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Sediments 2–Oysters 0: The Case Histories of Two Legal Disputes Involving Fine Sediment and Oysters

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ABSTRACT

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The essential elements of two prolonged legal disputes concerning fine sediment and oysters are reviewed. One relates to extensive subtidal oyster cultivation by traditional methods and alleged losses due to sediment claimed to be reworked during a capital dredge operation. The second relates to an intensive, modern oyster farm using fixed structures installed on a muddy tidal flat. In the latter case, a major stock kill due to mud incursion was indisputable but the Plaintiff claimed the source was mud liberated after a small scale experiment to eradicate *Spartina* from an adjacent embayment some years earlier. The evidence successfully amassed to resist both these actions is outlined. The judgements and the lessons arising from them are described. The shellfish industry in the U.K. and Eire will urgently require proper sedimentation engineering design criteria if the trend for larger commercial enterprises on fixed structures continues.

ADDITIONAL INDEX WORDS: *Court case, dredging, sediment reworking, suspended sediment monitoring, core sampling, grain size analysis, long-term tidal flat evolution, short-term tidal flat dynamics, oyster cultivation, salt marsh defoliation, hindcasting,* Mya arenaria *erosion.*

INTRODUCTION

Legal disputes concerning the marine environment are expensive and the lessons learned from them rarely enter the public domain to be assimilated into the general fund of scientific knowledge. An increasing number of interests are involved in coastal and nearshore waters with the result that disputes are likely to increase. A major cause of disputes is lack of attention to planning and monitoring of marine operations. It is also self-evident that a thorough understanding of coastal processes is an essential prerequisite. Insufficient attention is generally given to these issues. Legal disputes are inevitably stressful, and in the case of fine sediments and oysters involve aspects of marine physics, chemistry and biology. Furthermore, scientific literature relevant to such disputes requires a familiarity with several languages.

The case histories outlined here involve two typical but contrasted, disputes. One concerns the alleged interaction between the subtidal cultivation of the European native flat oyster, *Ostrea edulis* and a dredging operation. The other concerns alleged interaction between the Japanese rough oyster, *Crassostrea gigas,* grown in fixed structures in the intertidal zone and conservation of the marsh grass *Spartina anglica* on the nearby shore.

The purpose of the court system is to provide an avenue for settling disputes, whereas this appraisal provides a contribution towards preventing similar disputes in future. In the case of both disputes, the author was the principal sedimentological expert representing the Defendants, on both occasions being engaged when writs had already been issued.

THE TWO CASES

A capital dredge scheme to deepen the approach channel for the ferry plying the link between Stranraer, Loch Ryan in Scotland and Larne, County Antrim in Northern Ireland was undertaken in 1978 (Figure 1). Allegations of smothering and mortality of oysters arising from displaced silt were made in 1980–1981. The parties in the dispute were Loch Ryan Oyster Fishery Ltd. versus British Railways Board, later Sealink (U.K.) Ltd. The court case was heard by Lord C. Elliott guided by two land surveyors, Mr. W. Hall and Mr. T. Finlayson as assessors. Damages claimed were £0.75 Million and the case ran for 25 days at the Lands Tribunal in Edinburgh, 23

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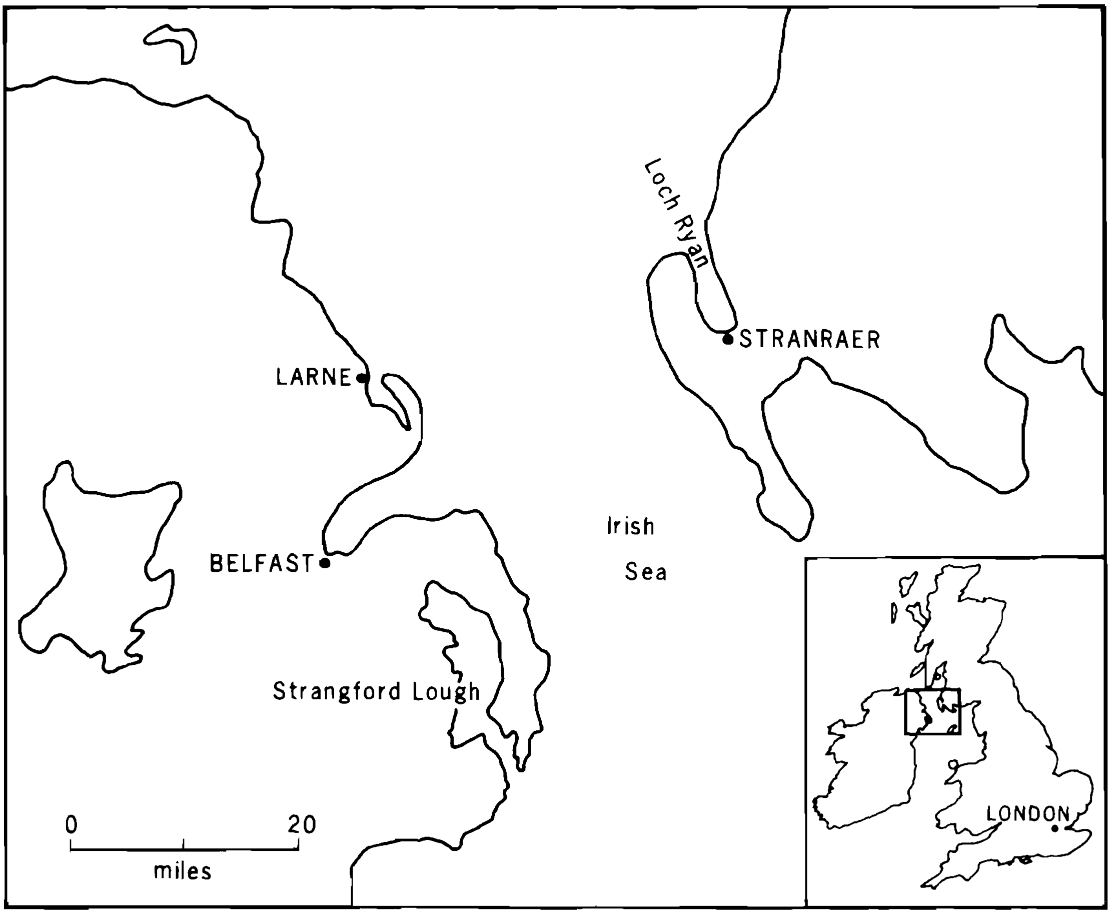

Figure 1. Map showing outline of the United Kingdom with locations of the two areas of dispute.

days in February and 2 days in July 1983. This case was scientifically difficult in that it related to a subtidal cultivation site with the result that only evidence obtained with instrumentation of various types was available. However, these difficulties were eased by the fact that contemporary monitoring of various kinds on the properties and behaviour of the sediment was available.

