F. Caddy, Wiley Interscience Publication.

Guyader, O. and S. Fifas (1999). Evaluation des bénéfices et des coûts de la transition vers une pêche responsable. La pêcherie de coquille Saint-Jacques (*Pecten maximus*, L.) de la Baie de Saint-Brieuc (France). Rapport à la Direction des Pêches Maritimes et des Cultures Marines dans le cadre du Comité des pêcheries de l'OCDE 120 p.

Magorrigan, B. H., M. Service and W. Clarke (1995). An acoustic bottom classification survey of Strangford Lough, Northern Ireland. J. Mar. Biol. Ass. U.K. 75: 987-992.

Marano, G., R. Vaccarella, A. M. Pastorelli, V. De Zio, I. Rositani and P. Paparella (1998a). Valutazioni e consistenza dei banchi di *Chamelea gallina* (L.) e dei bivalvi commerciali associati nell'Adriatico Meridionale (anni 1984-1995). Biologia Marina Mediterranea 5(3): 407-417.

Marano, G., R. Vaccarella, A. M. Pastorelli, C. Piccinetti and D. Del Piero (1998b). Valutazione della biomassa di *Callista chione* (L.) (Fasolaro) in Adriatico. Biologia Marina Mediterranea 5(3): 451-456.

Mariani, A., A. Maccaroni, R. Mamone, M. Dell'Aquila, D. Fezzardi and A. Cerasi (1998). Studio sulla biologia e distribuzione del cannolicchio (*Ensis siliqua minor*) nei Compartimenti marittimi di Roma, Gaeta, Napoli e Salerno. Biologia Marina Mediterranea 5(3): 457-462.

Mattei, N. and M. Pellizzato (1997). Mollusk fisheries and aquaculture in Italy NOAA 129,3201-216

Ministero delle Risorse Agricole Alimentari e Forestali (1996). Risorsa Molluschi. A cura del C.I.R.S.P.E**:** 86pp.

Murphy, E. J. (1986). An investigation of the population dynamics of the exploited scallop, *Pecten maximus* (L.), in the North Irish Sea., University of Liverpool.

Piboubes, R. (1974). Pêche et conchyliculture en Bretagne Nord. Première partie. Bulletin C.E.R.S 4: 30-150.

Tétard, A., Boon, M. et al. (1995). Catalogue international des activités des flotilles de la Manche. Brest, IFREMER**:** p. 154, 162.

5 ENVIRONMENTAL EFFECTS

This review divides the environmental effects of dredging into:

- Physical and chemical effects on the substrates
- Biological effects on the target and non target organisms
- Ecological effects

5.1 Physical effects

Physical effects on the seabed include mechanical disturbance of the seabed sediments and substrata, chipping and breaking up of seabed features and suspension of the sediment plume. Features likely to affect the degree of physical effect include the energy input into the seabed and the nature of the seabed. High speed towed dredges or high-pressure hydraulic dredges would be expected to have a greater effect than lower speeds and pressures. The nature of the seabed and the other sources of energy input into the seabed environment would also be expected to influence the likely effects. Hard, coarse sand across which strong tidal flows occur would be expected to have greater resilience to dredge impacts than finer sediments in lower energy environments. Rocky substrates can also be affected in areas where dredge fisheries are pursued adjacent to reefs.

5.1.1 Scallop dredging

Efforts to study the physical effects of scallop dredging have used diver observations (Chapman et al. 1977; Munro 1992; Lart et al. 1993), observations of sediment transport and disturbance (Black and Parry 1994) and studying the mechanical aspects of dredge design and operation (Cover and Sterling 1994).

Chapman *et al* (1977) describe the build-up of a mound of stones in front of fixed-tooth dredges set up to catch *P. maximus* in Scottish waters; the use of springs in modern spring-toothed dredges appears to reduce this tendency. It also reduces the ridge of material deposited each side of the dredge.

Rocky substrates (Munro 1992; Lart et al. 1993) can be affected by scallop dredging. It is important to recognise that scallops are targeted where they live, on the sediments. Impacts on rocky substrates are incidental when targeting the patches of sand amongst the rocks. Effects are potentially more important when these areas contain habitats for fish and shellfish. Bradstock and Gordon (1983) reported on the impact of trawling on extensive coral grounds off Tasmania where fishing gear with otter boards and sweep wires destroyed erect bryozoans, such as *Celloporaria agglutinas* and *Hippomenella vellicata*, and subsequently reduced the numbers of juvenile fish in the area.

Some maerl (*Lithothamnion coralloides* and *Phymatolithon calcarum)* beds contain scallops (*Pecten maximus*) and are considered to be scallop nursery areas (Hall-Spencer 1998; Hall-Spencer and Moore 2000b). Physical effects on maerl can be severe and long lasting (2.5 years for physical disturbance >4 years for biological effects) (Hall-Spencer and Moore 2000a), and management of maerl beds is required under the EU Habitats Directive.

Black and Parry (1994) compared sediment transport and disturbance in Port Phillip Bay, Australia, by scallop dredging with that created by storms. Sediment concentrations immediately surrounding the dredged area were 2-3 orders of magnitude higher than those found during storms. These levels fell rapidly to the upper range of natural storm levels after about 9 minutes as the coarser particles settled out. More time is required for settlement of fine sediments so dredging may be responsible for re-distribution of finer sediments (See Section 5.1.2).

Cover and Sterling (1994) describe the action of toothed mud dredges (a type of box dredge; Figure 3-42) in terms of mechanical forces acting on the dredge and seabed. It was found that although the average downward pressure exerted by the tooth mud dredge was reasonably low, the point loading and dynamic action might mean that very high intermittent contact pressures could occur between the seabed and the rigid surface of the dredge. In contrast, the more flexible bellies on European scallop Figure 3-25 and Japanese keta-ami dredges Figure 3-46, and Figure 3-47 exhibited much lower downward pressure with less point loading on the bellies. In these dredges point loading is encountered at the teeth.

5.1.2 Hydraulic dredging

From the description of this type of fishing gear, (Figure 3-30 and Figure 3-31) it is easy to deduce that all the "traumatic" actions carried out on the sediment are due to the cage, which produces the following effects:

1) Sediment compression due to the sled runners, which can be expressed in pressure terms
2) Sediment cutting due to the blade, which can be quantified by the volume of moved sediment
3) Jetting action on the sediment, due to the jets located at the front of the cage (header), which can be expressed by a force in correlation with the pressure acting in the cage and the power of the pump (Ferretti et al. 1990)

Compression action

The stress on the sediment can be expressed in terms of pressure by the expression:

$$p = m_c\, g\, [1 - (\rho_a / \rho_c)] / 2\, A_s$$

with p = static pressure (N/m^2); g = acceleration of gravity (m/s^2); ρ = density (kg/m^3); A_s = surface of the cage sledge (m^2).

The ratio between the water/cage density can be considered as a constant value, so that the relationship can be rewritten as follows:

$$p = 0.435\, m_c\, g / A_s$$

The value assumed by p is low, even though the cage mass can easily reach 600kg; the large surfaces of the sledges and the hydrostatic thrust effect on the cage determine values of 350 - 400 N/m^2 (Ferretti et al. 1990).

Cutting action

The cutting action is exerted by a thin steel blade working across the whole width of the cage; it is regulated, according to the mollusc species to be caught, at a level of 30-50mm below that of the sledges. The blade, which is firmly fixed to the cage, cuts or better scraps the sediment, due to the dragging motion, loading everything that it finds above its working level into the cage mouth.

The volume of the sediment removed by the blade is:

$$V = \alpha \, L \, c \, T \, s / 1000$$

with V = volume of the removed sediment (m^3); α = reductive coefficient, which considers the fact that the bottom is not completely plane; L = width of the cage mouth (m); c = mean speed of the considered section (m/s); T = length of the dragging time (s); s = depth of the blade regulation (mm).

Given the considerable uniformity of the seabed in which clam fishing is performed, the volume of sediment moved by a vessel with hydraulic dredges during a fishing period (a season) can amount to some tens of thousands of cubic meters (Ferretti et al. 1990).

Jetting action

The action of a water jet on a sand bed has been discussed by a number of workers (Rajaratnam et al. 1995; Niven and Khalili 1998). Most workers in this field have not found it possible to develop rigorous mathematical relationships. This is due to the large number of variables, including particle grain size, jet diffusion in the vicinity of the scour hole, and the movement and effect of scoured materials. For this reason most workers have developed empirical models (See Investigations Section 3.1.1.4.).

Sediment re-suspension

To assess the impact of clam fishing with hydraulic dredges on the littoral zone of the Venetian region, a simulation experiment was performed in 1986 on sediment re-suspension and deposition (Brambati and Fontolan 1990). This was done by creating sediment re-suspension by means of a pump containing water under pressure, manoeuvred manually by a diver along a rectilinear transect.

The experiment identified a "two-layer" transport system, one onshore and near the bottom (presumably consisting of a graded suspension sediment), and the other offshore (characterised by a uniform suspension). It was calculated that the amount of sediment transported onshore was about 0.3% of re-suspended sediment, while the sediment transported offshore was 0.002%.

