The Molluscan Fisheries of Germany*

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ABSTRACT

The German molluscan fishery has always concentrated on the North Sea. Mollusks occur in the Baltic Sea, but are not as marketable. In prehistory and the Middle Ages, coastal inhabitants gathered mussels, *Mytilus edulis*, cockles, *Cerastoderma edule*, and flat oysters, *Ostrea edulis*, for food and also used mussels as agricultural fertilizer. An organized oyster fishery developed in the 16th century and had considerable economic importance for 300 years. Oysters were dredged with sailing vessels near the coast, as well as far offshore. Catches peaked in the second half of the 19th century at 3–5 million oysters per year. They declined dramatically in the following decades due to permanent recruitment failures, and the flat oyster finally disappeared from the German coast in the 1950's. An organized fishery for freshwater pearl mussels, *Margaritifera margaritifera*, also developed at the end of the Middle Ages, but mismanagement and environmental degradation since the late 19th century have brought this species to the brink of extinction as well. Other mollusks harvested on a smaller scale in the past have been softshell clams, *Mya arenaria*, and whelks, *Buccinum undatum*. The modern mussel fishery for human food began in 1929 with the introduction of novel dredging methods. Annual catches were in the order of a few thousand tons during the first half of this century and have attained 20,000–60,000 tons since the early 1980's; concomitantly, prices have increased five-fold in recent decades. The fishery is now based on 14 highly specialized vessels harvesting from 3,800 ha (9,500 acres) of culture plots which are seeded with mussels from natural beds. Pacific oysters, *Crassostrea gigas*, were first introduced in the 1970's, and a natural population has recently begun to establish itself. They are cultured by one company which imports half-grown seed from the British Isles. A nearshore hydraulic dredge fishery for cockles began in 1973, but was banned for political reasons in 1992. It was replaced by a new offshore fishery for hard clams, *Spisula solida*, which ended when the clam stock suffered total mortality in the 1995–96 ice winter. The molluscan fisheries and aquaculture sector (production and processing) in 1995 employed almost 100 people year-round and another 50–100 seasonally. The annual product is about US$35 million.

Introduction

Germany has about 2,000 km of coast (about half on the North Sea and half on the Baltic); the German molluscan fishery, however, has always been concentrated in the North Sea sector (Fig. 1). Shellfish consumption was of only local importance until the 20th century. Modern processing and marketing now make fish and shellfish available throughout the country, and per capita seafood consumption is slowly increasing. It has

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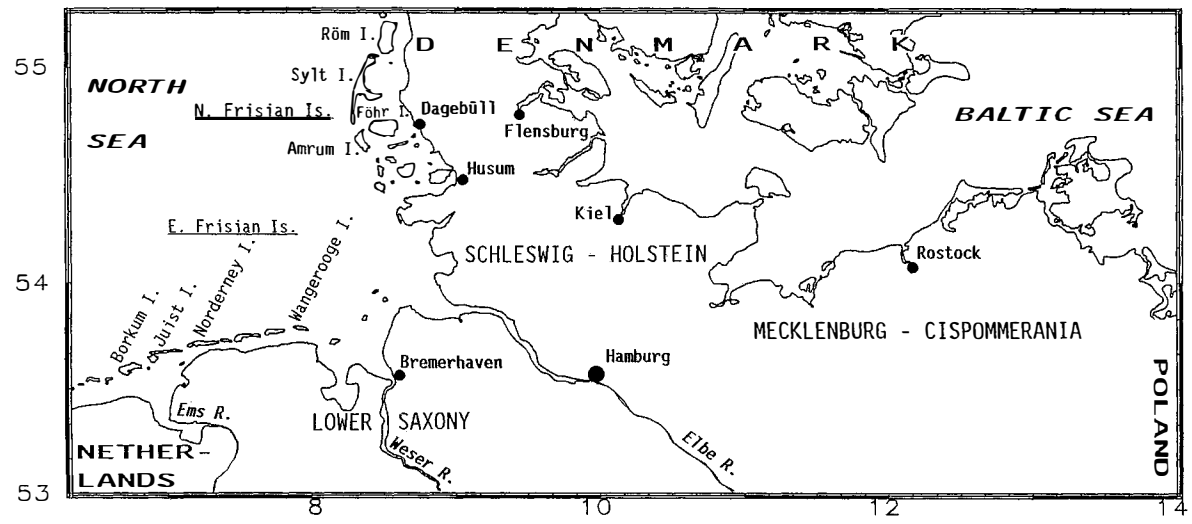

Figure 1
The German coast: Molluscan fisheries have always been based on the North Sea sector.

attained 14 kg per year (twice as much as in the U.S., but only one-tenth that of Japan), 20% of which is shellfish.

The Wadden Sea

The German North Sea coast is characterized by 5,000 km^2 of tidal flats and channels, which are largely protected by island chains and interrupted by the Weser and Elbe estuaries. This shallow coastal area (Fig. 2), termed the Wadden Sea, extends up to 30 km off the mainland shore. There are two daily tides, with average amplitudes between 1.7 m on the open coast and 3.5 m in inlets; current speeds may surpass 3 m/second in the tidal channels, and 1 m/second on the flats. Storms are frequent. The turbidity of the water is very high, and particulate inorganic matter levels may attain several grams per liter. The grain size of the bottom sediments varies from 2 mm (coarse sand) to 0.002 mm (clay), depending on local current and wave action.

The Wadden Sea is subject to extreme environmental fluctuations. The average salinity is around 30‰, but the effects of evaporation and precipitation are often very important; annual fluctuations from 20° to 34‰ are common, and short-term variability is from 0 to 40‰. Water temperatures are around the freezing point in winter and may be more than 20°C in the summer; on the tidal flats, the daily temperature variation at the surface of the substrate may be more than 30°C, and more than 60°C in the course of the year. Periodic winter ice conditions may almost wipe out the macrofauna on the tidal flats, but the populations generally recover in the following spring and summer (Wolff, 1983; Reise, 1985; Beukema, 1989).

The vegetation consists mainly of *Spartina, Zostera, Enteromorpha, Ulva,* and *Fucus* species. The benthic macrofauna consists of relatively few particularly adapted species, but these may be present in enormous numbers. Bivalves account for more than two-thirds of the Wadden Sea biomass. According to Wolff (1983), the most important are blue mussels, *Mytilus edulis* (23% of the biomass in ash-free dry weight); softshell clams, *Mya arenaria* (17%); cockles, *Cerastoderma edule* (16%); and *Macoma balthica* (8%). These biomass values are subject to great fluctuations from one year to another (Asmus, 1987; Beukema, 1989; Obert and Michaelis, 1991).

Except in the case of blue mussels, there are no recent large-scale surveys of the German bivalve stocks; we estimate that the predominant species at present are the Atlantic jackknife clam, *Ensis directus* (introduced from America in the late 1970's; Essink, 1986); the hard clam, *Spisula solida* (in deeper waters seaward of the Wadden Sea); *Mytilus edulis;* and *Cerastoderma edule,* in that order. The larvae of *Ensis* are by far the most abundant in the plankton (Pulfrich, 1995). All of these bivalves are burrowers, except for blue mussels, which form dense natural beds in which the individuals attach to each other by their byssus threads; although the mussels make up 20–70% of the biomass in many areas, they occupy only 1% of the space. The once very com-

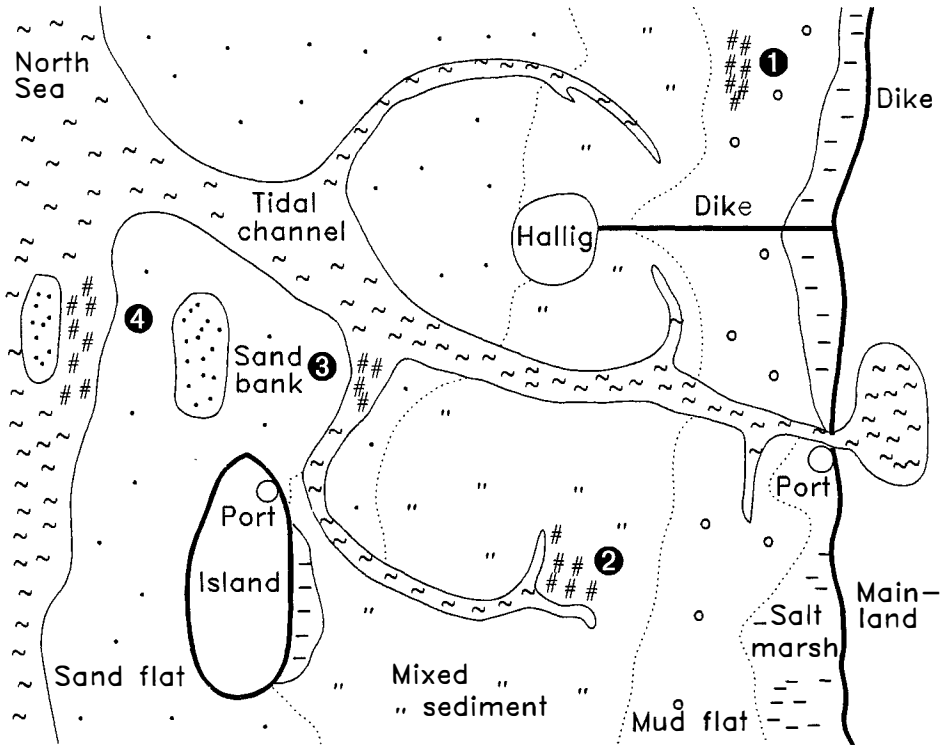

Figure 2
Diagram of the Wadden Sea coastal area: # are mussel aggregations (1 = wild bed, high intertidal; 2 = wild bed, low intertidal; 3 = culture plot; 4 = wild bed, subtidal). A "hallig" is a small island not protected by a dike.

mon flat oyster, *Ostrea edulis*, vanished from the German coast in the 1950's. The most important gastropods are whelks, *Buccinum undatum*; periwinkles, *Littorina* spp.; and *Hydrobia* spp.

The adult mollusks are preyed upon by large numbers of birds, mainly eider ducks, *Somateria mollissima*; seagulls, *Larus* spp.; and oystercatchers, *Haematopus ostralegus*. Mussels are also consumed by starfish, *Asterias rubens*. Bivalve spat and juveniles are taken by shore crabs, *Carcinus maenas*; brown shrimps, *Crangon* spp.; and by fishes (mainly plaice, *Pleuronectes platessa*) (Wolff, 1983; Reise, 1985, 1992; Michaelis, 1992; Nehls and Ruth, 1994a, b).

The Western Baltic Sea

In the Baltic Sea, tides and currents are negligible, and the water attains depths of more than 10 m very close to shore. Bottom sediments are mainly fine sand and silt. Environmental conditions are more stable than in the Wadden Sea, except for marked seasonal fluctuations in salinity, with surface values from 15 to 23‰ at Flensburg Fjord, and 8–17‰ off the coast of Mecklenburg; bottom water salinities are about 10‰ higher. Annual temperature fluctuations are between 0°C and 20°C (Siedler and Hatje, 1974). Oxygen deficiency in the bottom water has become an increasing problem in recent years (Weigelt and Rumohr, 1986).

The brackish character of the Baltic Sea reduces the number of species, and there is also a reduction in benthic biomass with decreasing salinity. Bivalves generally account for 90% or more of the benthic biomass off the German coast. The main bivalve is the quahog, *Arctica islandica*, with local densities of 100–500 g/m^2 fresh weight; other important bivalves are *Abra alba*, *Macoma balthica*, *Astarte borealis*, *Cerastoderma* spp., and *M. edulis*. The low salinities in the inner Baltic cause stunted growth, sterility, and brittle shells in many species; on the other hand, many shallow-water species are also found at greater depths where the salinity is higher (e.g. mussels at 100 m). The main predators of bivalves are fishes, such as cod, *Gadus morrhua*, and flatfishes (Arntz, 1978; Theede, 1981).

History of the German Molluscan Fisheries

Large piles of molluscan shells have been found associated with Stone and Iron Age and Viking settlements. The most common shells found in Iron Age kitchen middens are those of blue mussels, *Mytilus edulis*, and cockles, *Cerastoderma edule*; other bivalves (mostly flat oysters, *Ostrea edulis*), and gastropods (mostly periwinkles, *Littorina littorea*) were consumed less often (Harck, 1973). Canute the Great, King of England, Denmark and Norway, reportedly had oysters brought from England to the West Coast of Schleswig in the first half of the 11th century A.D.; artificial oyster beds are also said to have been established during his reign (Müller, 1938; Arnold, 1939). Since the 13th century, the North Frisians brought their produce, fish, and oysters by boat to the market in Hamburg (Hansen, 1877).

Reliable descriptions of the prehistoric and medieval fisheries, however, are lacking. Coastal inhabitants gathered mussels and oysters for private consumption, and mussels and brown algae were also used as agricultural fertilizer. The mollusks were presumably collected by hand, rake, or fork on the extensive tidal flats at low tide and transported to the shore, either on small boats or with mud sledges drawn across the flats. There were attempts to reserve oyster consumption for noblemen, but poaching was common. There are no indications of trade or transport inland, and molluscan consumption was probably limited to the coastal zone.