Cultivation of *Crassostrea gigas* in wooden trays mounted on low trestles began in Ardmillan Bay, Strangford Lough, County Down, Northern Ireland, in a small way prior to 1978 and expanded rapidly to a commercial operation eventually involving 8 million oysters during 1980–1982. *Crassostrea gigas* will grow but not reproduce in ambient water temperatures in northwest Europe. During 1983 and 1984, the trestles were steadily smothered in mud and the oysters asphyxiated. In late 1978, a small scale experiment to defoliate a *Spartina* marsh with a view to eventually restoring the area to use as a bird feeding area had been carried out in an adjacent embayment within Ardmillan Bay. The oyster company alleged that silt liberated subsequent to this short-term defoliation had killed the oyster stock. The parties in the dispute were Cuan Sea Fisheries Ltd versus the Department of the Environment for Northern Ireland, the Department of Agriculture for Northern Ireland and Her Majesty's Attorney General. The case was heard in the High Court in Belfast. The damages claim was for £1.75 Million and the case ran for 85 days between November 1989 and May 1990. This dispute was easier to evaluate, in that it related to an intertidal mud flat exposed to visual inspection at low water. It was made difficult in respect that no quantitative monitoring of the oyster cultivation site or the marsh had been carried out contemporaneously with either activity.

LOCH RYAN

Background

The dispute arose from an alleged shortfall in the number of harvestable oysters in 1979 and 1980. The roots of the issue in contention actually lay in the Department of Agriculture and Fisheries for Scotland's (DAFS) monitoring and records of oyster abundance in Loch Ryan (MILLAR, 1963). The European oyster, *Ostrea edulis*, is close to the northern limit of its range in Loch Ryan and DAFS records, although rather fragmentary, reveal clearly that oyster spatfall has been extremely variable and unpredictable during the present century. Furthermore, partly related to the above, the loch has experienced sudden and large fluctuations in the live adult oyster population over the same period. One consequence is that commercial operations have been discontinuous. The key to this variability lies in natural fluctuations in parameters controlling reproduction and survival which are often not readily detected and appreciated. They are clearly unrelated to sedimentological factors because the loch is a sheltered and stable regime which is rarely subjected to dredging.

A further major contributing factor is that Loch Ryan Oyster Fisheries' methodology for evaluating stock was sufficiently crude that little reliance could be placed on it. It depended upon a work boat towing an oyster dredge a known distance across the loch bed, recovering and counting the live oysters and multiplying the area covered by the dredge by the total area of the fishery, assuming a constant areal distribution of oysters. One major problem was that the vessels used had no position fixing equipment on board and used visual transits to estimate trawling distances. As a result, estimates of oyster density were unreliable.

In the circumstances, the Defence case concentrated upon the fact that this was, in reality, a biological controversy and no substantive evidence could ever be provided by the Plaintiff that the alleged loss of oysters had actually occurred. The key arguments hinged upon population dynamics, statistics, sampling procedures and criteria. Sedimentological issues were secondary and entirely peripheral, although the Plaintiff had brought these questions into the focus of the dispute by alleging burial by mud liberated from the dredging as the principle cause of the loss. The Plaintiff was further seriously constrained in pursuit of his claim by his lack of any contemporary records or evidence of sedimentological impacts. The entire case was hindcasted using nebulous retrospective evidence. Nonetheless, it was a serious dispute which, initially at least, gave British Railways Board staff cause for concern.

The Loch Ryan Oyster Fishery was principally located in the inner loch south of Wig Sands and Cairn Point (Figure 2). The approach channel to the Stranraer ferry terminal was flanked by commercial oyster beds in the 1970's. The oysters bred on a highly irregular basis, partly dictated by water temperature and grew on the sea bed or on cultch (shells, tiles, brick debris, etc.) laid by the oyster farmer. In the mid-1970's, British Railways Board applied to DAFS for a license to carry out a capital dredge scheme to deepen the approach channel and turning basin at Stranraer and to dispose of 1 million m^3 of spoil in the loch entrance. An agreement was reached with Loch Ryan Oyster Fishery that payment would be made for oysters removed from the channel itself.

A pre-dredge survey was carried out on the nature of the bed materials and *in situ* quantities to be removed. It was found that 653,000 m^3 (68%) of the material needed to be moved from the turning basin and 211,000 m^3 (32%) from the channel. Several metres had to be removed from the turning basin and a maximum of 90 cm (but more commonly 30–60 cm) from the channel. Some 12% of the total, chiefly in the turning basin, consisted of over-consolidated red silt and boulder clay. The remainder was an organic silt with shell debris which became more sandy seawards. From 36 boreholes in the area, the average content of channel material proved to be 39% sand grade or coarser and a further 41% of the remainder silt, coarser than 6 μm. Consequently, only about 20% of 211,000 m^3 of channel material was finer than 6 μm and approached the clay grade.

The dredging was carried out between November 5, 1978 and March 17, 1979 using a continuous ladder bucket dredger (Figure 3). This dredger was specifically chosen on grounds of its ability to dig the over-consolidated red silt and boulder clay, but also because its slow digging speed keeps sediment disturbance to a minimum. Within this