To provide an idea of the amount of sediment lost along the coastal area from Caorle to Chioggia, where hydraulic clam dredging is carried out regularly, some calculations have been made of the overall quantity of sediment affected by dredging. This indicated that up to 40 million m^3 per year of sediment was affected over an area of 20 km^2, suggesting that the seabed area affected by hydraulic dredges is dredged, on average, 8 times per year. The analyses carried out on the seabed sediments during the experiment showed that the sediment that re-deposited immediately after artificially induced re-suspension had a considerably lower density than (pre-) re-suspension sediment. It is likely, therefore, that the change in the geo-technical features of the bottom sediment can reduce shear stress resistance and thus the critical erosion velocity.

5.2 Chemical Effects

Soft sediments comprise sediments with very small mineral grains bound loosely with organic material and associated micro-organisms, on and in which epifaunal and infaunal macro-organisms live. Anoxic conditions can occur within a few millimetres of the sediment-water interface, except where pumping by burrow-dwellers oxygenate the surrounding sediment. On soft/sandy scallop grounds, the most noticeable environmental impact of dredging was observed to be the burial of organic material (Meyer et al. 1981). This makes it unavailable for consumption by animals further up the food chain, such as meio- and macro-faunal species, and instead favours anaerobic microbial respiration. This could lead to increased proportions of re-mineralisation products such as CO_2.

The importance of these effects is likely to depend on the amount of organic matter on and in the surface of the sediment. The relationship between the depth of the anoxic layer and the penetration of dredge disturbance would be expected to be important, as would be the relative magnitude of disturbance by burrow dwellers, tidal and other currents and dredging.

5.3 Biological effects

This section discusses observations of the effects of dredging on growth and incidental mortality or non-catch mortality on target and non-target species. The effects of dredging on population dynamics of target species are discussed at length in (Section 2) against the appropriate species.

Target species size selection and growth

The main scallop populations in French coastal waters have been overexploited for many years. In the case of Saint-Brieuc bay (ICES Area VIIe), analysis undertaken on patterns of individual growth since 1996, and comparisons with previous decades (1970s and 1980s), have shown obvious phenotypic modifications (Figure 5-1). These are related to dredging effects (a significant decrease of values of growth parameters and increased skewness of distributions of length frequencies).

The absence of an unexploited baseline population with which to compare these results led to a research survey on scallop populations found on the Western oceanic areas off the tip of Brittany. This study was subdivided into two areas, the first in an area of low exploitation (Island of Ouessant - Sea of Iroise - Ar Men), the second unexploited (as far as the continental slope *e.g.* out to 200m depth). Comparison of these results with those of Saint-Brieuc Bay showed several trends.

Saint-Brieuc Bay (Figure 5-1, Figure 5-2 and Table 5-1)

The long-term trend, on a scale of twenty-five years, is characterised by a strong decrease of the L_∞ (final length) parameter, with no equivalent increase in the value of the K parameter. This result was analysed in different ways. The effects of hydro-climatic changes, increasing concentration of competitive species, spatial and bathymetric differences of annual recruitment, and the selective effect of dredging activities were all examined for their effects on growth. The most probable cause of this effect is exploitation.

The short- and mean-term trends, for a given year-class from year to year, are characterised by modifications in the distribution patterns of back-calculated length frequencies according to three main processes:

(1) the effect on the most abundant sizes of scallops due to over-fishing of areas with high densities of scallops

(2) the effect on mean sizes because of selection of the largest individuals

(3) the effect on variation in scallop sizes because of selection of scallops characterised by a high growth rate.

In all cases, distributions are skewed with a dominance of small sizes.

Western areas off Brittany

The age composition (Figure 5-2) of the unexploited part of these areas is characterised by the presence of old age groups (dominance of year-classes between the end of the 1980's and the beginning of the 1990's because of favourable hydro-climatic conditions). In the areas of low exploitation in the western areas, the age composition is younger, but older than that of Saint-Brieuc Bay. In the long-term, a modification of values of growth parameters L_∞ and K (Table 5-1) is not obvious. In the case of distribution patterns of length frequencies (Figure 5-1), the modifications are less strong than those observed in the Saint-Brieuc Bay (see previous paragraph): only an effect on mean sizes seems be significant and distributions are symmetrical.

Table 5-1 Long-term effect on growth parameters L_∞ and K.

Area	*Decade*	*L∞*	*K*
Saint-Brieuc	1970's (Antoine et al. 1979)	124.2	0.56
	1980's (Fifas 1991)	113.3	0.58
	1990's (Fifas and J. 1997)	103.1	0.72
Western Brittany	1970's (Antoine et al. 1979)	107.1	0.52
exploited	1990's (Hergas 1999)	106.8	0.48
unexploited oceanic areas	1990's (Hergas 1999)	105.7	0.39

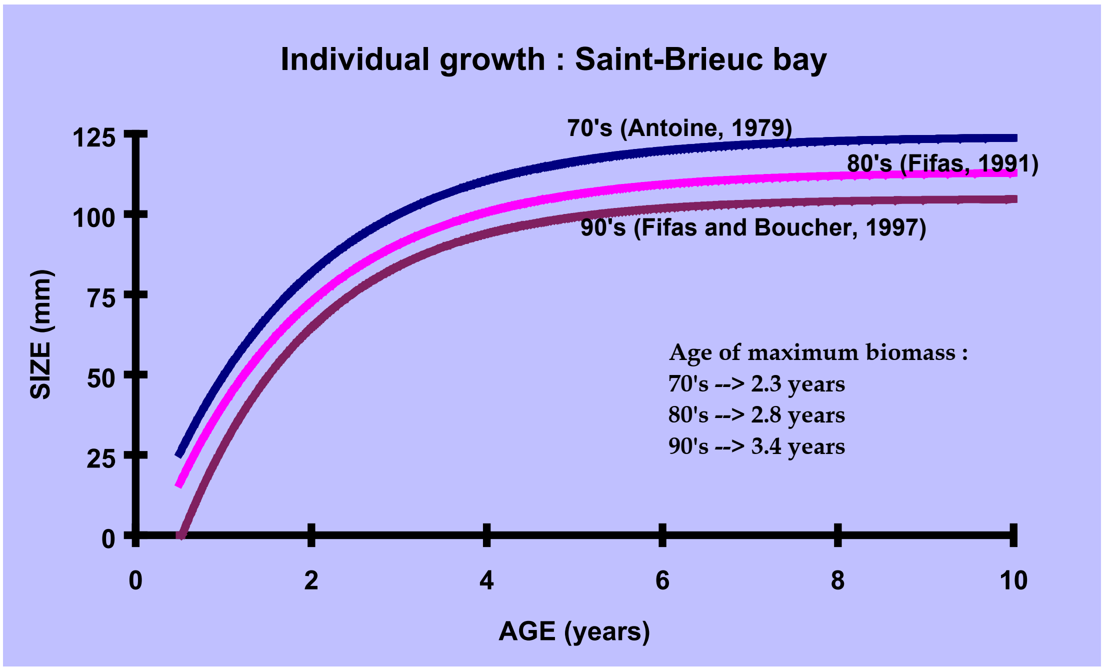


Figure 5-1 Variation in growth of scallops from Saint-Brieuc bay in the 1970s, 1980s and 1990s.

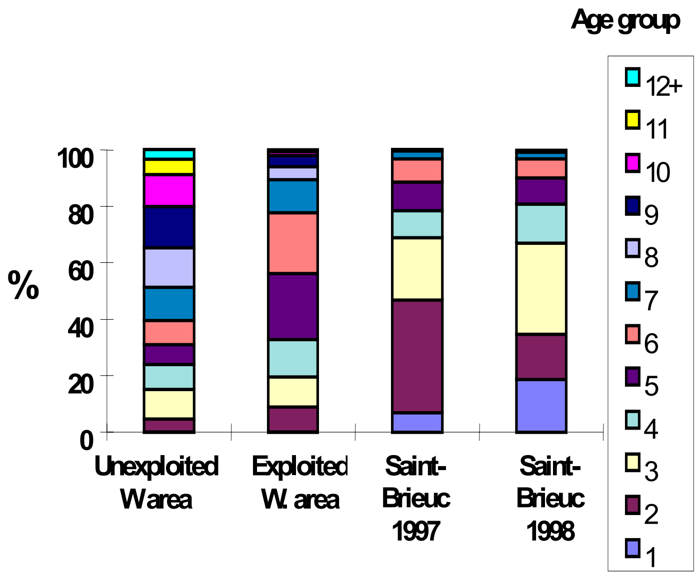


Figure 5-2 Age composition of experimental catches from western Brittany and Bay of St Brieuc (mesh size of 50mm).

Effect on growth of scallops

Analysis of the above results suggests that the apparent reduction in growth was related to dredging since the less exploited and unexploited stocks in the western areas showed no reduction of growth over the time period. Whether this is an effect of the dredge fishery introducing a metabolic load on the scallops and hence retarding growth, genetic selection of individuals with a propensity for faster growth, or simply due to removal of the larger scallops of each age group remains uncertain. It is clear that these scallop populations do not appear to respond to exploitation with increased growth. Indeed, these results suggest the converse; growth appears to be retarded.

Effect on target species: non-catch mortality

Apart from the obvious impact on target species (through catching marketable sized animals) dredging causes incidental mortality, either to animals on the seabed, which escape capture, or to undersized animals, which are caught and discarded.