Traditional Flat Oyster Fishery

A systematically organized German oyster fishery first developed off the islands of Sylt and Föhr on the west coast of Schleswig-Holstein in the 16th century. The region was still under Danish overlordship at the time, and the first historical record is a decree by the Danish King Frederick II, dated 4 February 1587, in which the harvesting of oysters without permission is placed under punishment in order to protect the stocks from overfishing. The oyster fishery, reviewed by Schnakenbeck (1928, 1953), Müller (1938), and Neudecker (1990), became an important economic activity in the 17th century, even leading to military skirmishes between German and Danish, and between German and Dutch fishermen, as well as among German fishermen from different islands. Swedish merchant ships repeatedly robbed North Frisian fishermen of their catch in the Elbe estuary, as they were sailing to market in Hamburg, temporarily bringing the oyster fishery to a halt in the 17th century (Hansen, 1877). In the 18th century the stock off the shore of Wangerooge in Lower Saxony was protected against poachers by the installation on the dike of four cannon and a gallows (Linke and Rüthning, 1937).

The oysters were fished with single-masted sailing vessels and iron dredges (Fig. 3, 4); this method had probably been used since the 13th century, but it was not until the 17th century that priests began to teach mathematics and navigation to the fishermen. Considering the frequently gusty winds and choppy seas, as well as shifting shoals and treacherous tidal currents in the Wadden Sea, the oyster fishery must have demanded extraordinary skill. According to parish chronicles, it also claimed many a fisherman's life. Conditions on the coast were generally harsh, and storm floods often killed thousands of people, sometimes depopulating entire islands.

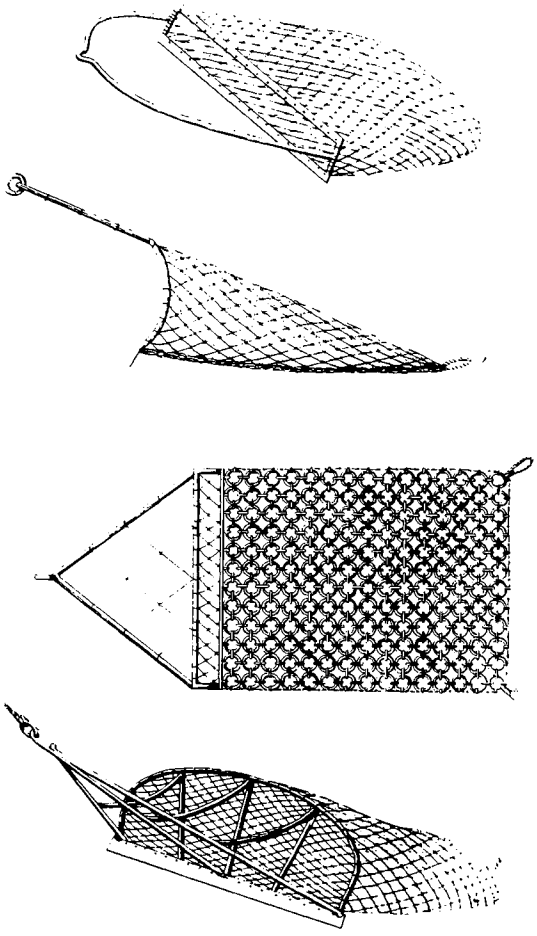

Figure 3
Early 19th century iron dredges used in the oyster fishery (after Kroyer, 1837; from Neudecker, 1990).

The Schleswig-Holstein oyster fishery was economically more important than that off Lower Saxony, and has consequently been described in better detail. The King of Denmark began leasing the beds of Schleswig-Holstein in 1627; the entire lease was held by one person (generally a wealthy merchant or a company) for several years. More than 100 fishermen from the islands of Rømø, Sylt, and Amrum, working on about 30 boats, were employed by the leaseholders, but due to natural constraints (such as tides and weather conditions), the oyster fishery probably offered employment for no more than 40 days per year; at other times, the men would engage in other seagoing activities (ranging, for instance, from acts of piracy to whaling in the Arctic Ocean), or they might tend to their land plots.

Crisis and Management of the Fishery—The price for the lease of the oyster beds in Schleswig-Holstein increased continuously from 60 Reichsthaler (Rtr.) in 1627 to 6,000 Rtr. in 1728 (at the time, 1 Rtr. probably corresponded to the weekly income of a worker, so that the 18th century price of the lease would be more than US$3 million in present terms); in addition, the leaseholders had to deliver several tons of oysters free of charge to the royal court in Copenhagen and to local noblemen every year. This created a financial pressure on the leaseholders that led to overexploitation.

Destruction of oyster beds by overfishing and ice winters was a constant problem since the end of the 17th century, and systematic management began in 1703 with the closure of the beds for 3 years. From 1709 on, overfishing, fishing during the reproductive season (May–August), and the sale of undersized oysters (less than 7 cm in diameter) were forbidden. Regular inspections of the oyster beds by government officials became the rule, and in the 18th century the position of royal superintendent of the oyster fishery became a highly respected and lucrative office (Müller, 1938).

As in Roman times, the oysters were eaten raw on the half-shell; they were reputed to have medicinal properties, but the ill effects of consuming raw oysters which had been stored out of water for too long were also well known (Anonymous, 1731). Most of the catch was marketed in Hamburg, and oysters were sometimes shipped

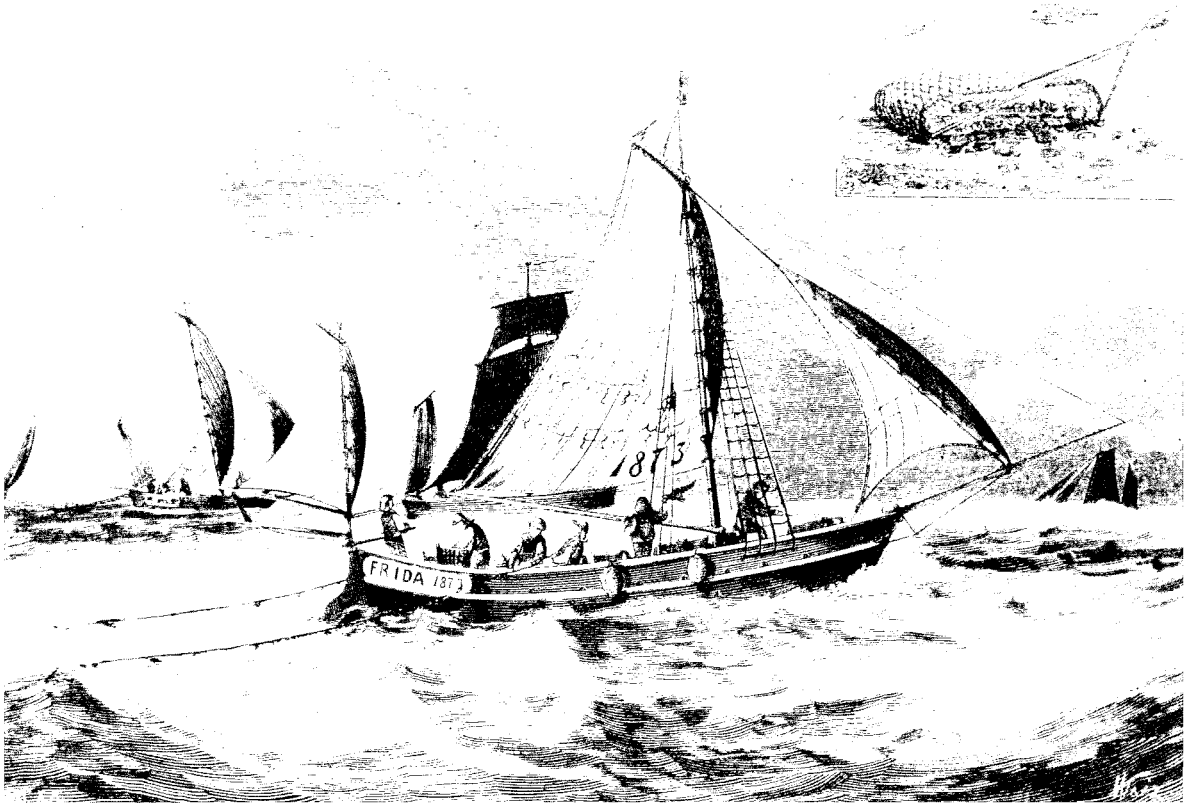

Figure 4
19th century oyster cutter from Sylt Island. The boat is towing two dredges; the inset (upper right) shows a typical dredge (Engraving by R. Weix; copyright by Altonaer Museum, Hamburg).

as far as Hungary and Russia. The increasing market demand was met by the import of cheaper oysters from England and the Netherlands; when landings from the Wadden Sea were high, the market price in Hamburg would drop by 75% in the course of one day, and the leaseholders often lost money on the venture.

After a severe ice winter nearly wiped out the stock in 1829–30, the fishery took 25 years to recover. Fishermen from Hamburg and the Netherlands attempted to exploit deep-water stocks off the coast of Schleswig-Holstein, but the activity proved too difficult at the time, and the oysters were too poor in quality, to be economically feasible. There were attempts to introduce oysters to Mecklenburg and Pomerania in the Baltic in 1753, 1830, and 1843, but the oysters quickly died in the low salinity (Möbius, 1887). The difficulties of the Schleswig-Holstein fishery also led to increased exploitation of the oyster stocks in Lower Saxony, and the fishery off Juist and Borkum yielded almost 200,000 oysters yearly from 1841 to 1846; it collapsed in the 1850's because of overfishing and silt deposition on the oyster beds (Linke and Rüthning, 1937).

From 1859 on, 40,000 oysters were relayed every year to repopulate the beds in Schleswig-Holstein. The market price in Hamburg tripled between 1860 and 1875 from M35 to M105/100 kg (at that time, M4 equaled US$1; Dean, 1893). This provided an incentive for overexploitation again, and production peaked in the 1860's at 4–5 million oysters per year. After Schleswig-Holstein came under Prussian control, the new authorities conducted a survey of the fishery in 1868 (Müller, 1938). The oyster fishery employed 60 fishermen from Sylt and Amrum, working on 23 boats, plus several artisans and the crew of a transport steamer. Harvested oysters were taken directly to the market in Hamburg or stocked in the port of Husum in four saltwater ponds with a storage capacity of 150,000–400,000 oysters. In 1878–80, 52 oyster beds were known (more than twice as many as in 1724), varying from 1 to 242 ha (2.5–598 acres) in size, and their total surface was 1,785 ha (4,410 acres).

Decline of the Wadden Sea Oyster Stock and Fishery on Deep-water Stocks—In the 1870's the annual catch from the Wadden Sea fluctuated between 1.2 and 3.2 million oysters, but the stocks suffered increasing recruitment problems, forcing a closure of the beds from 1882 to 1891. The stock, however, did not recover, and landings in Schleswig-Holstein decreased from 1 million oysters per year in the early 1890's to about 300,000 in 1910 (Müller, 1938), with consequent price increases. The fishery in Lower Saxony no longer existed and a deep-water stock off Heligoland Island collapsed in 1882.

The market supply was maintained by a wintertime fishery on the oyster stocks of the outer German Bight, located 100–150 n.mi. offshore in 40 m of water. This fishery lasted from 1885 until 1914 and was based on the port of Finkenwerder near Hamburg (Schnakenbeck, 1928; Broelmann and Weski, 1992). The initial landings were 3 or 4 million oysters per year, and roughly 1 million per year from the mid–1890's until the beginning of World War I (estimated after Ehrenbaum, 1892, and Anonymous, 1913). The overall annual catch, however, must have been much higher (possibly close to 10 million oysters), because the same stocks were sometimes exploited by other German, Dutch and English fishermen, including motorized vessels catching demersal fishes (with oysters as bycatch).

The boats from Finkenwerder were two-masted ketch-rigged smacks and cutters (Fig. 5) 20 m in length, with crews of three. The oysters were caught with 26-ft (8 m) beam trawls (and with British-type otter trawls after 1903) whose netting was reinforced with coconut fiber. The fishing season was from November to March; a single trip generally lasted 2 weeks, but under adverse conditions the men were sometimes forced to stay at sea as long as 4 weeks. The oysters were landed at Cuxhaven, where they sold for M4 (US$1) per hundred. When winds were foul, however, the men might sail to the Netherlands, Denmark or England to sell the catch, and then return directly to the oyster grounds.

Until the 1880's the fishermen of Finkenwerder, a port with 100–200 boats at the time, had been content catching flatfish near the coast from March to November, laying up the boats in winter. At the end of the 19th century, however, the increasing competition from capitalist fishing steamers, the ensuing decline in fish stocks, and the loss of other sources of income in the Elbe estuary due to the competition from steam-powered tugboats and ferries made the upkeep of a smack unprofitable unless the fishery continued year-round. Most of the fishermen fished in the estuary during the winter, but the young captains, often desperately in debt after purchasing boats, were forced into the profitable oyster fishery, regardless of the risk and hardship it meant.