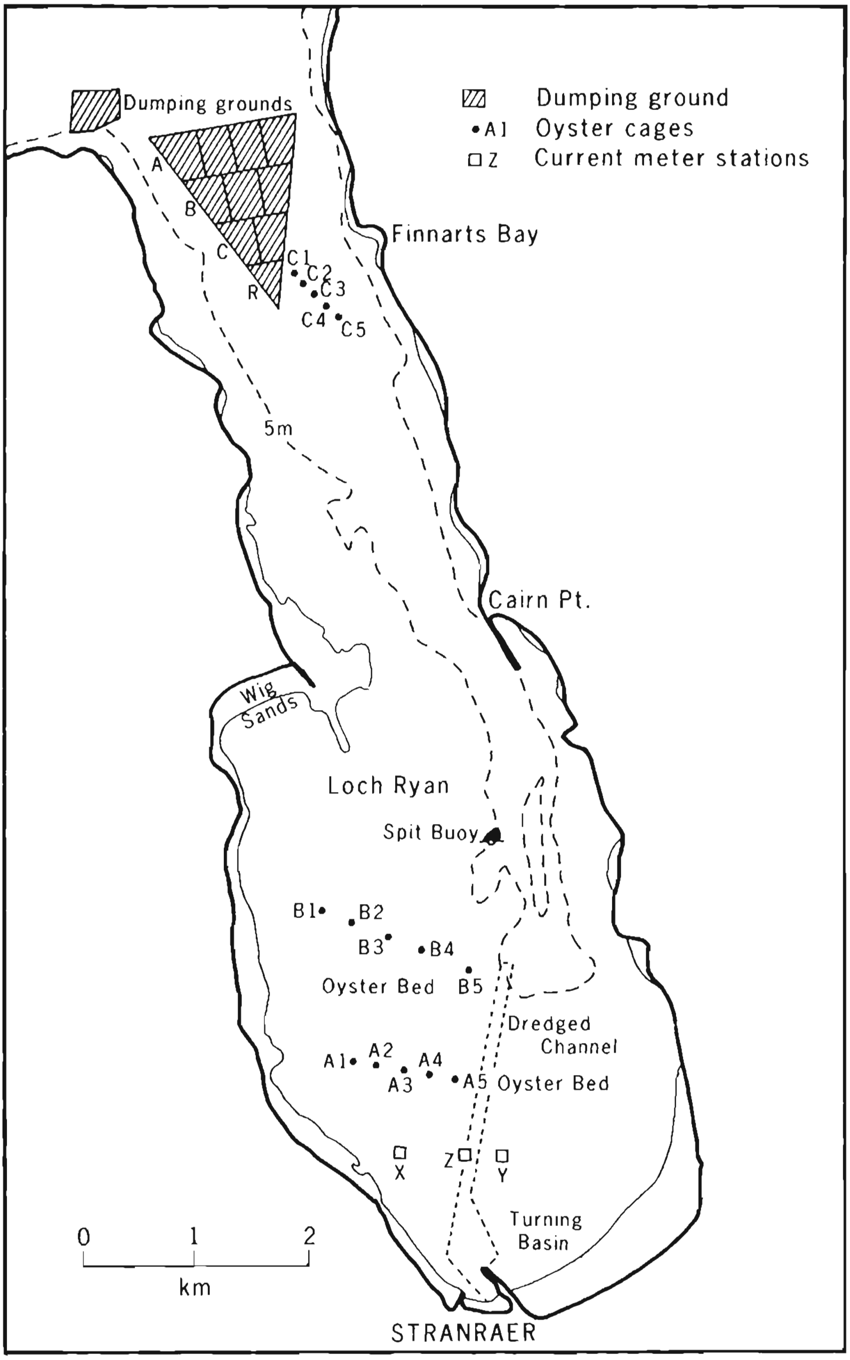

Figure 2. Loch Ryan showing ferry terminal and approach channel to Stranraer, dump sites, main oyster beds and some monitoring stations.

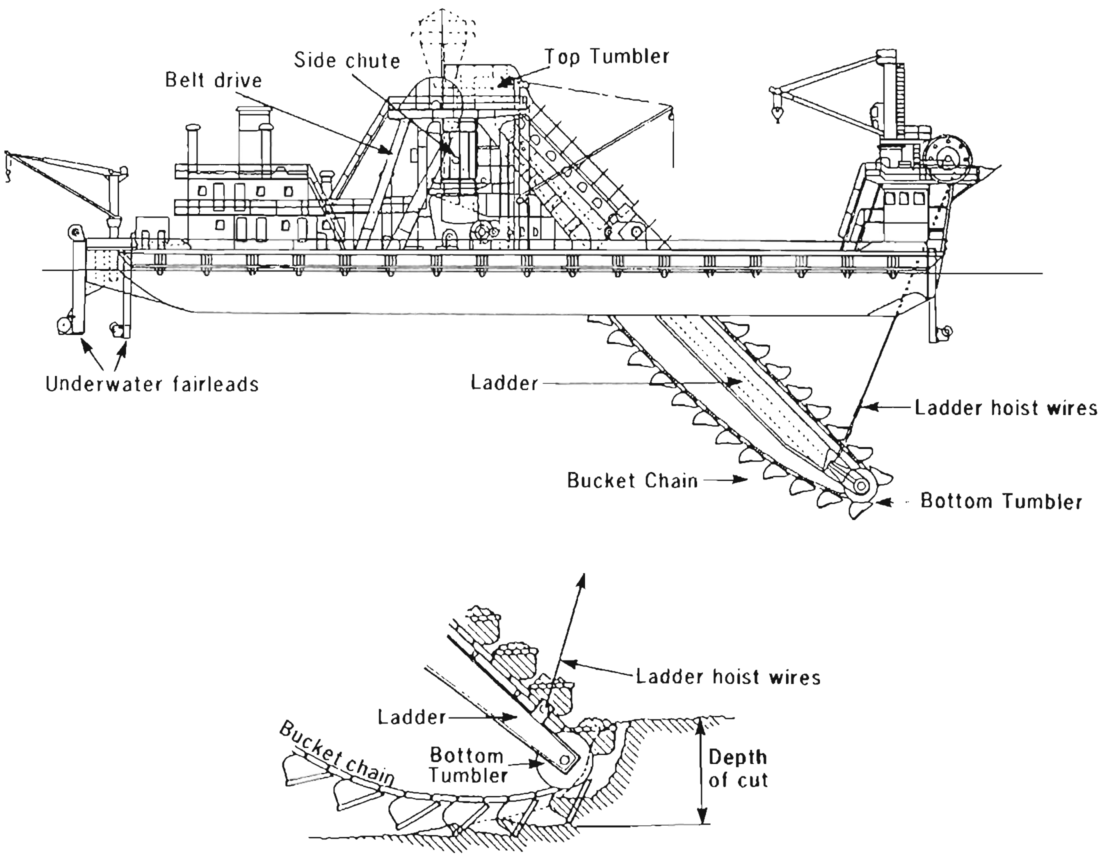

Figure 3. Continuous ladder bucket dredger.

period, the relatively small amount of channel dredging was undertaken between December 18, 1978 and February 28, 1979. The channel cut was 100 m wide and the dredger worked by traversing to and fro across the channel in a series of arcs controlled by wires and anchors. The down-channel traverse speed was approximately 1.3 m/hr and varied from 32 to 75 m/day depending on whether 12 hr or 24 hr working was in progress. The average rate was 43 m/day. Tidal streams run perpendicular to the channel and are very weak. In addition to the relatively rapid down-channel traverse rate, it was only during the short period when the dredger was tight up against the channel margin and the tide was flowing from its opposite side that any spoil could be spread laterally onto the channel margin.