Table 5-2 describes a selection of results of efficiency and incidental mortality studies. The low efficiency means that a proportion of scallops encountering dredges are not caught but may be damaged or stressed.

Incidental mortality of target species in dredge fisheries may thus be significant. The dominant types of incidental damage caused to bivalves, which can be assessed visually, include chipped valve margins and the separation of hinges. Also, some animals become filled with sediment or ‘sand-packed’. There is also a need to understand the effects of dredging that are sub-lethal at the point of encounter with the gear but may have an adverse effect on survival or growth.

Repeated encounters with dredges may compound the effect. Additionally, undersized scallops that are captured and discarded can suffer mortality as a result of damage inflicted within the dredge or exposure to air. These experiments are restricted to scallops, which can be observed by divers, or captured and tagged, so our knowledge of the mortality of very small scallops is limited.

The results cited in Table 5-2 suggest that dredge efficiency is maximised, and incidental mortality minimised, on smooth ground with dredges using a diving vane in calm weather (Dupouy 1982). On rougher grounds, efficiency is reduced and incidental mortality increases. Thus, it appears that the stability of the dredge and its mechanical action on the seabed and shellfish could be important factors affecting non-catch mortality. The severity of the damage may be related to the catch weight and number of tows impacted on the individuals. As the bag fills during the tow, the dredge becomes heavier and the weight moves to the rear of the bag until it fills. This would also be expected to affect dredge operation and hence non-catch mortality.

Other factors, such as substrate type (Naidu 1988), performance of gear (Gruffydd 1972) and scallop size (Medcof and Bourne 1964), all play roles in the incidental damage and mortality of scallops. Also, a significant number of scallops may be buried while others may become sand-packed due to dredging activity. Gruffydd (1972) suggests that this type of damage/mortality would be much more difficult to estimate but should be considered in studies addressing the impact of dredging activities on the target species.

Additional impacts on target species include the detrimental effects of increased concentrations of suspended silt on scallop spat, either directly (e.g.Stevens 1987) or indirectly through the smothering of erect hydroids and bryozoans on which scallop larvae byssally attach at spat settlement (Brand et al. 1980).

Table 5-2: Percentage efficiency and mortality for shellfish dredges per passage of the dredge unless otherwise stated.

Dredge type, target species	Species and location	Seabed type	% Efficiency	% Mortality of target species	Comments
Fixed tooth bar with diving vane. Dupouy, 1982	*P.maximus* Bay of Saint-Brieuc (period = 1970's and 1980's)	Sand-gravel-shell	34-40	Less than 15	
Fixed tooth bar with diving vane.	*P.maximus* Bay of Saint-Brieuc (1990's)	Sand-gravel-shell	60-80	1.2 low damage in dredge track, 1.2 low damage dredge caught	The damage increases on rough bottom and with bad weather conditions
Fixed tooth bar without diving plate. Dupouy, 1982	*P.maximus* Bay of Brest (period = 1970's)	Muddy sand-gravel-shell	15-20	More than 20	
Fixed tooth bar without diving vane.	*P.maximus* Bay of Brest	Muddy sand-gravel-shell	35 maximum	low damage in dredge track, low damage dredge caught	
Fixed blade without diving vane.	*T. Rhomboïdes* Bay of Saint-Brieuc	Sand-gravel-shell	15-20	10-20 severe damage in dredge track, 5-20 severe damage dredge caught	Related to blade designs and may be the width of the dredge
Flexible dredge Fixed tooth bar	*V.verrucosa* Bay of Brest	Muddy sand-gravel-shell		low damage in dredge track, 0-1 low damage dredge caught	
Box dredge Fixed blade	*V.verrucosa* Norman-breton gulf	Sand-gravel-shell-stone		severe damage in dredge track, 5-20 severe damage dredge caught	
Flexible dredge Fixed blade	*Tapes, Spisula* South Brittany	Sand-gravel-shell		Low damage	
Fixed tooth bar . Chapman *et al.*, 1977	*P.maximus* W. Scotland	Sand-gravel-shell	18-21	0.6 severe damage in dredge track, 0.5-2.3 severe damage dredge caught	
Spring tooth bar Chapman *et al.*, 1977	*P.maximus* W. Scotland	Sand-gravel-shell	13-14	2.8 severe damage in dredge track, 5.0 severe damage dredge caught	
Spring tooth bar Chapman *et al.*, 1977	*P. maximus* W. Scotland	Sand-gravel-shell		0-25	Related to haul duration
Spring tooth bar Brand pers comm.	*P. maximus* Irish sea			15	Tagging study
Spring tooth bar Brand pers comm.	*A.opercularis.* Irish sea			30 per month	Comparison with Natural mortality Section 2.2

Non-target species

The selectivity of dredge fishing varies with dredge design and fishing technique. However, inevitably there is a by-catch, which typically comprises the larger members of the epibenthos that have a sufficiently large body-size to be retained in the gear. On rougher grounds, the by-catch may also comprise a large proportion of smaller bodied animals that live epiphytically on stones and shells retained in the dredge (Hill et al. 1997). Variation in dredge gear affects not only the target species but also the level and type of by-catch. In a comparison of spring-toothed dredge gear adapted for queen scallops (*Aequipecten opercularis*) and for scallops (*Pecten maximus*), Hill *et al*. (1997) found much greater numbers and biomass of by-catch in the gear adapted for the smaller target species, the queen scallop.

Damage to the by-catch may be caused by the initial encounter with the tooth-bar, impaction or crushing by other components of the catch, or by the sorting process on the deck of the fishing vessel. Studies of both dredges (Hill et al. 1997; Veale et al. 2001) and beam trawls (Kaiser and Spencer 1995) have shown that the types of injuries and their extent are species-specific. Differences in the damage between species will depend on a variety of factors, including the fragility of their body (Brown 1989; Eleftheriou and Robertson 1992) and time of year when dredging is undertaken (Hill et al. 1997). In addition, the level of damage sustained by the by-catch may vary with the composition of the substratum. For instance, a greater proportion of stones and debris in the gear may lead to greater damage (Medcof and Bourne 1964; Shepard and Auster 1991; Veale et al. 2001).

Table 5-3: Species that are vulnerable to trawl and dredge damage

Group		Damaged or Killed (%)	Source
Hydroids:	*Tubullaria*	100	(de Groot and Apeldoorn 1971)
Crustaceans:	*Liocarcinus*	45	(Kaiser and Spencer 1994)
	Echinocardium	40 – 70	(Houghton 1971)
Echinoderms:	*Echinocardium*	100	(Bergman et al. 1990)
Molluscs:	*Artica*	90	(Bergman et al. 1990)
	Spisula	30 – 92	(Meyer et al. 1981)
Fish:	*Ammodytes*	Large Numbers	(Eleftheriou and Robertson 1992)

Although numerous studies have reported by-catch composition and damage levels, both for dredges (Medcof 1971; Jamieson 1985; Hawkins et al. 1991; Eleftheriou and Robertson 1992), and other demersal fishing techniques (de Groot and Apeldoorn 1971; Houghton 1971; Bergman et al. 1990), few studies have followed the subsequent survival of damaged organisms. Hill el al.(1997) and Veale *et al*.(2001) used a simple subjective index to score damage in a range of species caught in both queen (*Aequipecten opercularis*) and scallop (*Pecten maximus*) dredges and monitored survival over a 72 hour period.

In general the damage scoring system was supported by the survival studies, with animals scored as most severely damaged suffering highest mortality. However, there was considerable variation between species. Some apparently undamaged animals, such as

Eledone cirrhosa and *Alcyonium digitatum,* suffered high levels of subsequent mortality while others, such as *Modiolus modiolus,* survived well after suffering high degrees of damage. No investigations of the survival of animals that pass through dredges have been made. Survival of animals that passed through the cod-end of a 4 m beam trawl was much higher than those that were caught (Kaiser and Spencer 1994).

However, recent evidence suggests that even undamaged animals left on the seabed are more vulnerable to predation following disturbance by beam trawling (Ramsay 1998). Experimental investigation of the cause of damage to certain species in beam trawls concluded that the chain matrix fitted to the gear was largely responsible for the injuries sustained (Kaiser and Spencer 1995)

5.4 Ecological effects

Scallop dredging

A number of studies have specifically assessed the impact of scallop dredging on benthic communities, both in the UK (Bullimore 1985; Sheader 1986; Brown 1989; Fowler 1989; Eleftheriou and Robertson 1992; MacDonald 1993; Hall-Spencer 1995; Hill et al. 1996; Kaiser et al. 1996; Hill et al. 1997; Hill et al. 1999a; Bradshaw et al. 2000; Brand 2000; Veale et al. 2000b) and further afield (Bourne 1964; Caddy 1973; Butcher 1981; Murawski and Serchuk 1989; Thrush 1995; Currie and Parry 1996).