Because the gear had to be hauled aboard every few hours and the catch was immediately cleaned on board, the men were always wet and never able to sleep more than two hours at a time; rheumatism and arthritis often forced them to give up at an early age. The boats were not designed to sail in open seas, nor did they have the maneuverability required in the German Bight, with permanent lee shores to the south and east. The men never survived if their boats sank; the annual mortality rate of fishermen was 5%, and there were hardly any pensions for the widows and orphans (Broelmann and Weski, 1992).

The deep-water fishery had to be discontinued during World War I; it did not resume after the war because the oysters rapidly disappeared.

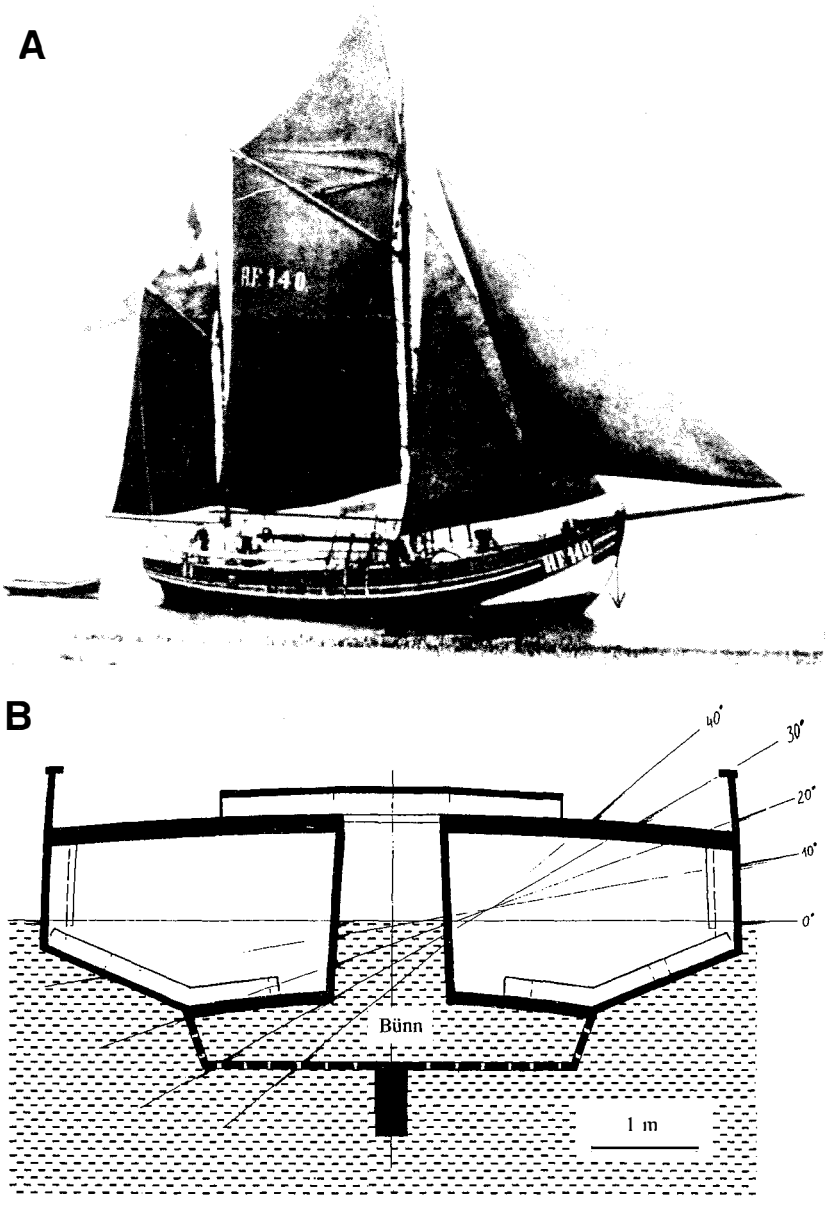

Figure 5

A (top)=Fishing smack from Finkenwerder, Hamburg (copyright by Museum of Transportation and Technology, Berlin). For centuries this type of boat was used in shallow-water finfisheries. It had a flooded hold (the "Bünn") under the water line (B, after J. Broelmann, modified), enabling the fishermen to bring the catch (mostly flatfish) alive into the port. In the oyster fishery on the open sea, however, the Bünn might cause the boat to capsize in heavy weather; if it listed by more than 20°, air could enter into the hold through the perforations below and leave the boat without ballast (Reproductions from Broelmann and Weski, 1992).

Disappearance of the Flat Oyster—In the late 19th and early 20th century there were repeated attempts at oyster culture, spat collection, and artificial breeding by French and Dutch methods (initiated by Möbius, 1877; see also Dean, 1893), as well as various management efforts (Hagmeier, 1916; Hagmeier and Kändler, 1927),

but they all failed. From 1894 to the 1930's, hundreds of thousands and sometimes millions of spat and half-grown oysters from the Netherlands, France, and Norway were relayed on the Schleswig-Holstein beds almost every year. This allowed the shallow-water fishery to resume, and a fishing steamer (Fig. 6) was put into service in 1911. The continuous introduction of foreign oysters, however, also introduced various diseases and fouling organisms. Moreover, the imported oysters were not as resistant to the harsh environmental conditions as the native oysters, and they apparently failed to reproduce (Hagmeier, 1941); in Lower Saxony, the introduction of Dutch and British oysters met with outright failure (Sarrazin, 1987).

By 1925, about one-fourth of the coastal oyster beds had disappeared under sand banks, and almost half had given way to mussel beds and *Sabellaria* (tube-dwelling polychaete) reefs, or they had been colonized by various other organisms; most of the remaining oyster beds were depleted, and the oysters and oyster shells were so strongly fouled that they could hardly provide settlement surfaces for oyster larvae (Hagmeier and Kändler, 1927). The fishery continued on Sylt and Föhr with Dutch seed into the 1930's, but annual production ultimately declined to a few thousand oysters. By then, Hagmeier (1941) had already concluded that the oysters had been outcompeted by mussels (and also by slipper shells, *Crepidula fornicata*), and he predicted that a return to the traditional fishery would not be possible. The last living oysters were sighted in the early 1950's.

The deep-water oyster stocks were almost certainly destroyed by the heavy gear of motorized fish trawlers (Anonymous, 1913), but the reasons for the prolonged recruitment failures which resulted in the extinction of the Wadden Sea stocks are unknown. Habitat changes, such as the secular rise of the sea level and the increase in tidal amplitude (Führböter, 1989) may have favored some species over others, but there have also been various speculations regarding anthropogenic effects. The same phenomena as described by Hagmeier and Kändler (1927) have been made responsible for the disappearance of the Wangerooge oyster stock in 1806 and for the downfall of the oyster fishery of Lower Saxony in the mid–19th century (Linke and Rüthning, 1937).

Since the 17th century, the continuous building of dikes for land reclamation and for connecting various islands to the mainland caused changes in the Wadden Sea hydrography; the topography of the bottom always needs a few decades to adjust (Gerritsen, 1992; Höck and Runte, 1992), and there may have been a perpetual mismatch between hydrographic conditions and the

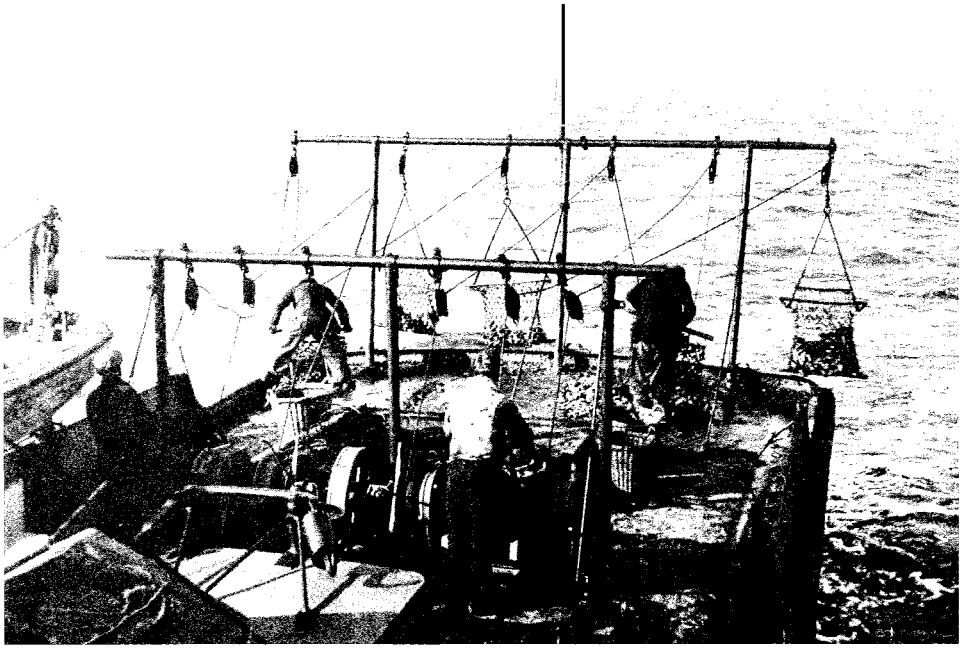

Figure 6
Oyster steamer "Gelbstern" from List (Sylt) in 1927. This vessel was about 25 m long and was propelled by two paddlewheels located amidships on either side of the hull. It could tow six dredges simultaneously (Photograph by R. Kändler; courtesy of Heye Rumohr).

substrate for larval settlement. This may also explain why existing oyster beds constantly suffered from siltation or disappeared under sandbanks. In the 1920's, finally, the recruitment problems may have been compounded by the destruction of the offshore stocks, which were probably ten times greater than the Wadden Sea stock and which may have been an important source of larvae.

Evolution of the Fishery for Blue Mussels

The German mussel fishery is a relatively recent activity. Before the 19th century, mussels were mentioned in documents only in relation to the necessity for their removal from oyster beds. The first written records on mussel consumption are from the Napoleonic Wars; in 1812, the East Frisian Islands were occupied by French troops, and in the following severe winter the mussels saved the soldiers from starving. As is still the case today, the mussels were eaten after being boiled in water. Nineteenth century documents show that the coastal population regularly consumed mussels in times of famine, and in the Western Baltic mussels were cultured on "stakes" (trees with the smallest branches removed). In Kiel Fjord during the second half of the 19th century about 1,000 such stakes were driven into the bottom in 4–5 m depths every year. The mussels were harvested after 2–5 years for an annual yield of about 80 metric tons (t) (over 3 million mussels; Meyer and Möbius, 1865). Mussel cultivation in the Baltic was given up during the 20th century for unknown reasons.

Heins (1868) urged North Sea fishermen to attempt the cultivation as well, but mussels were regarded as a poor man's food, and on the North Sea coast they were mainly fished for use as fertilizer until the beginning of the 20th century. The mussels were caught at low tide with rakes and forks and brought in small boats to sailing cutters waiting in deeper water, from which the catch was landed in the harbors at high tide. The fishing season was from September to April, avoiding warm weather. Landings have been recorded by fisheries authorities since 1887 in Lower Saxony and since 1914 in Schleswig-Holstein[1].

The first motor-powered vessel was put into use in 1909, but until 1914 only a few hundred tons were landed annually, and only a dozen fishermen and vessels participated in the fishery. Increased demand during World War I resulted in a record catch of almost 10,000 t in 1916–17, and almost all German fishing vessels with a sufficiently shallow draft were involved. The strong fishing pressure and the effects of ice winters led to a collapse of the fishery in Schleswig-Holstein in 1919. In Lower Saxony, annual landings were about 1,100 t throughout the 1920's (Schnakenbeck, 1928, 1953; Nolte, 1976; Sarrazin, 1987; Kleinsteuber et al., 1988).

Development of a Mixed Fishery in Lower Saxony—The mussel fishery in Lower Saxony recovered with the beginning of mechanization in 1929. The rake-and-fork method was abandoned in favor of dredges developed by Dutch fishermen, leading to higher daily catches and to the exploitation of subtidal stocks. Annual landings more than doubled, and a marketing company was formed in 1933 to stabilize prices. The use of mussels as animal feed was banned in 1934. By 1937, the fishery employed more than 60 fishermen on 26 vessels; these were motor-powered (15–60 hp) and 10–15 m long (Fig. 7). Mussels were loaded on deck. Extensive cultivation on reserved plots around the low-water line was reintroduced (first attempts in the 1920's had failed), and more than 31 licensed plots existed by 1939. After the outbreak of World War II, catches peaked at more than 5,000 t in 1939–40, but the fishery subsequently collapsed due to overfishing and ice winters.

In the post-war period, mussel catches remained low, again owing to winter ice mortalities, and to the infestation of the mussels with *Mytilicola intestinalis*. These parasitic copepods initially caused high mortalities or rendered the mussels unmarketable because of the reduction in meat content; the mussel populations seem to have adapted in the following 20 years, and *Mytilicola* infestation no longer causes mortality or weight loss (Dethlefsen, 1975; Nolte, 1976). In the 1950's, however, many fishermen had to abandon their culture plots and use their multipurpose boats to catch mainly finfish and shrimp. In 1965, there were 10 fishermen involved in the mussel fishery in Lower Saxony using vessels 15–20 m in length with an average of 80 m^3 hold capacity and 130 hp engines. They managed 25 culture plots with 180 ha (450 acres), but most of them also engaged in other fisheries.