Subsequent to the pre-dredge hydrographic and coring programme, a semi-continuous post-dredge survey with echo sounders was carried out to prove the depths achieved before the dredger had moved on too far. These echo sounder records were preserved and turned out to be of further value to the Defence.

Prior to and on a semi-continuous basis during the dredging operations, suspended solids samples were also collected. Some 2,034 samples were obtained by consultant biologists ABBOTT and PERKINS (1980), 227 by BR Scientific Services and 211 obtained independently by the licensing authority, DAFS. The samples were obtained from heights 1 m below the water surface, at mid-depth and nominally 0.3 m above the bed at relevant localities. These included sites around the loch prior to operations commencing, around the working dredger at various distances, in the turning basin and at a number of times in the channel, in and out of the spoil plume, at and around the spoil ground, around the dump barges, around a moving ferry and in the breaker zone during inclement weather. The fact that the nearbed zone could not be monitored by the apparatus chosen turned out to be an Achilles heel of the data set. Nevertheless, the operation was otherwise closely supervised and monitored.

Separately and independently, DAFS deployed sets of predator-proof caged oysters in three groups of lines with five cages per line. These were located up-loch from the spoil ground and in lines perpendicular to the channel. One set of five was moved from the area of the turning basin to the outer channel as the dredger moved. DAFS also carried out parallel sea bed monitoring to assess any sedimentological impacts on the fauna. Two bed drifter experiments to assess spoil dispersal from the dump site were carried out.

Loch Ryan Oyster Fishery Evidence

The Plaintiffs claimed that a large quantity of very fine grained sediment had been liberated by the dredger and that this had formed a dense fluid mud layer. It was claimed that 75,000 m^3 was unaccounted for in dredging returns. It was alleged that fluid mud deposits 0.5 m deep had spread out to 1,000 m either side of the 2.5 km long dredged channel and smothered the oysters. A continuous veneer would have represented 2.5 million m^3 of fluid mud, more than ten times the volume of the channel material *in situ*. Both physical burial and death due to asphyxia in the deoxygenated suspension was specified. In fact the fluid mud was postulated to have formed patchy pools and to have been redistributed elsewhere in the loch 20–30 times per year, killing oysters on every occasion and leaving little trace other than in its final resting place, where a 4 cm layer was alleged. Dewatered fluid mud layers were allegedly recognised from organic fraction analyses in serial-sectioned core samples. Every core presented to the court had one or more low organic content zones within them, which were alleged to be the consolidated fluid mud deposits.

British Railways Board Evidence

(1) In respect of materials properties, it was pointed out that 12% was over-consolidated red clay and boulder clay and could not have been redistributed. Of the remainder, some 40% was sand and a further 40% silt coarser than 6 μm. Such materials do not generally form fluid muds owing to the high settling velocities of individual grains. Fluid muds tend to have a higher clay content. Grain size analyses were checked against other sediment analyses for a creamery waste outfall in the loch, which proved similar. Only 32% of the total sediment dredged came from the channel and could possibly have spread to its margins.

(2) The sediment thickness for most of the channel length varied between 30 and 60 cm. To give rise to a 4 cm sediment layer on one margin would require 13.3% and 6.6% respectively of the total sediment thickness in the channel to be redistributed on the margin. Where continuous ladder bucket dredgers have been monitored elsewhere, losses lie in the region of 1% and for the most part return to the immediate site of dredging. On grounds of the grain size and dredger working pattern, the claimed losses were consequently unlikely. Insufficient sediment is available to produce the equivalent to 4 cm of settled mud in the 45 minutes during which the dredger traversed each metre length of channel.

(3) The material was generally firm and cohesive *in situ*, with the result that much of the disturbed material would return directly to the bottom beneath the dredger as mud lumps. Current velocities measured at 3 stations showed low velocities (< 10 cm/sec) near the bed and the water depth at the channel margin was generally about 5 m, with a neap tidal rise and fall of 2 m. In these conditions either linear or exponential spoil plume dispersal models and using worst case concentration values gave a range of results depending on the model used and the Stokes settling velocity applied. The heavy part of the plume was always deposited within 20 m of the dredger while the outer, dispersed part of the plume containing the finest sediment had a maximum concentration close to 100 mg l^{-1} and never extended further than 100 m to one side of the dredger. If a 100 mg l^{-1} suspension is continuously supplied and sedimented in 5 m of water for six hours and allowed to consolidate, the resulting mud layer is less than a tenth of a millimetre thick. More realistic exponential models showed a smaller spread than simpler linear models. It was evident that the dense part of the plume would always be contained within the channel and the most distant edge of the dispersed part of the plume would rarely impinge onto the channel margin.

(4) The pattern of dredger operation had a major influence on the sites of plume settlement. The vessel moved down-channel at 1 m every 45 min-

utes as well as to and fro across the channel. Only for very short periods when the dredger was working at the edge of the channel and the tidal stream coming from the opposite side was any spoil likely to reach the channel margin. Whether the tidal periodicity and the dredger traversing were ever synchronised in this way was not recorded. If the tidal stream was running off the channel margin close to which the dredger was located, the plume would spread back across the channel. Similarly, with the dredger towards the channel axis, almost all the displaced spoil would return to the sea bed. It is clear that for a large proportion of the time, the dredger would be in the channel and the current would carry any disturbed sediment back across it. Any spread would be to one side only in all circumstances. The evidence is that most sections of the channel margin would receive no silt.

(5) A geochemist gave evidence on behalf of the Defendants that all organic contents measured were within background levels for Scottish sea lochs and showed normal variability with depth.

(6) Of the total 2,472 suspended sediment samples, only 12 had a suspended solids concentration in excess of 1.0 g l^{-1}. Of these, seven were from the spoil ground, three were natural elevations from the breaker zone and one was prop-wash from a ferry. Only one was from the spoil cloud around the dredger. This sample came from within 20 m of the bucket ladder and had a concentration 1.5 g l^{-1}, still 20–50 times lower than the normal low range for fluid mud. No elevations even to this modest level occurred from channel margin samples.

(7) Bed drifter recoveries and bed topography showed that there was no return pathway for fluid mud from the spoil ground. The nearest buoyed oyster cage to the spoil ground showed a good survival rate.