The destruction and damage of non-target species by dredging may result in short-term changes in benthic community structure in two ways. Firstly, by removal of a significant number of large epifaunal species and, secondly, by changes in scavenger and predator abundance in dredge tracks. Estimates of the numbers of by-catch species removed from commercially exploited grounds may be made by scaling by-catch data from dredging to allow for the number of commercial boats fishing the area, and the type and size of gear employed. However, even if an estimate of fishing effort could be made, the proportion of by-catch that survives after discard would be required. This is likely to vary between species and grounds (e.g. Kaiser and Spencer 1995). Hill *et al.* (1996) estimated the number of individuals of non-target species killed on commercial grounds by scallop and queen dredging around the Isle of Man. This was placed in context by considering the by-catch as a proportion of total population size. Estimates showed that scallop and queen dredge gear generally killed in the by-catch was a very small proportion of the total population of benthic species each year. For most species the number killed in the bycatch represented less than 1% of the population size in each ground. Only in the case of the edible crab *Cancer pagarus* was mortality a relatively large fraction of the total population, ranging from 0.5 to 14.1% on different grounds. It must be appreciated that by-catch records will inevitably underestimate the total numbers of species and individuals affected by demersal fishing gear since they do not include damaged fauna left on the seabed (Dare et al. 1993). This is an area which requires further investigation see Investigations Section 3.1.4.1.

Large numbers of dead or damaged animals left in the wake of a passing dredge, including those discarded from the boat on hauling, may form an important food source for mobile, scavenging species (Caddy 1968). Stomach content analysis has demonstrated the importance of dredge spoil and discards as a food source for scavengers and predators (Rauck 1989; Kaiser and Ramsay 1997). Elevated levels of predator and scavenger density have been demonstrated in tracks of conventional dredge gear (Caddy

1973; Hill et al. 1997; Bradshaw et al. 2000), hydraulic dredge gear (Meyer et al. 1981; Murawski and Serchuk 1989) and beam trawls (Kaiser and Spencer 1994; Kaiser and Spencer 1996a). For example, towed video and diver surveys of experimentally dredged plots in the Irish Sea showed increased numbers of predators and scavengers such as *Neptunea antiqua*, *Aporrhais pespelecani*, spider crabs, and *Crossaster papposus* immediately after dredging (Bradshaw et al. 2000). In addition, fixed video of by-catch-baited cameras showed a significant increase in a wide variety of predators and scavengers (e.g. *Asterias rubens*, *Astropecten irregularis*, *Cancer pagurus, Pagurus* spp., *Liocarcinus* spp;) (Bradshaw et al. 2000; Veale et al. 2000a). Localised aggregations of predator and scavenger numbers around the dredge spoil immediately after it has settled on the seabed will add to the immediate mortality resulting from the dredge impact, thus increasing the mortality of discards. Mobile epifauna are abundant on coarse substrata and may have more of an effect on dredge-impacted animals immediately after dredging than on more homogeneous fine sediments where mobile epifauna are sparser. Aggregations of scavengers and predators on dredge tracks are typically short-term. For example, (Meyer et al. 1981) observed that enhanced levels of predators in hydraulic clam dredge tracks returned to pre-dredge levels within 24 hours.

A range of studies has demonstrated clearly that scallop dredging has significant short-term effects on benthic communities. Evidence for long-term changes is less clear. One of the most effective ways of addressing this question is in areas where long-term data sets are available on fishing effort (Hill et al. 1997). In the north Irish Sea, spatially distinct fishing grounds with differing known histories of exploitation by dredging allow investigation of long-term ecological effects of fishing (Brand et al. 1991). Hill *et al.* (1997) and (Veale et al. 2000b) have shown a clear link between fishing effort and by-catch assemblage structure. Higher effort was correlated with a reduction in diversity and richness, and an increase in dominance by a few species. The hierarchy of sensitivity to dredge capture among different species, as demonstrated by a number of studies (e.g.Currie and Parry 1996; Veale et al. 2001), may lead to long-term alterations in community structure as more sensitive species are removed from the community. A surprising result of the work of Hill *et al.*, (1997) was the decline in populations of asteroids and prosobranchs with increasing fishing effort, contradicting the generally held view that scavenger populations benefit from fishing disturbance (e.g.Kaiser and Spencer 1996a). It seems likely that the frequency of dredging in the Irish Sea, even in the highest effort areas, is unable to provide a reliable or continuous enough food supply to sustain elevated populations of benthic scavengers or predators (Bradshaw et al. 2002). For example, in the Irish Sea the commercial scallop fishing fleet generally exploits grounds sequentially and will only spend, at most, a few weeks each year fishing on any one ground (Brand and Prudden 1997).

Time series data from before and after the onset of large-scale commercial fisheries provide a useful indication of the effects of fishing disturbance (Reise and Schubert 1987; Greenstreet and Hall 1996; de Vooys and van der Meer 1998; Hill et al. 1999b; Bradshaw et al. 2002). Of these, only Hill *et al.* (Hill et al. 1999b) and Bradshaw *et al.*(2002) have used this approach to determine dredging effects. An extensive dataset from the 1940s (before the onset of intensive scallop dredging) of subtidal benthic epifauna and infauna in the Irish Sea (Jones 1950, 1951, 1956) has been compared with recent data from areas known to have been subject to heavy dredging effort and areas only lightly dredged (Hill et al. 1999b). Both areas showed changes. In the heavily dredged areas some of the changes were typical of dredging impact - an increased polychaete: mollusc ratio, loss of some delicate species and an increase in scavenger/predator species. However, changes in lightly dredged areas also included loss of delicate species, which cannot be explained.

The potential of demersal fishing gear to cause long-term changes in community structure will depend on the habitat and type of community over which it is fished. For example certain habitats such as maerl beds (Hall-Spencer 1995; Hall-Spencer and Moore 2000a; Hall-Spencer and Moore 2000b) and beds of *Modiolus* spp. (Brown 1989) have been shown to be particularly sensitive to dredge disturbance. Communities adapted to frequent natural disturbance would be expected to be more resilient to repeated fishing disturbance (Kaiser and Spencer 1996b). For example, (Brylinsky et al. 1994) found no significant effects of flounder trawling in intertidal habitats, possibly because of the naturally high levels of storm and ice disturbance. Currie and Parry (1996) demonstrated changes in community structure following experimental scallop dredging but such changes were smaller than those attributable to season and year.

Studies investigating the environmental impact of dredging have demonstrated not only a change in assemblage structure but also in sediment structure (Caddy 1973) and topography (Eleftheriou and Robertson 1992). Dredging tends to make a ground harder, possibly by causing erosion of fine particles (Caddy 1973). This may increase the hard substrata available for the attachment of the fast-growing hydroids and bryozoans on which scallop and queen spat settle. Large-scale changes in sediment topography and structure caused by dredging has strong implications for long-term changes in benthic communities. It is well known that areas of heterogeneous bottom types support more diverse assemblages. Homogenisation of sediments over large areas may cause homogenisation of assemblage structure.

Recent observations by sonar system in Bay of Saint-Brieuc and comparison with previous data (middle of 1980s) showed a spectacular increase of slipper limpet (*Crepidula fornicata)* populations, probably due to towing activities. However, to date, it has not been easy to dissociate effects obtained by dredging and by trawling: results cited by Grall *et al*. (1996) indicate some differences between dredged seabeds in the Bay of Brest and the Bay of Saint-Brieuc. In the Bay of Brest, clusters of scallops and slipper limpets did not coincide. The effect is opposite in the Bay of Saint-Brieuc; clusters of scallops and slipper limpets occur together. The Bay of Brest is closed for otter trawling activities and this could explain the observed differences.

Much of the above discussion has concentrated specifically on the effects of dredges on benthic communities. However, as already pointed out, there is a range of demersal fishing techniques that produce potentially similar disturbance effects. In the Irish Sea the use of otter and beam trawls is widespread and, as with scallop dredges, they are designed to disturb the sediment surface. In a short-term experimental comparison of the effects of beam trawling and scallop dredging Kaiser *et al.,* (1996) found beam trawls caught a greater total number of taxa than scallop dredges. Scallop dredge catches contained a lower proportion of non-target species, possibly because the rigid belly rings of the dredge allows a greater proportion of the by-catch to escape than through the diamond meshes of the beam trawl cod-end (Kaiser and Spencer 1996a). Despite these observations, no difference in the community composition of fished lines between the two fishing techniques could be detected, demonstrating the similarity of disturbance caused by different fishing techniques.

Clam dredging: North Adriatic

Given the need to achieve a deeper insight into both dredge efficiency, and its effects on the benthic community, some research in recent years has been carried out along the Apulian and Venetian coasts. The object of study in the Apulian area was the *Chamelea* community located near Barletta and the Solenoidea (*Solen*) community located in the northern part of the Gargano (Vaccarella 1998). In order to observe the effects of this type of fishing, the density, biomass and diversity index were estimated before and after the passage of the dredge (for clams and razor clams), and the density in adjacent undisturbed areas was also estimated. Samplings, by SCUBA-diving with an air-lift device provided with a collecting bag, was carried out both in areas within the dredged surface and in control (not dredged) areas. This was repeated after 2, 15, and 30 days to evaluate the required time and phases of re-colonisation of the area.

The results obtained showed that the dredge collects by-catch organisms associated with the bivalve community, such as annelids, holothurians and small fish (striped bream, red mullet, common sole). These organisms undergo direct or indirect damage according to the structure and the morphology of the sediment. The more delicate organisms are destroyed, both by the dredge passage and during the sieving operation on board. Other organisms, although avoiding the catch, return to the seabed severely stressed, becoming easy prey to predator species.