A Specialized Fishery in Schleswig-Holstein—The mussel fishery in Schleswig-Holstein resumed in 1934 with the introduction of the first specialized Dutch-type mussel dredging vessel. These low-draft boats were 15–21 m long and had engines of 75–100 hp; they could simultaneously operate 2 or 4 dredges which were emptied into a hold. Most of the landings were from natural beds; the catch could attain 40 t in one day, and total landings increased to 2,000 t in 1939. More than 9 such boats (some of them confiscated from Dutch owners) were in operation during World War II, leading to a

[1] In Lower Saxony: Staatliches Fischereiamt, 27534 Bremerhaven. In Schleswig-Holstein: Fischereiamt des Landes Schleswig-Holstein, 24148 Kiel. Data on landings and prices are also regularly published as part of the annual reports of the state fisheries agencies in Das Fischerblatt, Schleswig-Holstein Chamber of Agriculture, Kiel.

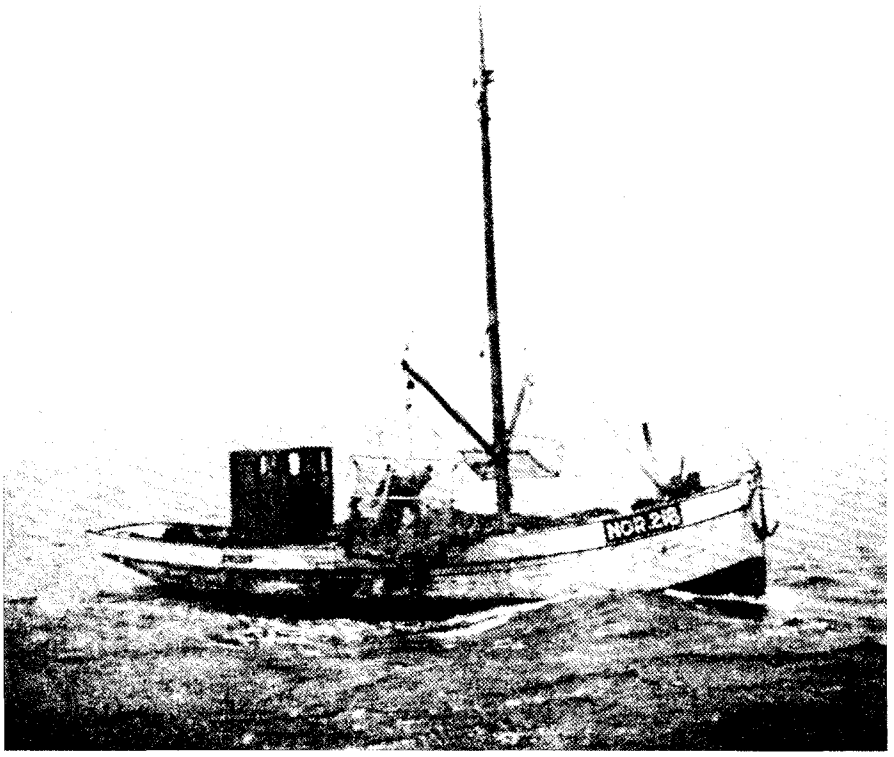

Figure 7
Boat used in the mussel fishery off Lower Saxony around 1930. Two dredges can be seen hanging from the booms. This type of boat could also be used to catch finfish and shrimp (Photograph by Willy Nolte; from Nolte, 1976).

record yield of 15,000 t in 1942–43. The fishery lost most of its Dutch vessels in 1945, but catches remained stable at 2,000–4,000 t in the post-war period; *Mytilicola* infestation of mussels in the Netherlands and Lower Saxony gave the fishermen from Schleswig-Holstein the opportunity to supply the Dutch market. On the other hand, the market demand also motivated shrimpers and Dutch fishermen to exploit the stocks of Schleswig-Holstein, thus increasing the fishing pressure.

In 1950 and 1953, the state legislature passed laws to protect the first post-war culture plots and prevent overfishing of natural mussel beds. The size of the boat hold was limited to 50 m^3, and the number of dredges to two (in addition, engines were limited to 35 hp for mussel boats in the Baltic sector). It was forbidden to transport mussels from other regions into or through the coastal waters of Schleswig-Holstein; culture plots were made subject to licensing, and their borders were defined by decree. These regulations are still in effect, but exemptions concerning the boats' performance are the rule. In 1965 there were 8 companies in Schleswig-Holstein devoted exclusively to mussel fishery, with specialized vessels (about 20 m length, 110 m^3 hold capacity, and 90-hp engines), leasing 35 mostly subtidal culture plots with 380 ha (950 acres).

Other Marine Molluscan Fisheries

Whelks—These gastropods (*Buccinum undatum*) were caught from 1951 to 1974 in Lower Saxony, initially by one boat using special dredges (Fig. 8). The total catch for the 24-year period was 3,000 t (Table 1), mostly originating from the Ems estuary, and all of it was exported to the Netherlands. A consumer demand never developed in Germany. Catches continuously increased at first, inducing other fishermen to join the fishery. Landings peaked at 450 t in 1971, and two specialized vessels (19 m long, 220-hp engines) were built for the whelk fishery in that year. Landings, however, subsequently declined dramatically, and the fishery was given up 3 years later (Nolte, 1976), as the Netherlands began to buy from English producers. According to Lozán (1994), the downfall was due to the fact that 90% of the catch was undersized, making on-board sorting too tedious; on the other hand, the refusal of the German

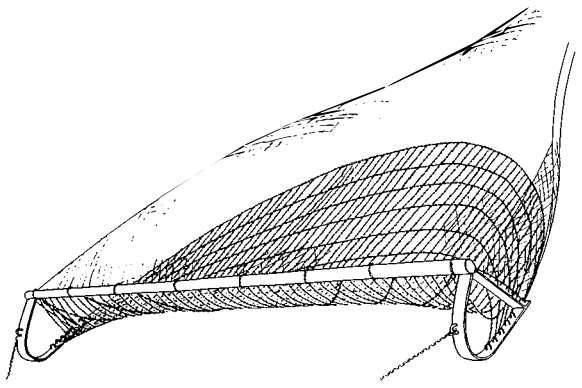

Figure 8
Buccinum dredge. The chain mesh in front of the opening is designed to repel stones, but may also inflict damage on benthic fauna (from von Brandt, 1984).

fishermen to supply the Dutch industry on a regular basis also contributed to the termination of the relationship[2].

Softshell Clams—These clams (*Mya arenaria*), are never found in prehistoric and medieval kitchen middens, nor in recent geological records, and it is presumed that they were introduced accidentally from North America, either around the year 1600 (Hessland, 1946; cited after Berghahn, 1990), or by the Vikings in medieval times (Petersen et al., 1992). They have been fished in the Wadden Sea for use as pig fodder (and for human consumption in times of famine). A regular fishery has never existed, however, and data are scarce, except for the last post-war period.

From 1945 to the early 1950's more than 14,000 t were collected by the coastal population, mainly by digging the clams out of the sand with pitchforks and shovels at low tide (Kühl, 1955). Sometimes, they would be washed out of the sediment by the action of a boat's propeller going full throttle against a dragging anchor in shallow water; the boat would be beached, and the clams loaded aboard at low tide. The most important source of clams was the area north of the Elbe estuary. A clam sausage was produced in the late 1940's, but attempts to initiate a commercial fishery were given up due to the lack of market demand (Neudecker, 1990).

Cockles—According to older fishermen[3], Dutch boats used to land on sand banks off the German coast into the 1960's to collect cockles, *Cerastoderma edule*, by rake; a large-scale fishery, however, did not begin in Germany until 1973. Annual catches fluctuated greatly, because of nearly total ice mortalities in some winters; in Schleswig-Holstein, for instance, landings were nil from 1978 to 1983, and the record catch of 12,500 t (1,600 t cooked meat) in 1983 was all from Lower Saxony. Catches and prices[1] are summarized in Table 2. The landings were almost exclusively exported to the Netherlands for processing and reexport to southern Europe.

Table 1
Landings and prices of the whelk fishery (5-year averages, after Hagena, 1992a).

Period	Catch (t/year)	Price (DM/t)
1951–1954	4	430
1955–1959	26	940
1960–1964	89	810
1965–1969	173	980
1970–1974	304	1,220

There were three companies in Schleswig-Holstein and two in Lower Saxony engaged in the fishery. In each state, one company fished cockles exclusively, whereas the others also held mussel licenses. The fishery was open from July to February, and the cockles were caught by the Dutch method of hydraulic dredging (discussed later). The boats were 30–35 m long, 8 m wide, and had a particularly shallow draft; they were equipped with motors of up to 300 hp and special pumps, as well as with culling and cooking facilities. The catch was usually cooked on board; the empty shells had to be either deposited on land, or ground to a fragment size of less than 6 mm before being thrown overboard at assigned dumping areas. As a minimum size regulation, 600 cockles had to yield at least 1 kg of meat (Hagena, 1992a).

The inception of three national parks covering the entire German Wadden Sea in 1985, 1986, and 1990, drastically reduced the area available to the fishery. In addition, the fishery became increasingly hampered by protests against the hydraulic dredging method, which may remove up to 5 cm off the surface of the sediment. Environmental concern focused on the resulting mortality of benthic organisms, as well as on the dredge marks, which may remain visible on the tidal flats for months. Although scientific studies have demonstrated that the cockle fishery does not seriously harm the environment (de Vlas, 1982, 1987), the fishery was banned for political reasons (1989 in Schleswig-Holstein and 1992 in Lower Saxony; Hagena, 1992b:50).

[2] Wolfgang Hagena, State Fisheries Agency for Lower Saxony and Bremen, 27534 Bremerhaven, Germany. Personal commun., 1992.

[3] Jürgen Petersen, retired fisherman from Wittdün, Amrum Island, and others. Personal commun., 1992.

Table 2
Landings and prices of the German cockle fishery (calculated from official data in the annual reports of the state fisheries agencies; some of the landings were raw cockles, and these have been converted to cooked meat by multiplying by 0.13).

Year	Catch[1] (t/year)	Price (DM/t)
1973	150	1,720
1974	833	1,970
1975	583	1,900
1976	156	1,110
1977	594	1,200
1978	790	2,040
1979	588	1,960
1980	190	1,180
1981	532	1,150
1982	281	970
1983	1,627	1,220
1984	1,319	1,450
1985	459	2,270
1986	194	4,160
1987	757	3,910
1988	191	2,160
1989	431	1,950
1990	744	2,800
1991	528	6,400
1992	14	3,180

[1] Cooked meat.

Extraction of Shell Deposits—Bivalve shells have been burned for the production of lime at least since the 16th century on the North Sea coast (Hansen, 1877). Marine deposits of mollusk shell fragments (so-called "Schill") attain a thickness of several meters in some tidal channels. They were strongly exploited off Lower Saxony by hydraulic dredging with boats in the 1930's and 1940's to meet the high demand resulting from military construction on the East Frisian islands. After World War II, the Schill fishery provided calcium for animal feeds (Michaelis, 1993). It ended in 1967 when the last dredging vessel was shipwrecked[4].

[4] Hermann Michaelis, Coastal Research Station, 26548 Norderney, Germany. Personal commun., 1992.

The Freshwater Pearl Mussel Fishery

Pearl mussels, *Margaritifera margaritifera*, were once extremely abundant throughout Europe, including Germany. Their biology and fishery have been reviewed by Wächtler (1986) and Bischoff et al. (1986). Pearl mussels inhabit cold, fast-flowing oligotrophic waters and are very slow growing; their life span ranges from 60 to >100 years, for a final size of about 15 cm. Although their ability to produce pearls has been known since ancient times, a systematic fishery did not develop in Germany until the 15th century.

Judging by the number of pearls found in 16th and 17th century treasures and relics, the German pearl mussel stocks must have numbered in the tens or even hundreds of millions of mussels. The church and the princes attempted to enforce their exclusive rights with harsh punitive measures (Fig. 9) and strict controls. For the fishermen, as well as for the government inspectors, the pearl fishery was only a part-time occupation, but it was very profitable and well managed in many areas. One rule, for example, was that a given brook or river would only be fished once every 10 years. Mussels with certain shell malformations (so-called "Perlzeichen," which had resulted from earlier damage and indicated that the mussel might carry a pearl) were pried open with a special tool (Fig. 10B), and the pearl was removed without serious injury to the mussel, which was returned to its site.

In some regions, however, it was not known that by the study of Perlzeichen and use of special tools the mussels need not be destroyed to ascertain whether they carried pearls (only one in several hundred actually does), and pearl mussels were broken and thrown on land by the millions. When German unification in 1866 put an end to local and regional management, the exploitation of pearl mussels became a free-for-all and caused a quick downfall of the fishery. Moreover, the species' complex life cycle (its larvae are obligatory parasites on the gills of brown trout, *Salmo trutta*) and its stringent ecological requirements were obscure at the time, and no major attempts were made to save its habitat, which was increasingly suffering the effects of industrial pollution, intensified agriculture, and stream regulation. By the early 20th century, the total number of pearl mussels in Germany had declined to about 5 million, and environmental degradation has since brought them nearly to extinction (Wächtler, 1986; Bischoff et al., 1986).