(8) After becoming acquainted with the suspended solids data, the Plaintiff claimed that the near-bed samples were not taken close enough to the bed and that a fluid mud layer would have existed in the lower 0.5 m of the water column and hence was not detected by the monitoring campaign. In Defence, it was calculated that a 4.0 cm settled mud layer would occupy about 45.0 cm at 50 g l^{-1} as the alleged fluid mud layer. Accordingly, the entire set of post-dredge survey echo sounder records were examined. Any fluid mud which might have been generated would be most likely to occur close to and behind the dredger while the operation was still in progress and where post-dredge surveying was concentrated. In no single case was there any sign of fluid mud, let alone approaching 0.5 m detected. This is consistent with the grain size and consolidated nature of the material and type of dredger employed.

(9) The grain size of the material is such that any displaced spoil would have consolidated within four days at most and not been liable to repeated redistribution.

(10) Yearly monitoring of the dredged channel until the time of the court hearing showed no redeposition. Had any fine sediment been spread across marginal shoals and had such sediment remained fluid and been moved around 20/30 times per year, a significant proportion would have been redeposited in the sediment trap formed by the dredged channel.

The 75,000 m^3 of spoil allegedly unaccounted for was in reality the difference between the quantity specified in the license application and that actually produced by dredging. There is no implication that any proportion went missing.

(11) Of the effective 15 oyster cages laid along the channel margin, one was not relocated. With the exception of the one, the remaining cages were all sediment free. The sedimented cage was found to be completely jammed with consolidated mud, consistent with being snagged and dragged into the consolidated bed deposits. Good survival in the other cages proved the alleged fluid mud had never existed.

(12) Other faunal dredge surveys carried out independently by DAFS showed that the normal, non-commercial equilibrium fauna of the site was unaffected by an environmental change. There was no indication of excess mortality. Some living oysters were still to be found throughout the area also. The Plaintiff claimed that the fluid mud layers had not only been ephemeral but also very patchy and this had led to a selective kill. This was countered by demonstrating that fluid mud deposits even when very thin almost invariably form continuous veneers. If present, they would have smothered both oysters and the entire non-commercial fauna.

(13) Measurements of dissolved oxygen concentration were made during the dredging operation and these invariably show a water column saturated with oxygen. There can have been no asphyxiation.

(14) Oysters are organisms well adjusted to ep-

isodic increases in suspended load. In this case, any enhancements were very local to the channel and of very short duration. Even close to the channel, oysters could cope with any enhancements by closing for a short period.

(15) It was evident that the harrowing and oyster dredging activities of the oyster company had a significantly greater impact on the margin of the channel than this low energy dredger with its single rapid traverse of the channel.

ARDMILLAN BAY

Background

Cuan Sea Fisheries (CSF) had satisfied existing requirements for a shellfish license in Britain and Northern Ireland by submitting a sketch of the proposed installation; *i.e.*, 1 trestle, and a site plan to the landowner, The Crown Estates Commission. An issue at the core of the dispute was that CSF had made no attempt to carry out a site investigation survey and indeed were unaware of what such a survey might entail. At the present time, shell-fish farms of any size can be set up without any feasibility study being required of its physical effects. CSF had judged the stability of the intertidal mud flats by eye. The related suspended sediment regime had not been evaluated other than to observe that it was generally low. A small number of trestles were placed at three separate localities to evaluate their behaviour. Eventually, almost all of the effort was focused at one locality, Straiddorn Creek.

The site was established on a small scale, experimental basis from the mid-1970's with trestle and tray culture at ankle height. The farm manager changed in 1978. The new manager redeployed the trestle arrays following criteria aimed solely at optimising growth and easing tray handling. Consequently, trestles were built at knee height and closely following the position of Low Water of Spring Tides on either side of the creek. Access to the site was gained by boat and the site was worked by walking on the few, low water spring tide periods each month when the trays and trestles were exposed. No other criteria were considered necessary.

The farm expanded rapidly following a large cash injection in about 1980, and the numbers of trestles and trays steadily increased through 1981, 1982, 1983 and 1984. During the winter of 1982–1983 and increasingly in 1983–1984, the array of trestles began to be inundated by silt deposition. CSF did not know how to combat the incursion and sought no outside advice. Instead they tried to safeguard their stocks by a crash programme of raising the trestle height. No consideration was apparently given to moving stock out of the area. At the start of the 1984 season, it became apparent that a major catastrophe had overtaken the farm and that a large proportion of the 8 million stock were buried under mud (Figure 4). At this time, CSF was two-thirds of the way through an investment and trestle expansion programme in Straiddorn Creek.

In 1978, CSF had expressed concern in writing to a plan to eradicate the marsh grass *Spartina anglica* on an experimental basis from two areas of the foreshore at Trench Bay and Ringneill Bay adjacent to the oyster farm (Figures 5 and 6). Correspondence makes it clear that it was chemical effects of the herbicide, Dalapon, which were the principle concern. Assurance was sought that the food of oysters and the shellfish themselves would be unaffected. CSF were assured that there was no risk of such effects, and in October 1978 about 2 hectares were sprayed in Ringneill Bay using a farm tractor fitted with a spray boom. A follow-up operation was carried out in 1980 when the same core area and some peripheral strips (2.2 ha) were resprayed. In August 1979, an attempt was made to spray the Trench Bay *Spartina* marsh. This marsh had established earlier than at Ringneill on a recent incursion of mud. These two factors resulted in mud depth being greater and the tractor sank almost to its axles, with the result that there was a risk of the vehicle becoming stuck and partly overwhelmed by the tide. Furthermore, the spray booms were brushing through the tops of the *Spartina* grass, as opposed to forming a coalescing cloud above. Consequently, the tractor was withdrawn from Trench Bay. Subsequently, it proved that a good kill was achieved in Ringneill Bay whereas virtually no kill was achieved in Trench Bay. Subsequent minor operations using a knapsack sprayer to kill re-growth in wheel tracks at Ringneill were carried out in 1981 and 1982, and the limited scale experiment was considered a success. In 1983, the area was designated a "Shellfish Water" and no further Dalapon spraying could be carried out. In 1979 and 1980, the *Spartina* first died back, aerial foliage was removed and the marsh began to recolonise with native *Salicornia* and *Puccinellia* species, which were more acceptable to the conservationists. With the banning of further