In all survey stations, a progressive increase of the diversity index values in the dredged area was determined. These values tended to reach values similar to those found in the control area as time passes. In this latter area, the values found on the first day of sampling were slightly lower than those obtained during subsequent samplings, probably due to disturbance caused by the dredge passage (vibrations, noise, etc.).

The texture of the incoherent substrate undergoes alteration by the dredge passage. The depth of the furrow varies depending on dredge type (about 5cm for clam dredges and about 20cm for razor clam dredges). After a few days, the furrow is covered in a different manner in the two environments; slowly for the deeper beds with muddy sediments, (clam beds), and more quickly in the more superficial area with sandy sediments (razor clam beds).

Re-colonisation of the surface takes place mostly by annelids. The razor clam beds, which comprise fine sands, become populated by psammophile species, and therefore a greater homogeneity between species within the dredged area and those within the control area is observed. In contrast, the dredged areas on clams beds are re-colonised predominantly by limophile species, and it appears that a longer time period is necessary for the two areas (dredged and control) to return to the same faunal composition. Complete re-colonisation of the razor clam and clam beds is estimated to take approximately 30 and 60 days, respectively (Vaccarella 1998).

References for Section 5 environmental effects

Antoine L, Arzel P, Laurec A, Morize E (1979) La croissance de la coquille Saint-Jaques (*Pecten maximus* (L.)) dans les divers gisements francais. Rapport et Procès-Verbaux des Réunions. Conseil International pour l'Exploration de la mer 175: 85-90

Bergman MJN *et al.* (1990) Direct effects of beam trawl fishing on benthic fauna in the North Sea - a pilot study. In: Effects of beam trawl fishery on the bottom fauna of the North Sea. BEON-rapport, 8: 33-57 II

Black KP, G.D. P (1994) Sediment transport rates and sediment disturbance due to scallop dredging in Port Phillip Bay. Memoirs of the Queensland Museum 36: 327-341

Bourne N (1964) Scallops and the offshore fishery of the Maritimes. Bulletin of the Fisheries Research Board of Canada 145: 1-60

Bradshaw C, Veale LO, Brand AR (2002) The role of scallop-dredge disturbance in long-term changes in Irish Sea benthic communities: a re-analysis of an historical dataset. Journal of Sea Research 47: 161-184

Bradshaw C, Veale LO, Hill AS, Brand AR (2000) The effects of scallop dredging on gravelly sea-bed communities. In: Kaiser MJ, de Groot SJ (eds) Effects of Fishing on Non-Target Species and Habitats. Blackwell Science, Oxford, pp 83-104

Bradstock M, Gordon DP (1983) Coral - like bryozoan growths in Tasman Bay and their protection to conserve fish stocks. New Zealand Journal of Marine and Freshwater Research 17: 159-163

Brambati A, Fontolan G (1990) Sediment resuspension induced by clam fishing with hydraulic dredges in the Gulf of Venice (Adriatic Sea). A preliminary experimental approach. Boll. Oceanol. Teor. Appl 8: 113-121

Brand AR (2000) North Irish Sea scallop (*Pecten maximus* and *Aequipecten opercularis*) fisheries: effects of 60 years of dredging on scallop populations and the environment. Alaska Department of Fish and Game, Special Publication 14: 37-43

Brand AR, Allison EH, Murphy EJ (1991) North Irish Sea scallop fisheries: a review of changes. In: Shumway SE, Sandifer PA (eds) An international compendium of scallop biology and culture. World Aquaculture Society, World Aquaculture Society, Baton Rouge, pp 204-218

Brand AR, Paul JD, Hoogesteger JN (1980) Spat settlement of the scallops *Chlamys opercularis* (L.) and *Pecten maximus* (L.) on artificial collectors. Journal of the Marine Biological Association UK 60: 379-390

Brand AR, Prudden KL (1997) The Isle of Man scallop and queen fisheries: past, present and future. Report to Isle of Man Department of Agriculture, Fisheries and Forestry by Port Erin Marine Laboratory, University of Liverpool

Brown RA (1989) Bottom trawling in Strangford Lough: Problems and policies. 3rd North Sea Seminar.

Brylinsky M, Gibson J, Gordon DC (1994) Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. Can J Fish Aquat Sci 51: 650-661

Bullimore B (1985) An investigation into the effects of scallop dredging within the Skomer Marine Reserve, Skomer Marine Reserve Subtidal Monitoring Project: 29pp

Butcher TJ, Matthews, J., Glaister, J. and Hamer, G. (1981) Study suggests scallop dredges causing few problems in Jervis Bay. Aust. Fisheries 49: 9-12

Caddy JF (1968) Underwater observations on scallop (*Placopecten magellanicus* L.) behaviour and drag efficiency. J. Fish. Res. Board Can 25: 2123-2124

Caddy JF (1973) Underwater observations on tracks of dredges and trawls and some effects of dredging on scallop ground. Journal of Fisheries Research Board on Canada 30: 173-180

Chapman CJ, Mason J, Kinnear JAM (1977) Diving observations on the efficiency of dredges used in the Scottish fishery for the scallop, *Pecten maximus* (L.), Aberdeen

Cover P, Sterling D (1994) Scallop dredging: an engineering approach. Memoirs of the Queensland Museum 36: 343-349

Currie DR, Parry GD (1996) Effects of scallop dredging on a soft sediment community: a large-scale experimental study. Mar. Ecol. Prog. Ser 134: 131-150

Dare PJ, Darby C.D., Durance J.A. and Palmer D.W (1994) The distribution of scallops (*Pecten maximus*) in the English Channel and Celtic Sea in relation to hydrographic and substrate features affecting larval dispersal and settlement. In: Bourne, NF, Bunting, BL, Townsend, LD (eds). Proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22-27, 1993. Volume 1:20-27.

de Groot SJ, Apeldoorn J (1971) Some experiments on the influence of the beam trawl on the bottom fauna, CM 1971/B:2

de Vooys CGN, van der Meer J (1998) Changes between 1931 and 1990 in by-catches of 27 animal species from the southern North Sea. Journal of Sea Research 39: 291-298

Dupouy H (1982) Comparative study of scallop drags used in France. Can. Transl. Fish. Aquat. Sci., Transl. from French, La Pêche Maritime: 213-218

Eleftheriou A, Robertson MR (1992) The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. Neth. J. Sea Res 30: 289-299

Ferretti M, Lombardo F, Romani G (1990) Metodi di Pesca dei Molluschi Bivalvi. Vongolare tradizionali e turbo soffianti. Quaderni ICRAP Pesca , 157 pp. Ministero delle Politiche Agricole, 1998a

Fifas S (1991) Analyse et modélisation des paramètres d'exploitation du stock de coquilles Saint-Jacques (*Pecten maximus*, L.) en baie de Saint-Brieuc (Manche Ouest, France). Thèse de Doctorat, Brest

Fifas S, Boucher J. (1997) Analyse de l'impact de la pêche sur la croissance. Exemple de la population de coquilles Saint-Jacques (*Pecten maximus*, L.) de la baie de Saint-Brieuc (Manche Ouest, France). In: C.I.E.M D (ed) Working Group on Ecosystem Effects of Fishing Activities, pp 18

Fowler S (1989) Nature conservation implications of damage to the seabed by commercial fishing operations. Nature Conservancy Council.

Grall J, *et al.* (1996) Distribution of *Pecten maximus* (L.) and its main potentiel competitors and predators in the Bay of Brest. Acad. Sci. ser. 3 Sci vie/Life Sci. 319: 931-937

Greenstreet SPR, Hall SJ (1996) Fishing and the ground-fish assemblage structure in the north-western North Sea: an analysis of long-term and spatial trends. Journal of Animal Ecology 65: 577-598

Gruffydd LD (1972) Mortality of scallops on a Manx scallop bed due to fishing. J Mar Biol Ass U K 52: 449-445

Hall-Spencer J (1995) The effects of scallop dredging on maerl beds in the Firth of Clyde. Porcupine Newsletter 6: 18-21