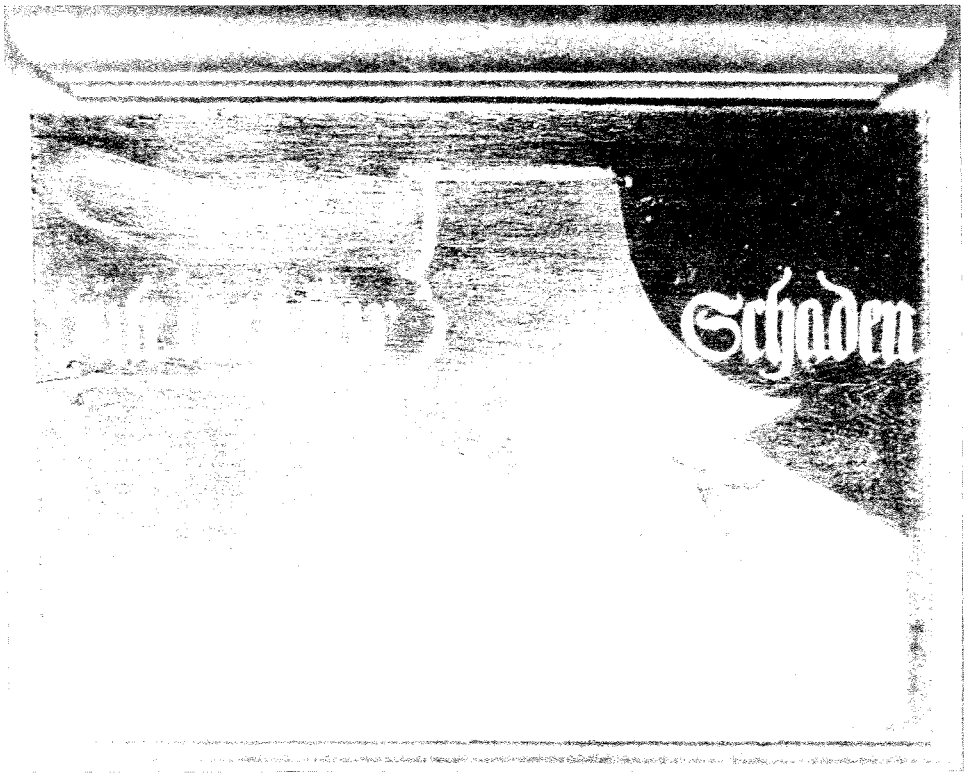

Figure 9
Warning to pearl mussel poachers (1736). The inscription reads: "Don't get yourself hurt." Poaching was generally punished by amputation of a hand (except in Bavaria, where poachers were executed by hanging), and similar signs were usually posted on river banks near pearl mussel stocks. For more than two centuries the sign shown here (a painted oak panel) kept guard over a stock in Schwienau Creek belonging to Ebstorf Monastery in northern Germany; it was finally removed in the 1950's (Original at Ebstorf Monastery; photograph courtesy of State Natural History Museum, Braunschweig).

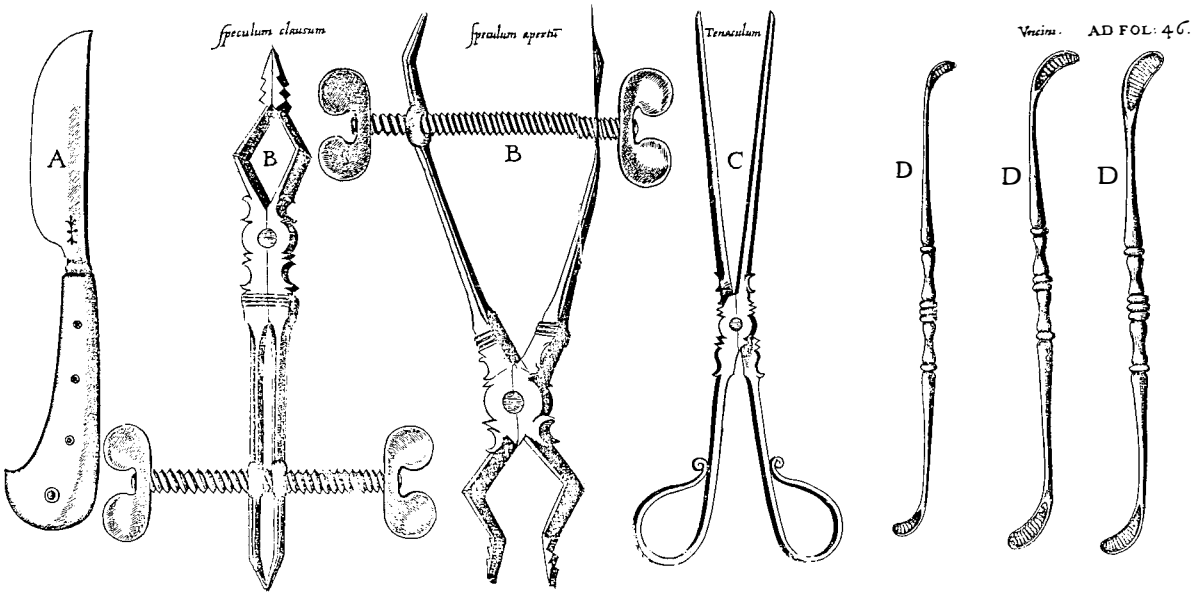

Figure 10
Instruments for the removal of pearls from live pearl mussels, developed in the 163●'s by Malachias Geiger, physician to the Duke of Bavaria (after Geiger, 1637; reproduction courtesy of State Natural History Museum, Braunschweig).

Figure 11
Intertidal oyster culture at List/Sylt. The oysters are in bags of plastic netting which are strapped to tables made of iron rods. Oysters and tables must be stored on land during the winter to avoid ice damage (Photograph courtesy of Dittmeyer's Austern-Compagnie, List/Sylt).

Current Molluscan Production

The German molluscan fisheries and aquaculture sector (production and processing) now employs nearly 100 people year-round and another 50–100 seasonally. It creates additional jobs in the marketing and transportation sector, but the actual number of jobs is impossible to estimate. The annual value generated is about DM 50 million (US$30 million); in exceptionally good years, this figure may be more than twice as high.

Culture of Pacific Oysters

Cupped oysters, *Crassostrea virginica* and *C. angulata*, were introduced to the German Baltic Sea and Wadden Sea in the late 19th (Möbius, 1887) and early 20th centuries, and again between 1954 and 1964; the experiments were discontinued, however, mostly for economic reasons (Neudecker, 1990). Pacific oysters, *C. gigas*, were introduced in the early 1970's, and an experimental hatchery of the Federal Fisheries Research Agency was in operation in Langballigau (Flensburg Fjord) from 1978 to 1984. The salinity in Flensburg Fjord proved too low for succesful growout (Seaman, 1985), but several fishermen and small companies attempted commercial production off various Wadden Sea islands in the 1980's.

Only one company survived by 1992; it is located in List (Sylt), and its production is based on the import of half-grown oysters from the British Isles. The oysters are imported in spring and grown in sacks made of plastic netting, which are strapped to iron tables on the tidal flats (French "poche and table" method, Fig. 11); they attain marketable size (70–90 g) in 1–2 years. The standing stock is almost 2 million oysters, and annual sales total 1.2 million (company information). More than 1 million oysters are overwintered in land-based tanks to avoid the risk of total loss during ice winters. The company has 5–10 employees year-round; it uses additional labor at the time the stock is brought out to the flats in spring, and at harvest time. The enterprise began with an original investment of DM3 million (US$2 million), and its annual sales now total DM1.5 million (US$1 million). The oysters sell in restaurants for DM6 (US$4) apiece.

The company conducts monthly sampling for algal toxins (DSP and PSP), as well as for bacteria, both in the oysters and in the ambient seawater; tests for heavy metals and for organic pollutants such as PCB's are done twice a year. In addition, there are further standards to be met for a government quality certificate. The oysters are shipped in baskets made of plywood, which are packed with moist reeds, *Fragmites comunis*, and sold to restaurants and wholesalers throughout the country; they are usually eaten raw on the half-shell. Although they have a very high quality, the production

method (the overwintering procedure, in particular) is also more expensive than elsewhere, and market competition with cheaper French imports is the main constraint.

Oyster consumption in Germany more than doubled during the 1980's, but is now stagnating at 700 t yearly. The German market is supplied mainly from France (400 t); imports from the British Isles and from the Netherlands, as well as German production itself, account for another 100 t each (Neudecker, 1991; Neudecker[5]). The oysters from Sylt are often preferred over the French during the summer, because they have a lower spawning activity, and the company has now recovered the original investment and is making a profit.

Blue Mussel Fishery

In the past two decades, the North Sea blue mussel fishery, reviewed by Ruth and Asmus (1994), has undergone further sophistication, whereas mussel production in the Baltic sector has ceased altogether. Evolution of the fishery has been stimulated by international developments, but it was also encouraged by a concerted management effort in the 1970's and 1980's, focusing on sanitation, marketing, and environmental aspects (Kleinsteuber and Will, 1976–86). The mussel fishermen in Lower Saxony have given up their mixed fishery in favor of a highly specialized mussel fishery. The surface area of the culture plots and the landings have risen steadily; boats have been modernized and new vessels (Fig. 12) have been built and, although the number of boats has decreased, the power and capacity of the fleet have become greater.

Coinciding with the trend toward specialization and modernization, the German mussel fishery has increasingly come under foreign control in recent years, even though the various companies are all based in Germany. At present, there are 14 boats in the fishery (6 in Lower Saxony and 8 in Schleswig-Holstein), but one is subject to restrictions. The six licenses (boats) in Lower Saxony are owned by three German fishermen (one license each) and one German-Dutch company, which holds the remaining three; in Schleswig-Holstein there are two German companies with one license each, as well as one Dutch-controlled and one British-controlled company with three licenses each.

The German mussel culture is an extensive bottom culture. The fishermen must submit an application specifying location and size of the culture plots; state authorities will grant the plot (at a nominal fee) if there is no conflict with other user groups. There are now more than 80 culture plots off the German North Sea coast; the size of a plot is between a few dozen and more than 100 ha (about 100–300 acres). Since 1990 the total culture area has remained at 2850 ha (7,000 acres) in

[5] Thomas Neudecker, Federal Fisheries Research Agency, Palmaille, 22767 Hamburg, Germany. Personal commun., 1992.

Figure 12
Mussel dredger *Ex Mare Gratia* from Schlüttsiel (Schleswig-Holstein), built 1987 in Husum. The boat is carrying a full load (Photograph by Maarten Ruth).

Schleswig-Holstein and 1012 ha (2,500 acres) in Lower Saxony.

Equipment—Significant technical improvements in the procedures used to spread small mussels from the boats onto the subtidal culture plots have contributed to the growth of the mussel fishery in recent years. Initially, the seed mussels had been shoveled overboard by hand, and later by mechanical grabs. The development of seeding procedures using conveyor belts reduced the manpower required, but maintenance costs were high due to wear and corrosion, and a high proportion of mussels were damaged during seeding. Today, the method used exclusively involves flooding holds to flush out the mussels through hatches below the water line by means of strong injector pumps (Fig.13); the seeding density is regulated by pump pressure and sailing speed of the vessel. The system requires little maintenance, and hardly any mussels are damaged in the process. On the other hand, it has led to an increase in the vessels' total displacement for a hold of equal size.

The typical boat today is about 35 m long, up to 9 m wide, has a hold capacity of about 100 m^3, and has a draft of 0.7–1.3 m unloaded and 1.5–2.3 m at full load. The vessels are powered by one or two diesel engines (total of 300–600 hp) and driven by one or two screws which are enclosed in a broad ring and sometimes protected additionally by steel screens on both sides. There are two holds (fore and midships), each equipped with an injector pump and mechanically operated hatches on both sides of the hull. The mast (frequently an A-shaped frame) is located in front of the holds. The vessels have four booms (one for each dredge) and the dredges are operated by six (frequently hydraulic) winches, one to operate the warp of each dredge and the other two to pull two dredges simultaneously over the hold and empty them. The central hydraulic pump is generally driven by a separate diesel engine.

A mussel boat is usually operated by a captain and a crew of two. The pilot bridge and (nowadays luxurious) accomodations are located astern. The pilot bridge is equipped with custom electronic navigation aids such as radar, GPS or Decca[6], navigation plotter, FM radio set, and cordless telephone. Color echo sounders are used to find subtidal beds and to examine possible locations for new culture plots. A dory is used for shallow-water operations, such as landing on tidal flats to search for intertidal beds.