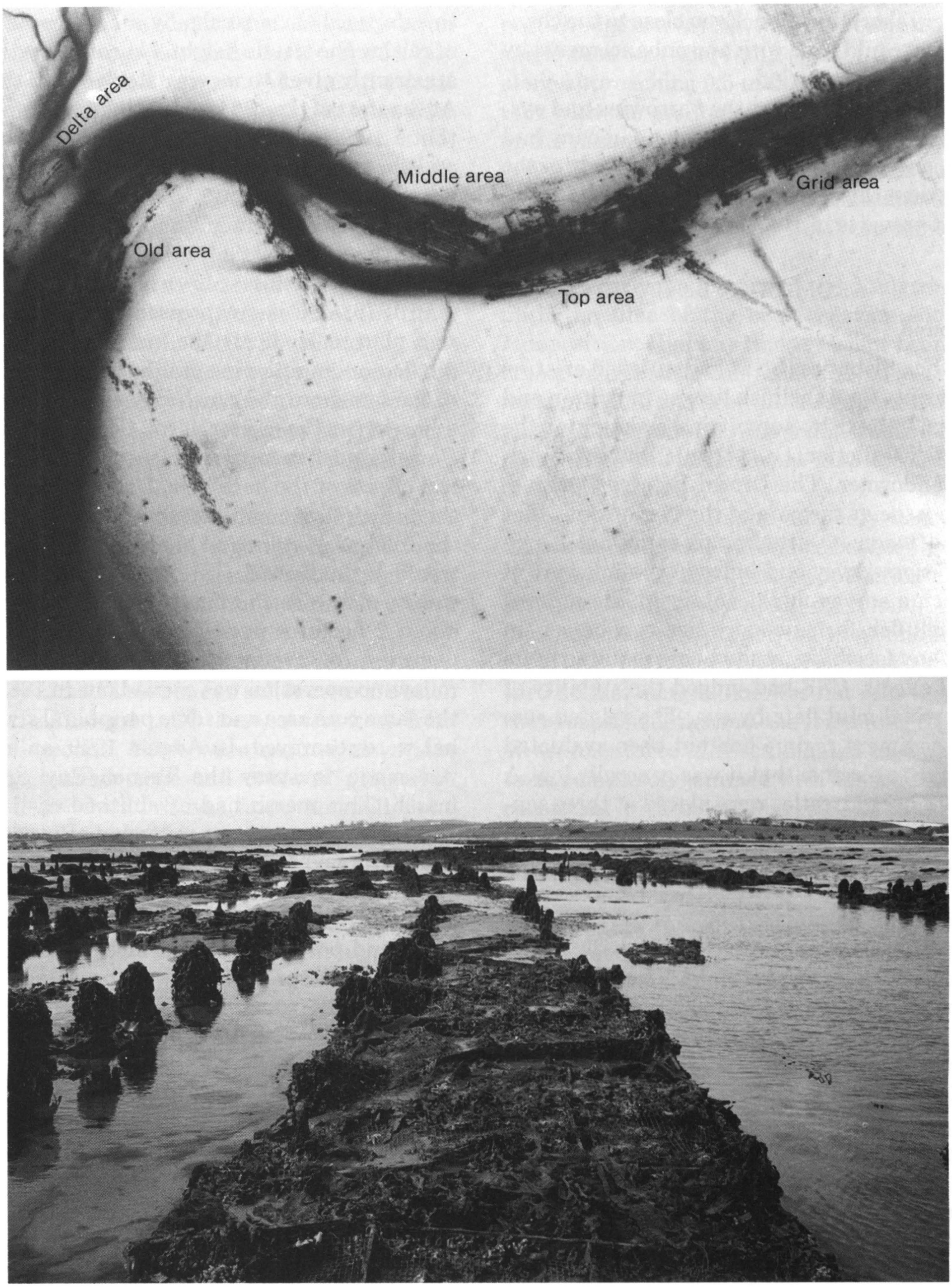

Figure 4. (Upper) Enlarged section of vertical air photograph taken at Low Water in April 1988 showing buried oyster trestles in Straiddorn Creek, Ardmillan Bay. Reproduced with permission of the RAF. (Lower) Ground photograph of left bank of Straiddorn Creek at Low Water taken April 27, 1990 looking seaward in "Grid" Area showing silted and collapsed trays and trestles.