Hall-Spencer J (1998) Conservation issues relating to maerl beds as habitats for molluscs. Journal of Conchology: 271-285
Hall-Spencer JM, Moore PG (2000a) Impact of scallop dredging on maerl grounds. In: Kaiser MJ, Groot. SJd (eds) The Effects of Fishing on Non-target Species and Habitats: Biological, Conservation, and Socio-econimic Issues. Blackwell Science, Oxford, pp 105-117
Hall-Spencer JM, Moore PG (2000b) Scallop dredging has profound, long-term impacts on maerl habitats. ICES Journal of Marine Science 57: 1407-1415
Hawkins SJ, Nash RDM, Brand AR (1991) The effects of disturbance in benthic communities: studies in an area closed to scallop dredging. University of Liverpool
Hergas C (1999) Croissance de populations de *Pecten maximus* en Bretagne : essai de qualification de l'effet de la pêche. Mémoire DEA Océan. Biol., Paris VI: 33p + figures, bibliographie, annexes
Hill AS, Brand AR, Veale LO, Hawkins SJ (1997) Assessment of the effects of scallop dredging on benthic communities. Final Report to MAFF by University of Liverpool, Contract CSA 2332
Hill AS, Brand AR, Wilson UAW, Veale LO, Hawkins SJ (1996) Estimation of by-catch composition and the numbers of by-catch animals killed annually on Manx scallop fishing grounds. In: Greenstreet SPR, Tasker ML (eds) Aquatic predators and their prey. Blackwell Scientific, Oxford, pp 111-115
Hill AS, Veale LO, Pennington D, Whyte SG, Brand AR, Hartnoll RG (1999) Changes in Irish Sea benthos: possible effects of forty years of dredging. Estuarine and Coastal Shelf Science 10.: 739-750
Houghton RG, Williams, T., Blacker, R.W. (1971) Some effects of double beam trawling. Comm Meet int Coun. Explor Sea C.M-ICES 1975/B: 5
Jamieson GS, Campbell, A. (1985) Sea scallop fishing impact on American lobsters in the Gulf of St Lawrence. Fish. Bull 83
Jones NS (1950) Marine bottom communities. Biological Review 25: 283-313
Jones NS (1951) The bottom fauna off the south of the Isle of Man. Journal of Animal Ecology 20: 132-144
Jones NS (1956) The fauna and biomass of a muddy sand deposit off Port Erin, Isle of Man. Journal of Animal Ecology 25: 217-252
Kaiser MJ, Hill AS, Ramsay K, Spencer BE, Brand AR, Veale LO, Prudden K, Rees EIS, Munday BW, Ball B, Hawkins SJ (1996) Benthic disturbance by fishing gear in the Irish Sea: a comparison of beam trawling and scallop dredging. Aquatic conservation: marine and freshwater ecosystems 6: 269-285
Kaiser MJ, Ramsay K (1997) Opportunistic feeding by dabs within areas of trawl disturbance: possible implications for increased survival. Marine Ecology Progress Series 152: 307-310
Kaiser MJ, Spencer BE (1994) Fish scavenging behaviour in recently trawled areas. Marine Ecology Progress Series 112: 41-49
Kaiser MJ, Spencer BE (1995) Survival of by-catch from a beam trawl. Marine Ecology Progress Series 126: 31-38
Kaiser MJ, Spencer BE (1996a) Behavioural responses of scavengers to beam trawl disturbance. In: Greenstreet SPR, Tasker ML (eds) Aquatic predators and their prey. Blackwell Scientific, Oxford, pp 116-123
Kaiser MJ, Spencer BE (1996b) The effects of beam-trawl disturbance on infaunal communities in different habitats. J. Anim. Ecol 65: 348-358

Kaiser MJS, B. E. (1995) Survival of by-catch from a beam trawl. Mar. Ecol. Prog. Ser 112: 41-49

Lart WJ, Dalby TM, MacMullen PH, Willerton PF (1993) Benthic and Ecosystem Impacts of Dredging for Pectinids. Commision of European Communities, Seafish CR No 71

MacDonald DS (1993) Ecological studies on the effects of scallop dredging on the benthos of the North Irish Sea. Ph.D. thesis, University of Liverpool

Medcof J, Bourne N (1964) Causes of mortality of the sea scallop *Placopecten magellanicus*. Proc. Natl. Shell. Assoc 53: 33-50

Medcof J, Caddy, J. F. (1971) Underwater observations on performance of clam dredges of three types. ICES C.M. 1971/B:10: 7 pp

Meyer TL, Cooper RA, J PK (1981) The performance and environmental effects of a hydraulic clam dredge. Mar Fish Rev 43: 14-22

Munro C (1992) An investigation into the effects of scallop dredging in Lyme Bay. Devon Wildlife Trust

Murawski SA, Serchuk FM (1989) Environmental effects of offshore dredge fisheries for bivalves. International Council for the Exploration of the Seas, ICES CM 1989/K:27, Copenhagen, Denmark

Naidu KS (1988) Estimating mortality rates in the Iceland scallop, *Chlamys islandica* (O.F. Muller). J. Shell. Res 7: 61-71

Niven RK, Khalili N (1998) In situ fluidisation by a single internal vertical jet. Journal of Hydraulic Research 36: 199-228

Rajaratnam N, Aderibigbe O, Pochylko D (1995) Erosion of sand beds by oblique plane water jets. Proceedings of the Instutute of Civil Engineers, Water, Maritime and Energy 112: 31-38

Ramsay K, Kaiser, M. J. (1998) Demersal fishing disturbance increases predation risk for whelks (B*uccinum undatum* L.). J. Sea. Res 39: 299-304

Rauck G (1989) What are the effects of bottom trawls on sea-bottom and zoobenthos?. Fischerblatt 37: 155-158

Reise K, Schubert A (1987) Macrobenthic turnover in the subtidal Wadden Sea: The Norderaue revisited after 60 years. Helgol Meeresunters 41: 69-82

Sheader M (1986) The effects of intensive dredging on benthic community structure. Nature Conservancy Council.

Shepard AN, Auster PJ (1991) Incidental (non-capture) damage to scallops caused by dragging on rock and sand substrates. In: Shumway SE, Sandifer PA (eds) An international compendium of scallop biology and culture. World Aquaculture Society, Baton Rouge, pp 219-230

Stevens PM (1987) Response of excised gill tissue from the New Zealand scallop *Pecten* novaezelandiae to suspended silt. New Zealand J Mar Freshwat Res 21: 605-614

Thrush SF, Hewitt, J. E., Cummings, V. J., Dayton, P. K., (1995) The impact of habitat disturbance by scallop dredging on marine benthic communities: What can be predicted from the results of experiments? Mar. Ecol. Prog. Ser 129: 141-150

Vaccarella R, Pastorelli, AM. Marano, G (1998) Studio sulla efficienza delle draghe turbosoffianti e loro effetti sulle comunità bentoniche. Biologia Marina Mediterranea 5: 676-683

Veale LO, Hill AS, Brand AR (2000a) An in situ study of predator aggregations on scallop (*Pecten maximus* (L.)) dredge discards using a static time-lapse camera system. Journal of Experimental Marine Biology and Ecology 255: 111-129

Veale LO, Hill AS, Hawkins SJ, Brand AR (2000b) Effects of long-term physical disturbance by commercial scallop fishing on subtidal sedimentary habitats and epifaunal assemblages. Marine Biology 137: 325-337

Veale LO, Hill AS, Hawkins SJ, Brand AR (2001) Distribution and damage to the by-catch assemblages of the northern Irish Sea scallop dredge fisheries. J Mar Biol Ass UK 81: 85-96

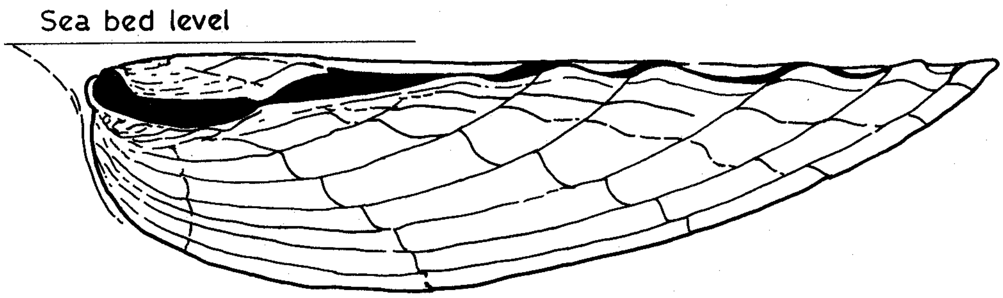
6 SELECTIVITY

Currently in UK waters there are no selectivity parameters set for dredges targeting *P. maximus* and there is a potential conflict of interest with queenie fisheries which require a smaller ring size. This part of the review examines current information on dredge selectivity both in terms of species and size and selectivity.

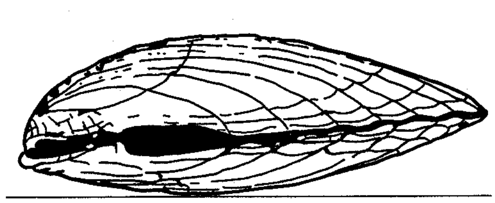
At present, the only study concerning selectivity of the Portuguese dredge was conducted by Gaspar et al. (1999). The authors investigated the effects of mesh size and tooth spacing for both the clam and razor clam dredges. These results were obtained in a limited geographical area and limited gear types. Further work is required with other gear types and species most notably in the northern fisheries.

6.1 Species selection

Features of scallop behaviour that could be exploited by gear designed to improve selectivity are associated mainly with habitat preference and mobility, especially in response to fishing gear.



Pecten maximus



Aequipecten opercularis

Figure 6-1. Seabed position of both species After Rolfe (1973)

Both *Pecten maximus and Aequipecten opercularis,* are bottom dwellers but assume different positions within the substrate, Figure 6-1. *P. maximus* exhibits burying behaviour and is found usually recessed into the seabed, with the upper flat shell level with the substrate, (large animals recess more deeply than small animals), whereas, *A. opercularis* lie on the seabed surface with the more curved shell uppermost.

When resting both species (*P. maximus* to a lesser degree) tend to orientate themselves against the direction of the tide and tend to swim in the direction that they are facing (Chapman et al. 1979). Thus, gear towed with the tide might be expected to produce higher catches as animals would tend to swim towards the gear.