Method of Extensive Culture—The fishermen seed their culture plots with mussels fished from natural beds (Fig. 14). The fishery typically removes only half of the

[6] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

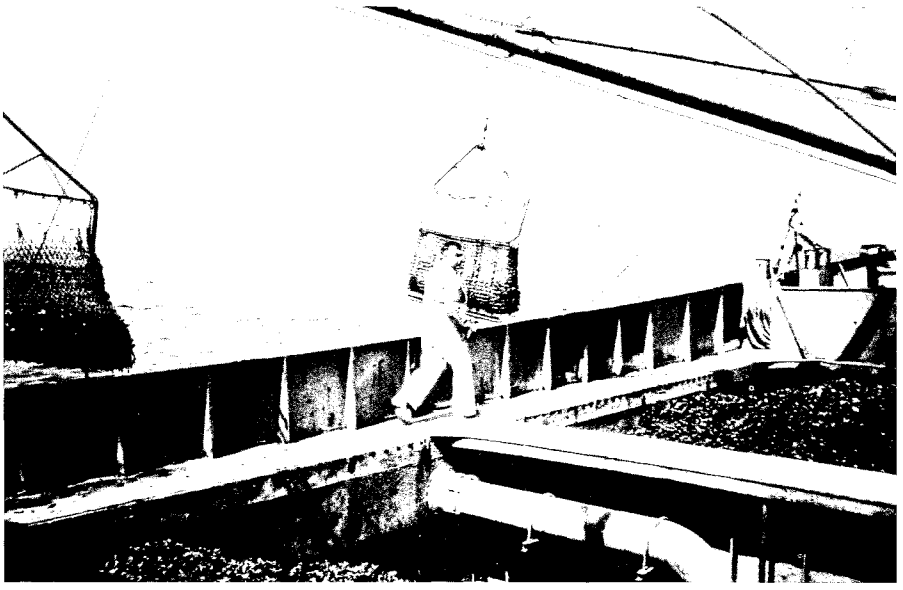

Figure 13
Mussel dredger: view of the dredges and holds. The pipe seen in the hold is used during the seeding procedure to pump water into the hold and flush out the mussels through lateral hatches below the water line (Photograph by Maarten Ruth).

actual mussel biomass of a mature natural bed with a mixed age distribution (Schirm, 1991); a higher proportion may be captured on dense beds of juveniles or in years when the standing stock is small and market demand is high. Daily catches are normally about 100–150 t, including so-called "tara" (i.e. empty shells, stones, mud, and bycatch), which represents a full hold. On dense subtidal beds or culture plots with sufficient water depth at low tide, the boat hold can be filled in 5 hours and, if the wild bed or culture plot is located close to the landing site (which is the exception), the daily catch can be doubled. Although subtidal stocks are generally preferred, they hardly exist in Lower Saxony; the reasons are unclear.

In the case of intertidal stocks and on low density natural subtidal beds the catch per unit effort is much smaller; the economic limit depends on market prices and on the amount of stock on the culture plots. The situation during the spring of 1990 provides a good example. At that time, there were no subtidal beds in Schleswig-Holstein, most of the culture plots were empty, and dense intertidal beds were missing due to recruitment failures in previous years; prices promised to hit record highs, and the fishermen fished on the remaining intertidal beds until the catches per flood tide fell below 30 t (including up to 50% tara).

The mussels from wild stocks seldom have the meat content required for immediate marketing. After being fished from a natural bed, the mussels are often kept in the hold for a few hours, sometimes in fresh water or with added salt, to kill noxious organisms such as starfish. Half-grown mussels (20–50 mm shell height) are seeded at densities of 100 t/ha; so-called seed mussels (5–20 mm shell height) are relayed at densities of 30–40 t/ha (these weights include tara, i.e. bycatch organisms, shells, mud, and stones). The success of a culture strongly depends on careful seeding; it may take up to 5 hours to spread 100 t of seed evenly across a plot.

Adequate culture sites must have good growing conditions, low storm risk (shelter of islands or sand banks), low ice risk (sufficient depth), stable bottom without moving sands, and a low probability of massive impact by predators (e.g. starfish, eider ducks) or other detrimental organisms (e.g. barnacles). Tidal currents should not exceed 1 m/second. Most of these factors are highly variable, and the fishermen try to offset the risk of unfavorable conditions in one particular subarea by distributing their plots as widely as possible. In Schleswig-

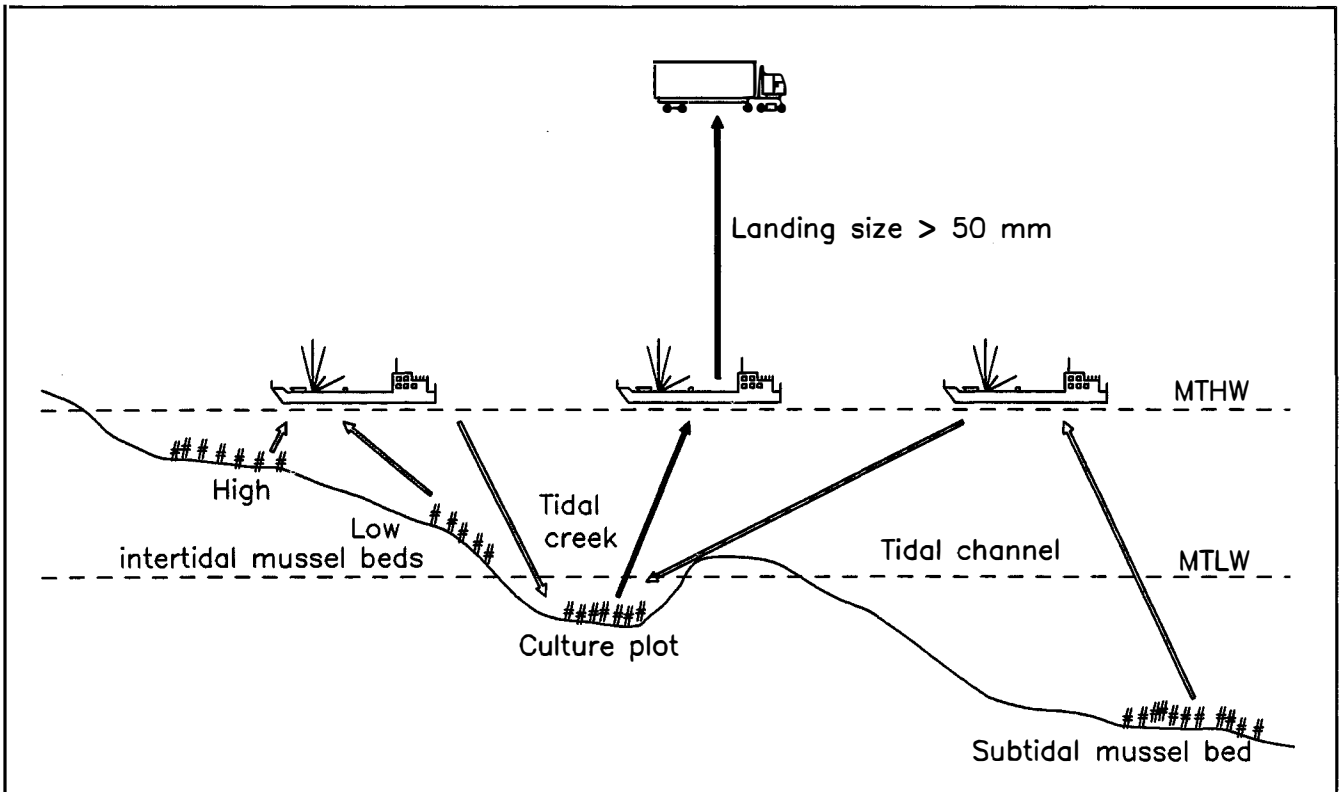

Figure 14
Diagram of the mussel cultivation procedure. Mussels are fished from wild beds, relayed on culture plots, and later fished again for landing.

Holstein all plots are subtidal, at depths of up to 10 m below the high-water mark; they are located in the region north of the Eiderstedt Peninsula. In Lower Saxony most of the culture plots are just above the low-water line, in the sheltered sector west of the Weser Estuary.

At good locations small mussels attain the meat content and size (well over 50 mm) required for marketing within 1–2 years. After harvest the plots are cleaned of remaining empty shells, starfish, mud, and pseudofeces deposits before reseeding. A good plot will return more than 100 t of mussels per ha (1,500 bushels/acre) including tara, and the yield is generally higher than the quantity seeded originally (in the Netherlands the yield-to-seed ratio is <1, because Dutch regulations until recently forced the fishermen to seed with haste, and because the large number of licenses that have been granted leads to the use of many less desirable sites, and to frequent relaying of stock).

Management and Regulations—The fishing licenses are the prime tool for managing the German mussel fishery. They are granted by the state governments for a period of 1–3 years, but the fishermen have no legal rights to be awarded licenses or to have them renewed. Any new regulations can be introduced and enforced by the state governments at will, particularly because the license conditions can be changed and the licenses can be revoked at any time. Laws and regulations are reviewed in CWSS (1991).

In Lower Saxony, the state reserves the right to impose restrictions on the fishing season, allowable catch, and fishing sites. The fishermen must inform the authorities about the natural beds on which they intend to fish; the beds between the polluted Elbe and Weser estuaries are closed to the fishery, and the other beds are opened only after the authorities have confirmed their safety. Although the size of the culture plots has been frozen at present levels, there are no catch limitations. Minimum size of mussels for the consumer market is 50 mm (10% undersized mussels, calculated by live weight, are permitted), and maximum size for seed is 40 mm (10% oversized permitted); relaying may only occur within the boundaries of the state. Mussels from culture plots may be landed year-round; wild beds may be fished only from 1 October to the end of February, but exceptions for the seed fishery are possible between 1 March and 15 June. Controls of minimum sizes, fishing areas, and fishermen's catch records are relatively frequent.

In Schleswig-Holstein, new regulations took effect in January 1996, and the State Fisheries Agency now employs a biologist concerned exclusively with monitoring the mussel fishery. There are no geographical restrictions or catch quotas, but the landing of mussels is forbidden from 15 April to early July (the precise date being set to coincide with the beginning of the fishing season in the Netherlands). The boats are operated under exemptions from the laws decreed in 1950–53; the number of licenses has now been definitely limited to eight. The fishermen have voluntarily relinquished the cultures located in "Zone 1" (the most protected area) of the National Park, and traded them in for sites in "Zone 2" (Fig. 15). Culture sites are granted by the State Ministry of Agriculture after consideration of other interests (shrimp fishery, navigation), and the overall surface has now been limited to 2,800 ha (7,000 acres). Minimum landing size is 50 mm (20–40% undersized mussels, calculated by live weight, will be permitted; this is subject to ongoing negotiations). Mussels from wild beds may no longer be sold on the market; they may be fished year-round, but exclusively to seed culture plots in Schleswig-Holstein, where they must remain for the duration of at least one growing season. The fishery on intertidal beds has been banned altogether, and the fishery in subtidal areas of "Zone 1" is permitted only when seed mussels are not to be found elsewhere.

Until 1996 the fishermen worked almost without government supervision, and only their adherence to the size regulations was checked a few times a year. There are no reliable economic and production data, because the catch statistics are derived from the fishermen's records and estimates, and because profits and losses of the international companies can be easily manipulated between the German daughter firm and the foreign parent. To better oversee the companies' activities, the State of Schleswig-Holstein has also introduced new reporting regulations in 1996, including an electronic surveillance system (see "Outlook" section).

Shellfish sanitation was rarely an issue in Germany in recent decades until the first massive outbreak of diarrhetic shellfish poisoning (DSP) in 1986 (Meixner and Luckas, 1988), which had a strong (but temporary) market effect; paralytic shellfish poisoning (PSP) has never been recorded in German waters. Health and quality tests are now conducted before and during the fishing season by various government laboratories. Before the season opens, both states analyze the mussels for bacteria, algal toxins (PSP and DSP), heavy metals (lead, cadmium, and mercury), and radioactive nuclides; in Lower Saxony, the mussels' gross chemical composition and their hydrocarbon (HCH and PCB) content are also analyzed and, in Schleswig-Holstein, bacterial concentrations in the seawater are determined. During the mussel fishing season, Lower Saxony measures algal toxins biweekly, and controls following the "European Community Regulations for Shellfish Water Quality" are conducted every 3 months. In Schleswig-Holstein, algal toxins and bacteria in the mussels are determined weekly during the fishing season. Both states have routine monitoring programs for noxious algae in