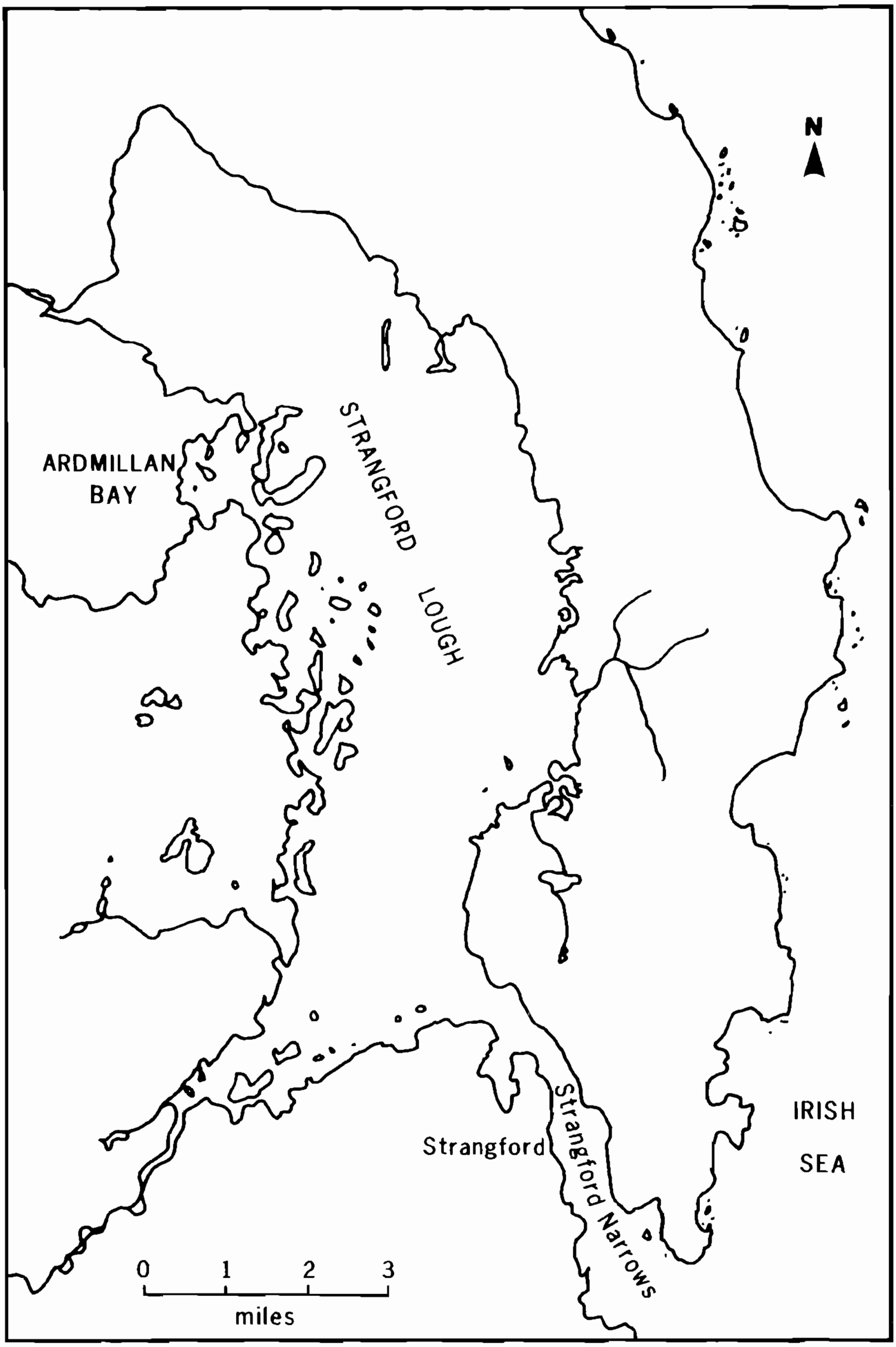

Figure 5. General locality map showing the site of Ardmillan Bay on the west coast of Strangford Lough.

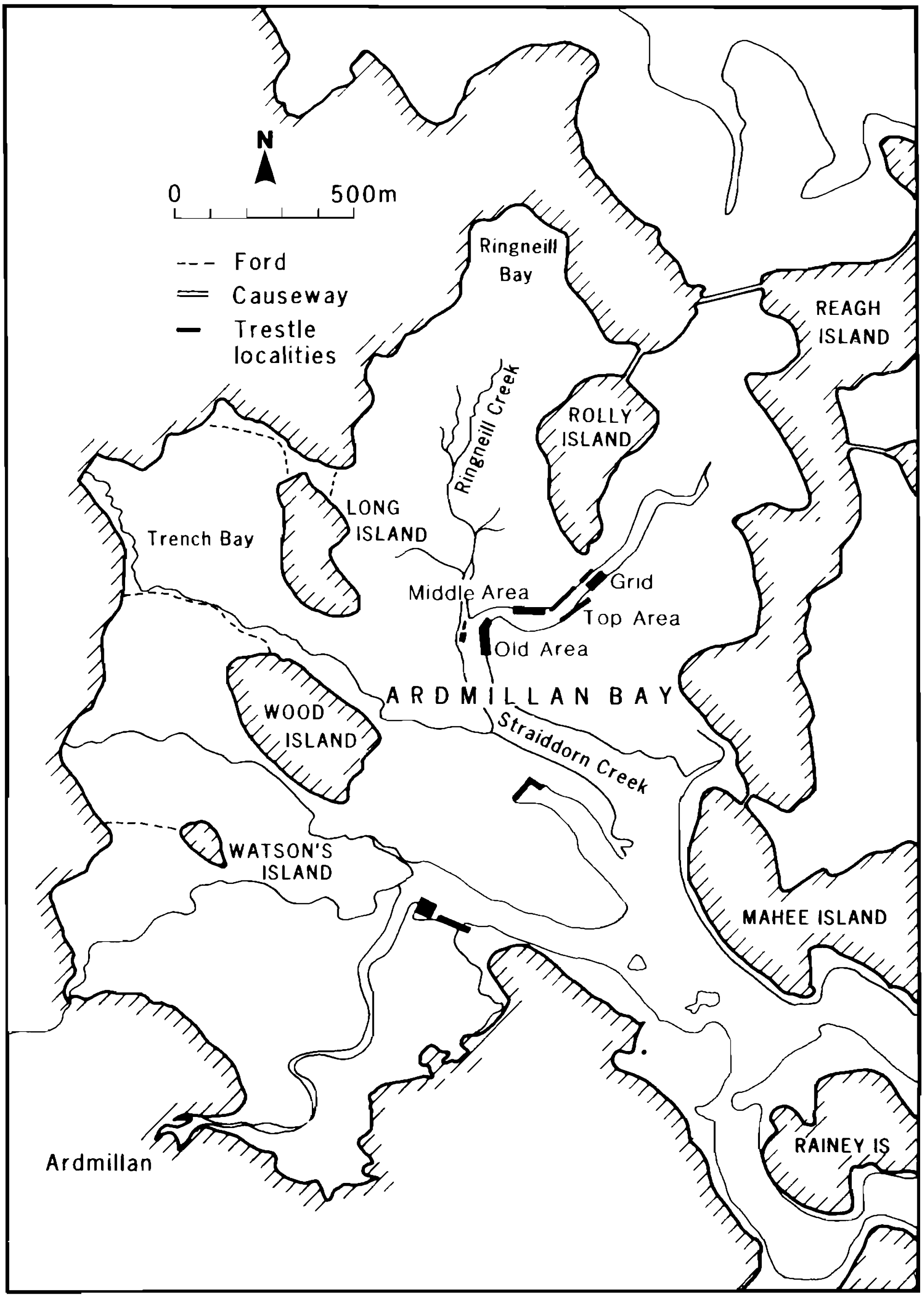

Figure 6. Ardmillan Bay showing position of oyster trestles and localities mentioned in the text.

spraying, however, *Spartina* subsequently spread back across the defoliated area from localities omitted in the experimental campaign. In 1990, *Spartina* had still not reached its former 1979 seaward limit. The total area of the intertidal zone in Ardmillan Bay is 279.2 ha, much of it very soft mud flats. There are 23.4 ha of *Spartina* marsh in the entire bay, 4.3 ha of which lie in Ringneill Bay and 2.2 ha was defoliated for a very short period. This 2.2 ha represents 0.8% of the entire intertidal zone.

CSF claimed following the 1983 and 1984 silt smothering that muddy sediment liberated from this defoliated marsh had caused the loss of the oysters and lodged a damages claim with the governent departments and representatives listed. The marsh was actually owned by the local authority, Ards Borough Council, and it was they who had carried out the spraying with the tractor. The Conservation Branch of the DOE were named in the writ because they had grant-aided the purchase of the Dalapon and coordinated spraying activities in Strangford Lough in general.

Cuan Sea Fisheries Evidence

A plant biologist gave evidence that the defoliated marsh would have been eroded by waves. He placed oranges in the tidal channel draining Ringneill Marsh on the ebb tide and showed that these reached the oyster trestles. In refutation, it was demonstrated that the movement of floating oranges does not replicate the erosion, transport, and settling behaviour of cohesive sediment. Furthermore, a *Spartina* marsh in Dublin Bay in an equivalent sheltered position to Ringneill Bay used as an example was shown not to have been eroded following defoliation with Dalapon.