The scallop's behavioural reactions to fishing gear are important considerations in designing and using fishing equipment. When encountering otter trawls *A. opercularis* reacts first to the otter boards, either by swimming over the boards or into the path of the net (Chapman et al. 1979) with a few animals escaping over the headline. By the time animals reach the fishing line most have produced several short bursts of swimming. They may fail to respond to the groundrope (presumably due to exhaustion) and thus can pass under the fishing line. Catches can be increased by adding devices that induce animals to swim, e.g a tickler chain.

A. opercularis response to dredging gear is variable, depending on dredge size and ground type. Heavy dredges used on hard ground often evoke mass swimming, with many animals escaping laterally or over the dredge 'headline'. In contrast, few animals have been reported escaping from the path of small light dredges with low headline height (15cm) used on soft sediments.. These observations suggest that high headline height is not always more efficient and may increase the shock wave in front of the gear and so give additional warning. Similarly, vibrations set up by heavy gear, especially on hard ground, may alert animals. To minimise disturbance short warps and fast towing speeds are often used to maintain warp and bridles off the bottom (Rolfe 1973).

Seasonality

Chapman et al. (1977) describe swimming behaviour in queen scallop *A. opercularis*. An important consideration in evaluating *A. opercularis'* swimming response to fishing gear is the influence of seasonality since activity is reported to be greatest during the spring/summer period. At other times of the year, swimming activity might be reduced or non-existent/negligible. The swimming speed and endurance of *A. opercularis* also are limited, with animals typically able to cover up to six metres in five or six swimming bursts before exhaustion. However, animals gain height usually only during the first two or three swimming bursts, thereafter moving only short distances without leaving the seabed. Height gained and distances moved are unaffected by the size of animal but are greatly reduced by encrusting organisms which increase weight and drag. Heavily encrusted animals often fail to swim even after repeated tactile stimulation.

P. maximus exhibits less dramatic behaviour. In response to sprung dredges operated on hard sandy/stony ground large scallops often fail to react and either escape between the teeth or are pushed aside or caught (Chapman et al. 1977). Small scallops, less than 90mm, often swim sideways out of the dredge's path but remain close (2-5cm) to the seabed. Most uncaught scallops remaining in the path of a dredge tend to be unrecessed, and exhibit signs of shell damage. In contrast, those that pass between the teeth remain recessed and suffer less damage and mortality (Chapman et al. 1977).

Avoidance and swimming reactions of both species are probably mediated through eyes that can respond to moving shadows, or via organs that detect vibration or pressure changes. The importance of vision in reacting to trawl gear is indicated by the fact that catches of *A. opercularis* by day generally exceed those at night when animals cannot see.

Differences in swimming behaviour might be influenced by density in that mass swimming in response to visual stimuli requires a minimal distance between animals. While *A. opercularis* often occur in dense aggregations it is likely that the low densities encountered on fishing grounds would prevent such behaviour occurring in *P. maximus.*

6.2 Size selection

Minimum Legal Landing Size

Setting of the Minimum Legal Landing Size (MLLS) of scallops is an important management tool that has implications for the sustainability of the fishery. The MLLS is set at an appropriate level to maximise the yield per recruit from the fishery. It is adjusted according to the growth of scallops in different areas. In the Irish Sea and eastern Channel (ICES area VIIa) the MLLS is set at 110mm whilst the general MLLS set by the EU is lower at 100mm.

The age at which scallops reach the MLLS of 110mm in the north Irish Sea varies owing to differences in growth rate among fishing grounds. It can vary from 3-7 years on different grounds (Brand and Prudden 1997). In Isle of Man waters, scallops spawn for the first time when about two years old (Mason 1958a). Thus, the MLLS of 110mm shell length in the Irish Sea ensures that scallops on most fishing grounds spawn at least twice before entering the fishery. The latest evidence from a number of studies in the Irish Sea suggests that the scallop stocks on the major fishing grounds may be largely self sustaining. Thus, maintenance of high local levels of spawning is vital to maintenance of the fishery. A higher level of MLLS may also affect local recruitment levels since fecundity of scallops increases with size.

Fixed tooth dredges

Fifas and Berthou (1999) presented a mathematical analysis and formulation for selectivity for experimental scallop dredges with dive vane. Dupouy (1982) compared selectivity and efficiency of dredges without and with depressor plate: this author found that adding a depressor plate modifies the deviation of selection of dredges giving sharper selection. The same author cited a value of 35% for efficiency for dredges equipped with depressor plate and 20 % without this equipment (at present, values of 80 % and 36 % are observed).

In general trends, selectivity and efficiency of French dredges can be described by logistical curves (Table 6-1, Figure 6-2 and Figure 6-3) expressing size-selectivity of fishing gears and fitted by different algorithms (maximum likelihood model: Millar (1991); multinomial likelihood method: Perez-Comas (1996). Deviation of selection and length at 50% selection seem be linear functions of mesh size.

Table 6-1 Fitting of logistical curves for selectivity of dredges with depressor plate (from Labbé 1983 ; Fifas 1991).

$$y(l) = \frac{1}{1 + \exp(-\alpha.(l - L_{50}))}$$

Mesh size (mm)	71	82	93	105
Estimation of α	1.094	0.342	0.239	0.285
L_{50} : size (height mm)	71.0	79.7	88.5	98.9
Market size (height mm)	81.5	91.7	102.1	114.5
Factor of selection	1.00	1.03	1.05	1.06
Deviation of selection (mm)	2.01	6.42	9.20	7.71

factor of selection : $Lmesh/L_{50}$

deviation of selection : $L_{75}-L_{25} = -2.\ln(3)/\alpha$

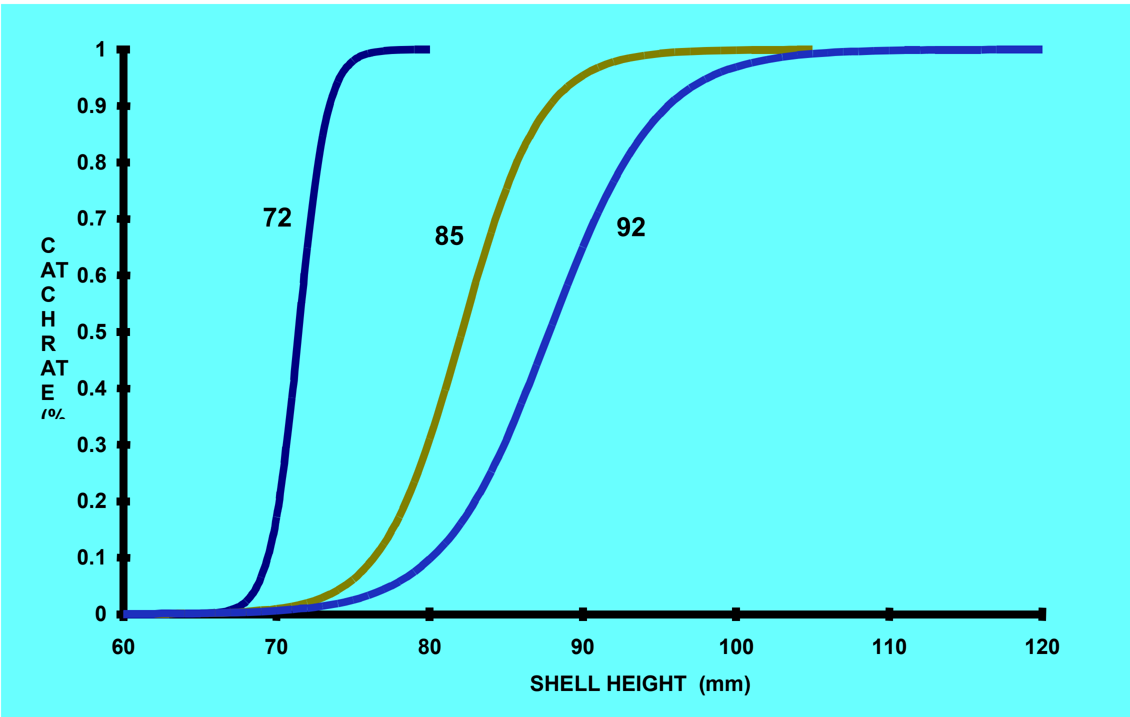


Figure 6-2: Dredge with depressor plate. Selectivity curves for different mesh sizes (in mm) (from IFREMER DRV/RH).