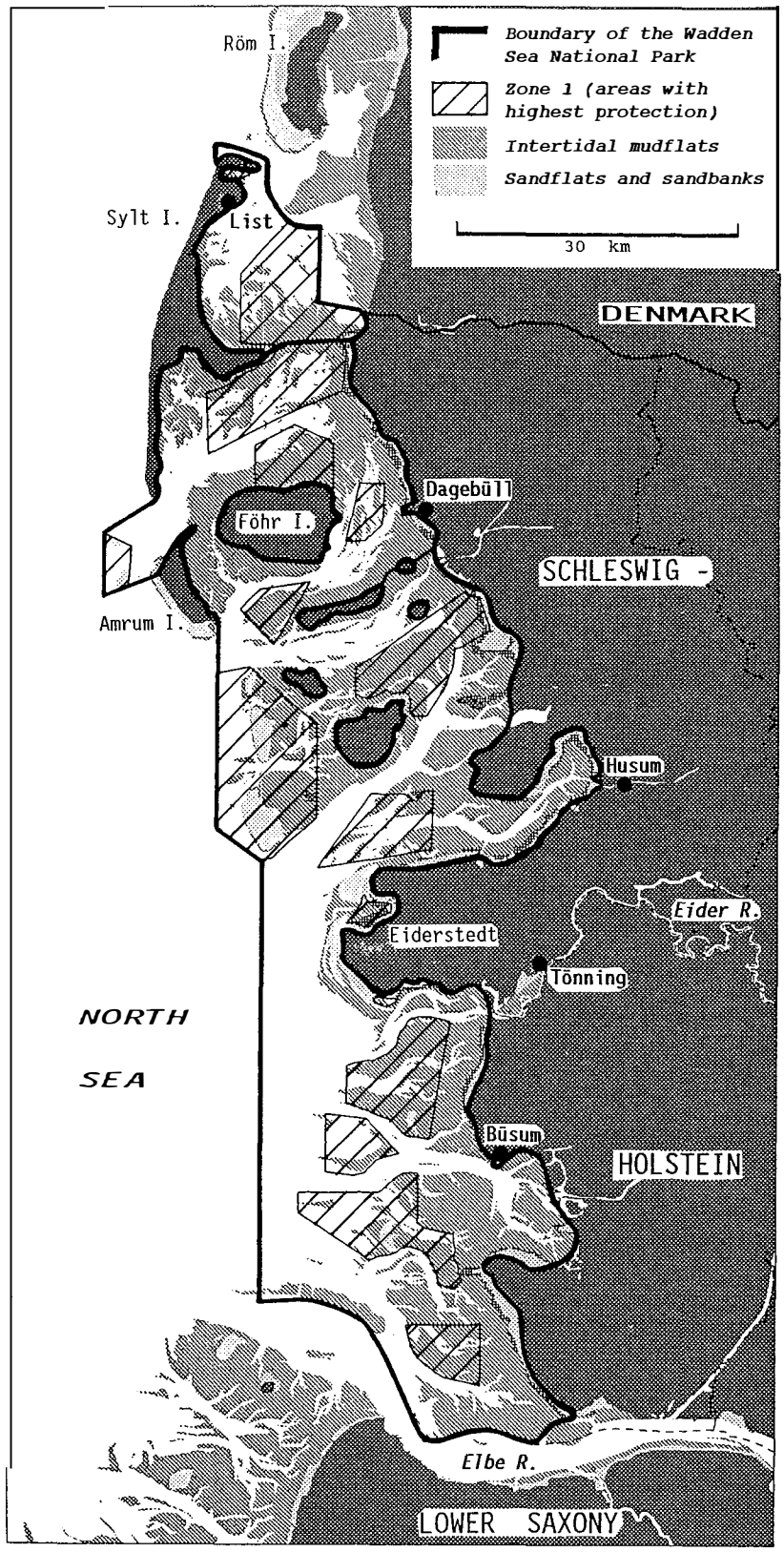

Figure 15
The Schleswig-Holstein Wadden Sea National Park. The isolated areas enclosed by solid lines represent "Zone 1" with the highest protection status. The structure of the Wadden Sea and of the corresponding national park in Lower Saxony are similar. Original map by the National Park Agency for the Schleswig-Holstein Wadden Sea, Tönning.

coastal waters. To prevent the introduction of diseases, Schleswig-Holstein enacted a new regulation in 1996, prohibiting mussel boats from entering or leaving the state's waters without prior official permission.

Marketing—When it is landed, the catch is loaded with a mechanical grab directly from the ship's hold onto trucks (about 5% of the mussels are destroyed in the process); this procedure precludes the use of refrigerator trucks, because they cannot be loaded from above. The trucks reach the most distant market, Italy, within 36 hours; shorter distances (e.g. to the Netherlands) are covered overnight. Most German mussels are sold fresh to wholesalers from the Dutch mussel center in Yerseke, who depurate them in large saltwater ponds and then process or resell them. The remaining landings are sold on the German market, as well as to wholesalers in Belgium, France, and Italy. Half-grown mussels may be sold directly to Dutch fishing companies (often the parent companies of German firms) as seed for their plots. Seed exports to the Netherlands were particularly important in the 1991–92 season, attaining 40,000 t (tara excluded). Landings and average prices[1] are shown in Figures 16 and 17.

When the wholesale price in Yerseke is very high the German catch goes almost exclusively to the Netherlands, and most of the fresh mussels sold on the German market are then imported from the Danish Limfjord (for various reasons, the Limfjord mussels are considered low in quality by the Dutch industry). On the other hand, some of the German fishermen traditionally sell their mussels in the population centers of western Germany (Rhine/Ruhr area), and one fisherman has an extensive marketing organization with up to 40 seasonal employees here. In years when the Dutch catches are high, however, the Germans may suffer intensive competition on the Rhineland market from the aggressive and well-organized Yerseke traders.

Consumer preference is for large mussels (>20–25 g live weight) with clean shells (even mussels with mechanically removed barnacles are difficult to sell to Belgian and French consumers), and high meat content (ratio of cooked meat weight to live weight >30%) with "white" meat (indicating low spawning activity); the French market will also accept smaller mussels. Other quality criteria are general appearance, taste, and smell. Insufficient market supply reduces the standards for acceptability, besides increasing the price. High quality mussels are generally sold fresh, mostly to restaurants, where they are boiled in water with spices, and eaten from the shell; except on the coast, mussels are rarely cooked by private households. Lower quality mussels are processed, which involves removal of sand, freezing or cooking, and packaging. Frozen mussels are sold to restaurants, which use them for a variety of dishes, or added to deep-freeze menus sold in supermarkets; cooked meats are sold in glasses, with or without spices, and often used for salads.

Germany has two processing plants with 40–100 employees each (depending on the season), both situated

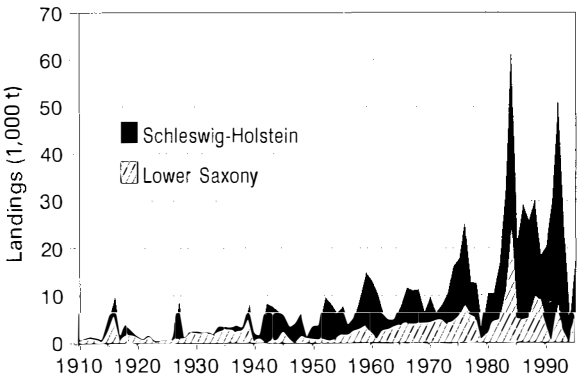

Figure 16
German blue mussel landings (in thousands of tons fresh weight) from 1910 to 1995. Official data from annual reports of the State Fisheries Agencies. The figures include 20–40% "tara" (bycatch, empty shells, mud, and stones) until the late 1980's; figures for recent years represent net weight of the sold catch (clean product). In general, the catch consists predominantly of large mussels for the consumer market; in 1991 and 1992, however, the landings were largely composed of seed for export to the Netherlands.

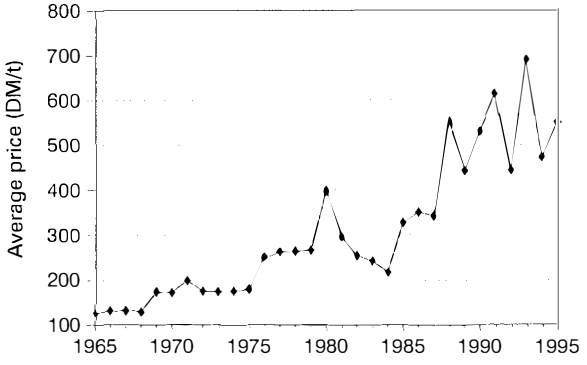

Figure 17
Average prices for blue mussels from 1965 to 1995 as calculated from official data in the annual reports of the State Fisheries Agencies. Auction prices in Yerseke (Netherlands) are better indicators of the market situation; e.g., auction prices of fresh mussels for the consumer market doubled from 1991 to 1992, but this is not reflected in the German data, which consisted mostly of half-grown mussels for reseeding on Dutch beds.

in Schleswig-Holstein. They are run by a British and a Dutch-controlled company. To promote the local economy, the state government has linked the mussel licenses granted to foreign-controlled companies to the operation of these plants, but both process mostly imported Danish mussels, because the German catch commands a better price in the Netherlands.

Economics—German retail price to consumers is about DM5.00/kg (US$1.50/lb), but prices vary widely during the year. At the Dutch mussel auction center of Yerseke, wholesale prices are highest at the beginning of the season in July, due to the high demand from Belgium at the beginning of the Belgian vacation season. Because of seasonal restrictions in Germany (particularly in Schleswig-Holstein), most of the German catch has not really reached the retail market until September, when prices were already declining; the new seasonal regulations enacted in 1996 should improve the profitability of the German fishery.

Price fluctuations are additionally affected by peculiarities of the market (Gibbs et al., 1994). In July 1992, for example, wholesale prices for top quality fresh mussels at Yerseke attained DM5.80/kg (US$1.70/lb), but the consumers did not accept the price increase. The dealers were unable to sell the merchandise and a lot of high-quality mussels had to be processed at a loss. Dutch wholesale prices consequently plunged at the beginning of the season and then stabilized below DM1.50/kg (US$0.40/lb); seed prices in 1991–92 were about half as high, attaining about DM800 (US$500) per ton (all wholesale prices are only estimates, because the transactions involve a lot of deal-making and exchanges of nonpecuniary favors).

The price of a new mussel boat exceeds DM3 million (US$2 million), and the operation costs for the vessel (including salaries for the crew, equipment repairs, depreciation, etc.) are about DM1.5 million (US$1 million) per year. A profitable operation requires annual landings of nearly 2,000 t per boat, but the catch fluctuates greatly from one year to the next. The combined landings of the Netherlands, Germany, and from the Danish Wadden Sea have been relatively stable during the past several decades, as low catches by one country were compensated by high landings of another, and rather than reflecting the state of the stocks on culture plots and natural beds, German mussel production is largely determined by the market situation in the Netherlands (which depends on the Dutch catch).

New Offshore Fishery for Hard Clams

In 1992 a large stock of hard clams, *Spisula solida*, was discovered about 10 n.mi. west of Amrum Island, and the fishermen have since found a series of hard clam beds all along the German North Sea coast. A 1975 study of the benthic macrofauna of the German Bight (Salzwedel et al., 1985) found only isolated beds of *Spisula solida*, and Meixner (1993) roughly estimates that the entire hard clam population had a biomass of 100,000–150,000 tons at that time. In 1992–93 the stock off Amrum, which is spread over several km^2, was estimated at about 100,000 t, and all the *Spisula* stocks probably added up to far more than 200,000 t (Ruth, unpubl. data). This implies a significant increase in biomass, and it would also mean that the hard clam population is superior in size to the stocks of blue mussels, which presently provide the mainstay of the German molluscan fishery.

The *Spisula* stocks are located partly within and partly beyond the Wadden Sea boundaries. The former fall under the jurisdiction of state authorities, which have granted six licenses to different companies. The latter fall under the jurisdiction of the European Union (EU), and are not subject to any regulation whatsoever; thus any fishing boat from a EU member country is allowed to catch offshore clams without restriction. The clam beds, which are also frequented by shrimp fishermen, are situated on banks of coarse sand at depths of about 10 m. The clams attain a maximum size of 45 mm at 7 years of age; in commercial catches they are 2–5 years old and have a size of 35–43 mm. Their flavor is excellent, and their meat content (20% cooked weight) is intermediate between cockles (13%) and mussels (30%). The clams disappear from the fishery from November to May, but this also is a common phenomenon in the *Spisula* fishery off the U.S. Atlantic coast. Presumably, the clams are out of reach of the dredges, because they dig in deeper and the soil hardens[7]; this assumption is supported by the fact that the catch per unit of effort decreases progressively during October while, at the same time, the number of broken clams in the dredge increases. Despite the temporary disappearance, there does not seem to be any serious winter mortality.

The boats employed are regular cockle dredgers; they use one modified hydraulic dredge (Fig. 18) that has pressure and suction pipes almost 40 m long. The dredge is set for maximum penetration into the sediment (6–7 cm). Bycatch organisms (mostly sandeels, flatfishes, and other bottom-dwelling fishes, as well as various crustaceans and bivalves) represent less than 1% of the weight of the catch. The fishing trips normally last 1 day. Due to the exposed locations, wave action at wind speeds higher than 4–5 Beaufort leads to damaged pipes and dredges, and the fishery can only take place 30–40 days per year. The catch (5–8 t/hour) passes directly from the exit of the suction pipe through

[7] Clyde L. MacKenzie, Jr., NMFS James J. Howard Laboratory, Highlands, NJ 07732. Personal commun., 1992.

a rotating drum for sieving and culling, and then proceeds onto a conveyor belt which empties into the hold. Clams for the frozen market are watered on board in tanks of 2–3 m^3 to allow them to eliminate the sand; the watering process is omitted when the catch is destined to be cooked, because the sand can be eliminated by thorough rinsing of the cooked meats.