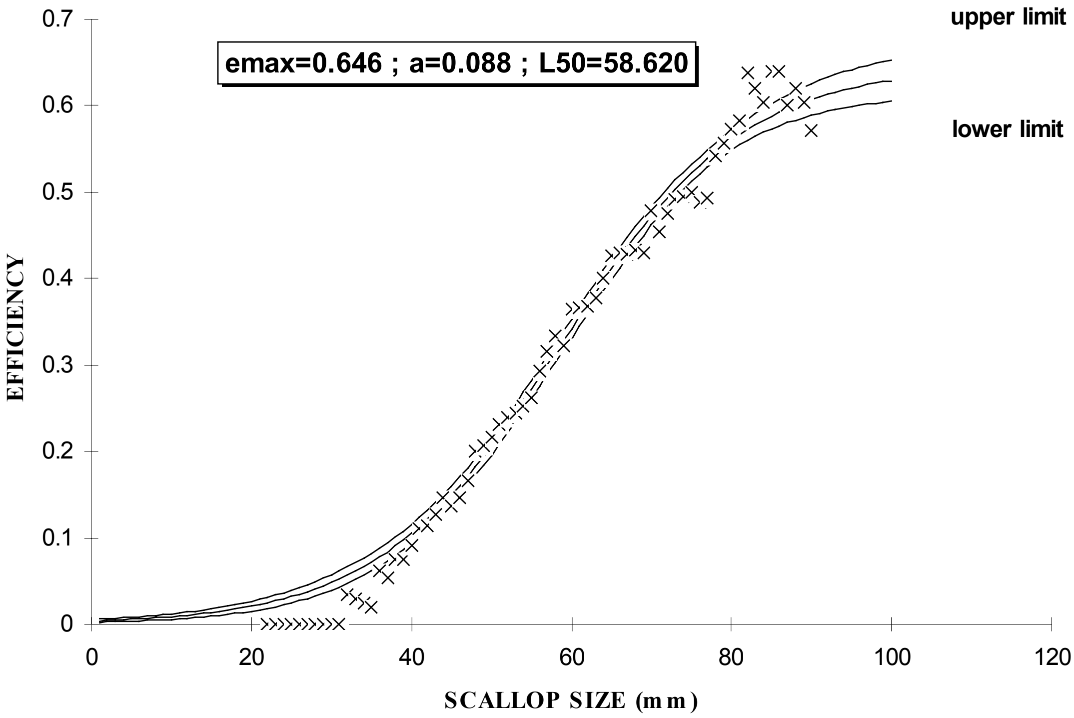


Figure 6-3. Fitted efficiency model of an experimental scallop dredge with depressor plate (*in* Fifas and Berthou 1999; mean confidence intervals are plotted with confidence level of 0.95).

Spring tooth dredges

Selectivity and efficiency of spring tooth scallop dredges has been studied by a number of workers (Scottish waters; Mason et al. 1979; Lart et al. 1997, Western English Channel: Dare and Palmer 1994). In the case of spring-toothed dredges, Dare et al. (1993) described a two-stage selection and retention process; by toothed bar and chained mail rings meshes. Lart et al. (1997) showed that both these factors could affect selectivity but not the mesh backs of the dredges.

Spring-tooth dredge selectivity may be more complex than fixed tooth dredges. It is probable that a component of avoiding reaction must be added in function because of behaviour of fishing gears on a rough seabed. This avoiding reaction may be only passive and may be done by cracking of scallop valves caused by the disturbance of sea bed by dredging. The avoiding additive function seems decrease against scallop size (Figure 6-4; Mason et al. 1979).

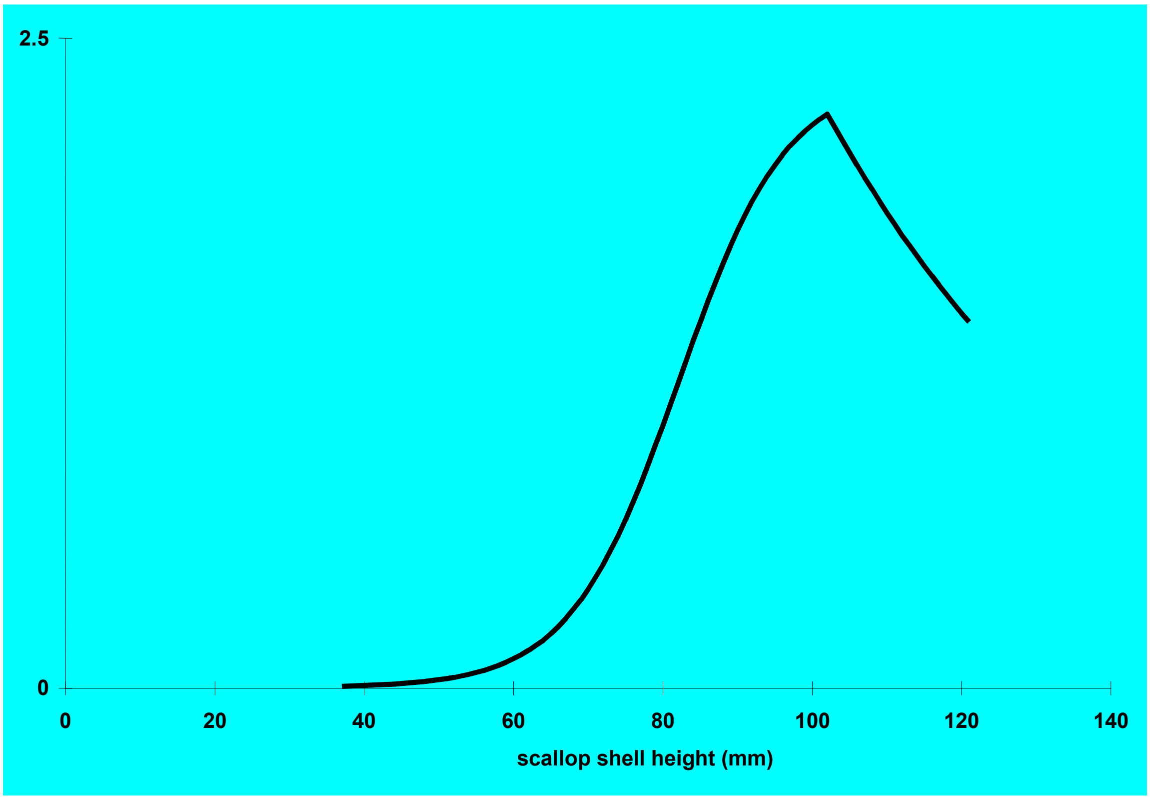


Figure 6-4 : Theorical efficiency curve of spring-toothed dredge (from S. Fifas IFREMER).

References for Section 6 Selectivity

Brand, A. R. and K. L. Prudden (1997). The Isle of Man scallop and queen fisheries: past, present and future Report to Isle of Man Department of Agriculture, Fisheries and Forestry by Port Erin Marine Laboratory, University of Liverpool 101 pp

Chapman, C. J., J. Main, T. Howell and G. I. Sangster (1979). The swimming speed and endurance of the queen scallop *Chlamys opercularis* in relation to trawling. Progress in Underwater Science: 57-72 (new series).

Chapman, C. J., J. Mason and J. A. M. Kinnear (1977). Diving observations on the efficiency of dredges used in the Scottish fishery for the scallop, *Pecten maximus* (L.) Marine Laboratory: Scottish Fisheries Research Report 1016 pp

Dare, P. J., D. Key, C. D. Darby and P. M. Connor (1993). The efficiency of spring-loaded dredges used in the western English Channel fishery for scallops, *Pecten maximus* (L.) ICES CM1993/B:15

Dare, P. J. and D. W. Palmer (1994). The use of dredge efficiency factors for estimating indirectly population composition and abundance of scallops, *Pecten maximus* (L.). 9th Int. Pectinid Workshop, Nanaimo, BC (Canada).

Dupouy, H. (1982). Comparative study of scallop drags used in France. Can. Transl. Fish. Aquat. Sci., Transl. from French, La Pêche Maritime: 213-218.

Fifas, S. (1991). Analyse et modélisation des paramètres d'exploitation du stock de coquilles Saint-Jacques (*Pecten maximus*, L.) en baie de Saint-Brieuc (Manche Ouest, France). Brest, d'Université, IFREMER/UBO**:** 422 p.

Fifas, S. and P. Berthou (1999). An efficiency model of a scallop (*Pecten maximus*, L.) experimental dredge: Sensitivity study. ICES Journal of Marine Science 56: 489-499.

Gaspar, M. B., M. Castro and C. C. Monteiro (1999). Effect of tooth spacing and mesh size on the catch of the Portuguese clam and razor clam dredge. ICES Journal of Marine Science 56: 103-110.

Labbé (1983). Contribution à l'étude de la dynamique d'exploitation du stock de coquilles Saint-Jacques (*Pecten maximus*) en baie de Saint-Brieuc; DEA Océan. Biol Univ Pierre et Marie Curie 30 p + annexes

Lart, W., R. Horton and R. Campbell (1997). Scallop dredge selectivity contribution of the tooth spacing, mesh and ring size; Part I. West of Scotland sea trials Sea Fish Industry Authority Seafish Report SR50956p

Mason, J. (1958a). The breeding of the scallop, *Pecten maximus*, in Manx waters. Journal of the Marine Biological Association of the United Kingdom 37: 653-671.

Mason, J., C. J. Chapman and J. A. M. Kinnear (1979). Population abundance and dredge efficiency studies on the scallop, *Pecten maximus* (L.). In : Population assessment of shellfish stocks. 175.

Millar, R. B. (1991). Estimating the size-selectivity of fishing gear by conditioning on the toal catch : The SELECT (Share Each Lengthclass's Catch Tota) model. Counc. Meet. of the Int. Counc. for Expl. of the Sea, La Rochelle (France), ICES-CM-1991/B 57: 21p.

Perez-Comas, J. A., Skalski J.R. (1996). A parametric multinomial model for size selection in alternate-haul experiments. Fisheries Research 27(1-3): 113-129.

Rolfe, M. S. (1973). Notes on queen scallops and how to catch them. Shellfish Information Leaflet 27. Ministry of Agriculture Fisheries and Food