The catch was initially shoveled by hand into wooden boxes and later transferred to refrigerated trucks. This was too time consuming and labor intensive, however, and the procedure followed now is the same as in the mussel fishery, i.e., the contents of the hold are loaded onto trucks with mechanical grabs, despite the fact that a higher proportion of clams is damaged by the procedure. The clams are landed at the ports of Harlingen (Netherlands), Havneby (Denmark), or Dagebüll (Germany), processed in the Netherlands, and sold to Spain and Italy. The official landings[1] from Germany (Table 3) are underestimates. The total landings of clams from the German coast were probably about 5,000 t in 1993 (Meixner, 1994), and well over 10,000 t in 1995 (including Dutch vessels fishing in EU waters). The price data are similarly unreliable, e.g., the clams are two orders of magnitude more expensive on the Spanish retail market, and the price to producers must therefore be much higher than given in Table 3.

Outlook

Most shellfishery activities are subject to substantial legal constraints and environmental pressures, such as those which led to the ban of the cockle fishery. Any new fishery or expansion of an existing fishery in the Wadden Sea will probably be blocked by pressure from environmental groups, and further growth of the molluscan fishery appears possible only in offshore areas situated beyond the limits of the National Parks. The following gives an estimation of the German production potential, and of the possible evolution of the German molluscan fisheries, although we must admit that developments are often too sudden and surprising to allow reliable prognostication.

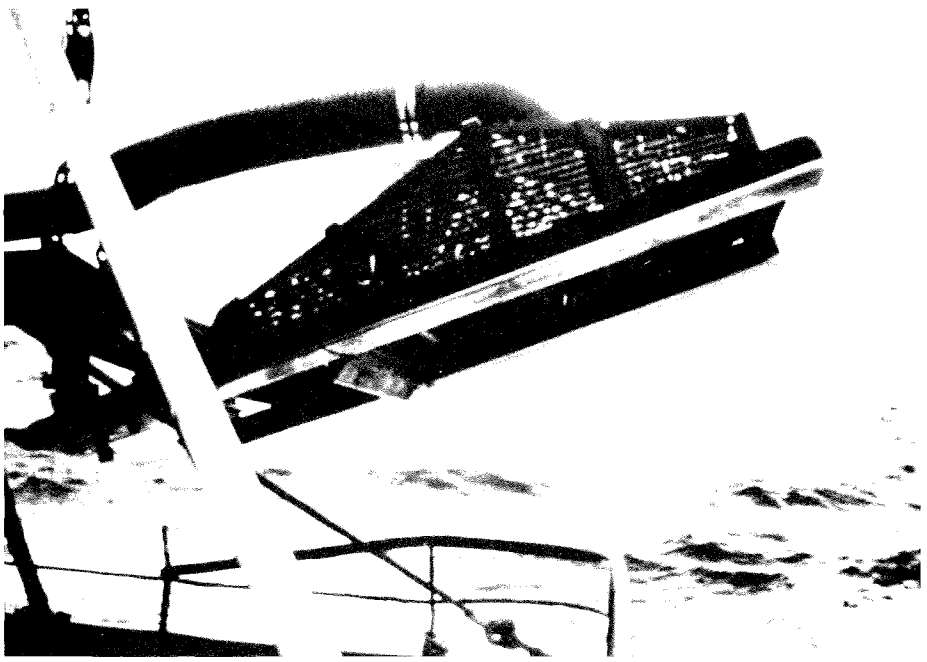

Figure 18
Hydraulic suction dredge used in the large-scale fishery for burrowing bivalves such as cockles and hard clams. On top of the opening of the dredge (left) is the pressure pipe, from which water is ejected at high pressure through a slot-shaped nozzle in order to disperse the sediment. The knife underneath (between the rails) lifts remaining sediment and clams into the cage; the penetration depth of the knife is adjustable. The catch is sucked into the suction pipe (top), is carried upward through the impeller of the vacuum pump, and is emptied aboard the ship into a rotating drum sieve (Photograph by Maarten Ruth).

Table 3
Landings and prices of hard clams, *Spisula solida*, in Germany (official data of the state fisheries agencies; some of the landings were cooked meat, and these have been converted to raw catch by multiplying by 5).

Year	Catch (t/year)	Price (DM/t)
1992	426	690
1993	1,301	370
1994	1,463	230
1995	7,314	230

Oyster Culture

Culture of Pacific oysters, *Crassostrea gigas*, has proven economically feasible in Germany, as long as it is conducted on a large-scale professional basis. Although the more expensive production method (land-based overwintering) is largely compensated for by the German oyster's high meat content, a reduction in production costs will still be necessary to make the German oyster truly competitive. There are some excellent potential sites along the German North Sea coast, and the annual oyster production could theoretically be expanded to several thousand tons if German consumer demand increased further or if the French market became accessible.

Present statutes forbid the introduction of exotic species into the Wadden Sea, whereas the culture depends exclusively on foreign imports of half-grown oysters. The authorities have, in practice, been treating Japanese oysters as an endemic species, because they were first introduced before the new regulations came into effect. Any proposed expansion of culture activities, however, would have to overcome resistance from other interest groups, such as environmentalists. On the other hand, a natural population of *C. gigas* has now finally established itself in the southeastern North Sea—two decades after the species' first introduction—ultimately leading in 1994 to widespread recruitment in the northern part of the Wadden Sea (Reise and Ruth, manuscr. in prep.). This second stock spawned in 1995, and its development should open a long-range perspective for Pacific oyster culture in Germany.

Blue Mussel Fishery

Annual catches have always undergone strong fluctuations, and this will remain so in the future. The latest decline in German landings resulted from a paucity of seed mussels, but it does not represent any fundamental change in the fishery itself. Environmental regulations and objections by the shrimp fishery will prevent any further expansion (number of licenses and total surface of culture plots). There are demands to further extend "Zone 1" (Fig. 15) and these may lead to the closure of considerable parts of the Wadden Sea to the fishery, with a subsequent reduction of landings. In addition, the diminishing eutrophication of the North Sea (due to the expected reduction of nutrient inputs) may also result in a decrease in productivity (Boddeke and Hagel, 1991). The present National Park statutes, however, do offer a secure perspective, and they will force the fishery to become more efficient in the long run (Ruth, 1991, 1992, 1993a, b).

The regulations introduced in Schleswig-Holstein in 1996 (such as the ban of the fishery in intertidal areas and in "Zone 1") completely fulfill the demands of environmental organizations. In addition, the Schleswig-Holstein fishermen are now required to report to the Fisheries Agency on a daily basis (geographic location and time of day of their fishing trips, weight and quality of the catch, seeding activities, etc.), and they will also have to install electronic devices to allow the authorities to monitor their ships' activities in detail, thus providing a solid basis for management and control of the fishery.

Environmentalists continue to criticize the mussel fishery, however, and some of them would probably like to see it banned altogether. Their demands for quotas and catch limitations must be rejected; stiff limits would cause enormous economic losses to the fishery in good years, and flexible limits are impractical because stock size fluctuates too strongly and too abruptly (Nehls and Ruth, 1994a,b). For example, in the case of an exceptionally strong local recruitment, a prolonged intensive seed fishery at the site of the spatfall greatly improves growth and survival of the remaining unfished juveniles by spreading them over a larger area and by reducing the local population density; this immensely increases the total biomass of seed mussels and enables the fishermen to stock their cultures with maximum economic profit and minimum use of ecologically sensitive intertidal beds.

Hard Clam Fishery

The new fishery at first merely provided some compensation to boats which had been grounded by the ban on cockles. By 1995, the fishermen succeeded in overcoming initial difficulties in processing and marketing, and the clam fishery was beginning to surpass the mussel fishery in economic importance. The stocks, however, were wiped out completely in the first months of 1996, when the most severe winter conditions in 33 years (–1°C and 36‰ salinity in the bottom water) persisted until

April. The size of the *Spisula* stocks was probably the result of a succession of strong recruitment events during the past several years. The clam population had an evenly mixed age distribution, opening prospects for a prolonged sustainable fishery. Considering that the official landings for 1995 represent the catch of only two vessels within the 12 mile zone (the other four boats did not exercise their licenses), the hard clam fishery is potentially much more profitable than that for blue mussels.

It is impossible to predict whether the hard clam stocks will recover, as has been the case with blue mussels, which frequently suffer high winter mortalities and always offset them by strong recruitment a few months later. In addition, the clam fishery faces various other constraints. It has now begun to attract the attention of environmentalists. Judicious management of the fishery will remain an impossibility for years to come, because the Federal government has relinquished its authority over the stocks, which now fall partly under regional and partly under European jurisdiction. A scientific assessment is long overdue, but proposals for a study of the stocks and the fishery have fallen prey to budget limitations on the part of the responsible government authorities. Germany is the only country with a hard clam fishery which has not conducted a survey, and we do not expect one to be carried out in the foreseeable future. Despite its enormous potential, the German *Spisula* fishery's future can only be characterized as completely uncertain.

Unexploited Stocks

Squids, *Alloteuthis subulata* and *Loligo vulgaris*, constitute part of the bycatch of the finfisheries in the German Bight. The annual catch is in the order of 10 t, but most of it is either discarded overboard or goes into fishmeal production, and only a few hundred kg per year are landed[8]. The stocks seem to have been increasing in recent years (Steimer, 1993), but an increase in landings is not expected.

Whelks, *Buccinum undatum*, are abundant locally, but the stock has never been studied. The toxic effects of tributyl tin (TBT) on whelk reproduction may have led to a decline of the population in recent decades. Past experience, and the fact that whelks are also K-strategists which reproduce slowly (Gendron, 1992), suggest that even a small-scale fishery (e.g. for export to southern Europe) could not be sustained.

Softshell clams, *Mya arenaria*, continue to be abundant in the Wadden Sea, but an exploitation of the stocks is not to be expected, due to the absence of a market, as well as environmental constraints (the stocks are within the limits of the National Parks, and a modern fishery would have to employ hydraulic dredges with deep penetration into the sediment).

Cockle, *Cerastoderma edule*, stocks would easily support a highly profitable fishery, but the present ban will remain in effect in the foreseeable future.

Atlantic jackknife clams, *Ensis directus*, have become extremely common in the Wadden Sea since their appearance in the late 1970's. They were presumably introduced accidentally with the ballast water of tankers (Essink, 1986). The clams have an excellent meat content and their retail market price is DM28/kg (US$7.50/lb). The stock has not been studied until now. Part of it is located outside of the Wadden Sea proper, and is therefore not subject to the restrictive National Park regulations. A fishery with methods used elsewhere (e.g. Scottish mechanical dredges[9]) may well be feasible, and the companies engaged in the hard clam fishery have also applied for Atlantic jackknife clam licenses. A fishery on *Ensis*, however, might well lead to new conflicts between environmental and economic interests. The next developments will probably depend on the immediate market situation.

Ocean quahog, *Arctica islandica*, and horse mussel, *Modiolus modiolus*, stocks in the North Sea are not very important and undergo continuous destruction by the beam and bottom trawls of the finfisheries (de Groot and Lindeboom, 1994). A fishery of either stock is unfeasible[10]. In the Baltic Sea, natural production of ocean quahogs probably far exceeds 100,000 t/year, but the quahogs grow and reproduce slowly, and they are subject to intensive predation by fishes as well as destruction by trawls (Brey et al., 1990; Rumohr and Krost, 1991). An attempt at a fishery by one fisherman in Schleswig-Holstein in the early 1980's was quickly given up[11]. The feasibility of quahog aquaculture (e.g. Kraus et al., 1992) has not been studied in Germany.

In the Baltic Sea, various attempts in recent years to use the mussel and cockle stocks off the coast of Mecklenburg have been abandoned. Mussels, for instance, may attain densities of 10 kg/m^2, but less than 10% of the natural population reaches market size (40 mm); in culture on ropes, less than half of the mussel biomass attains market size within 2 years (Böttcher and Mohr, 1991). On the east coast of Schleswig-Holstein (where salinities are higher), between 400 and 500 t were landed in 1986 and 1987, but this fishery was

[8] Silke Steimer and Uwe Piatkowski, Institut für Meereskunde, 24105 Kiel, Germany. Personal commun., 1992.

[9] Eric Edwards, Shellfish Association of Great Britain, Fishmonger's Hall, London, England. Personal commun., 1992.

[10] Heye Rumohr, Institut für Meereskunde, 24105 Kiel, Germany. Personal commun., 1992.

[11] Thomas Neudecker, Federal Fisheries Research Agency, Palmaille, 22767 Hamburg, Germany. Personal commun., 1992.

abandoned in 1989. Fishery and culture activities could only become economically attractive again here if the Wadden Sea mussel fishery has a major crisis, which appears unlikely at present.

Concluding Remarks

The historical record shows that user conflicts are nothing new to the molluscan fishery (and they were definitely more dreadful in the old days), and management of these fisheries has a tradition spanning at least three centuries. Today, political controls on the shellfisheries may often appear excessive. It should be kept in mind, however, that at the turn of the century the pearl mussel fishery was destroyed by the lifting of management regulations and by environmental degradation, and that the traditional oyster fishery in the Wadden Sea failed despite all regulation, stock enhancement, cultivation, and biological research efforts. This experience should be a stern warning to those involved in present-day molluscan fisheries and in the management of this valuable resource.

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