A geographer took samples from three sites in the bay, at Ringneill *Spartina* marsh, the oyster trestles at Straiddorn Creek and a sandy site elsewhere. Grain-size and geochemical analyses of the few samples from these three contrasted sites were used to attempt to provide a statistical link between the marsh and the oyster trestles and a contrast with the sandy site. In refutation, it was shown that the grain size of the oyster trestle samples at Straiddorn Creek was most comparable with tidal flat samples from the surrounding tidal flats. In respect of organic content, reflected in Loss on Ignition and Phosphorous concentrations, it was pointed out that:

(1) Organic content was within normal background levels for intertidal sediments.

(2) Many sediment samples from the surrounding tidal flat around the oyster trestle site had the same or similar organic concentrations.

(3) The high organic content of oyster trestle samples was not a unique manifestation of contamination by sediment rich in *Spartina* debris because other sources of organics in the oyster trays and trestles included:

3.1 The bladder wracks *Fucus* and *Ascophyllum* overgrown on trays and trestles.
3.2 The alga *Enteramorpha.*
3.3 Rafted-in kelp.
3.4 Overgrowth of filamentous algae.
3.5 Colonial sponges.
3.6 Pseudofaecies deposited by the oysters.
3.7 The emanations of the dead oysters themselves.
3.8 Had the case gone further the work of SORNIN *et al.* (1986) which shows living oysters themselves are major phosphorus fixators would have been produced. This documents the transference of dissolved phosphorus in the water column into the interstitial waters and sediments beneath and around oyster farms.

The statistical basis of the few samples analyzed was also strongly challenged.

A zoologist gave evidence that the presence of finely divided *Spartina* debris in the sediments smothering the oyster trestles at Straiddorn Creek proved that *Spartina* and sediment came from Ringneill Bay (or Trench Bay) only, and moreover had travelled together with its containing sediment to be deposited in 1983. It was claimed that *Spartina* could be determined from fragments as small as 6 cells. This conclusion was also disputed.

(1) A parallel study revealed that the only diagnostic tissue in *Spartina* plants is the inner crenulated cells of the epidermis. These had not been recognised by the CSF adviser.

(2) These epidermal cells apparently have a very short lifespan in the natural environment even though other non-diagnostic woody xylem material is more persistent.

(3) *Spartina* has colonised the bay since 1942. It dies off annually and at various times has colonised the shore all around the trestle site. Consequently, if it had been found entombed in sediment, this would not be a surprise and would not permit separation of 1978 defoliation from that produced naturally in the other 50 years before and after.

(4) Macroscopic *Spartina* debris did prove to be distinguishable at a number of other sediment sinks in Ardmillan Bay, not just in the oyster trestle site. This demonstrated that *Spartina* was widely distributed and not confined to the oyster trestle area.

(5) *Spartina* debris and silt and clay particles do not move in response to the same hydrodynamic forces. *Spartina* debris floats or moves as neutrally buoyant, water-logged particles. This differs from the erosion, transport, and settling behaviour of flocculated cohesive sediment.

(6) Core sample data presented as evidence not only had the defect that *Spartina* debris identification was highly suspect but, moreover, had no time frame with which to date the sediment succession. There was no way in which zones within a few short cores alleged to show enhancement in *Spartina* debris could be related to the timing of the spray campaign.

A sedimentologist who had carried out an examination of the area gave evidence. It was asserted that the *Spartina* marsh had preserved within it both macroscale evidence and grain size characteristics which demonstrated that it had been eroded. Air photographic measurements were used to show tidal flats were depositional and rising slowly at the rate of a few millimetres per year. They were alleged to be in equilibrium and not subject to short term, episodic, level changes. They were alleged to be stable and bound by microalgae. Such allegation was essential if blame was to be placed squarely and solely on the defoliated marsh. The quantities of sediment alleged to be eroded from the *Spartina* marshes at Trench Bay and Ringneill Bay precisely matched that deposited around the oyster trestles. The latter, moreover, were described as being intrinsically self-scouring and not susceptible to sediment incursion in the normal course of events. This evidence was shown to be erroneous on all counts.

(1) Four macroscopic features of the *Spartina* marsh said to demonstrate previous erosion at some stage were all recognised to be original features of the marsh detectable on pre-spraying photographs and at other unsprayed marshes nearby.

The four original features of the marsh are:

(1.1) A fronting microcliff. This is present elsewhere in the embayment at unsprayed marshes.

(1.2) Surface irregularity. This is due to the initial *Spartina* colonising a sand flat forming mounds which later become draped in mud after the colonies coalesce.

(1.3) Low, linear ridges and furrows perpendicular to the shore spaced at approximately 15–20 m. These represent a relic of the initial colonisation along barely perceptible local interfluves in the surface. These have become emphasised by preferential deposition.

(1.4) Cross-sections of mud thickness across the marsh showing thinner marsh deposits to either side of an axial stream were said to prove erosion from the thinner areas. Thickness variation was not disputed but was conclusively proved from air photographs, pre-dating the spraying, to be the site of previous bare patches which had been colonised by *Spartina* at a very late stage. As a consequence, the mud was naturally thin.

(2) Trench Bay was shown from contemporary air and ground photographs to have never lost its vegetation cover.

(3) Measurements of skew values of individual sediment samples used to distinguish "eroded" and "non-eroded" marshes from their grain size characteristics were shown to be invalid. Whether a sample is from an erosional or deposition site cannot be specified from a single grain size analysis. This is especially the case for cohesives, which are not eroded by winnowing, as are sands and muddy sands. Replicate analyses by the Defendants in which Malvern Laser Diffractometer and sieve analysis were used showed good agreement. Moreover, all marsh sediment, whether defoliated at some stage or not and whether first treated with hydrogen peroxide or not and whether analyzed by Malvern Laser or pipette, all proved to have a positive skew.

(4) The air photographic evidence produced in court was invalid on two counts. Firstly, a resolution beyond the ultimate instrument capability was claimed. Secondly, one set of photographs claimed to be on a scale of 1:10,000 were in fact 1:20,000, with the result that the maximum resolution with good ground control would have been ± 39 cm whereas ± 5 cm had been claimed. Ground control was in any case not optimal. This further emphasised the disparity in claimed versus achievable resolution. In fact, in contrast, strong

evidence for the erosional nature of much of the mudflats was produced by the Defendants.

(5) No evidence was produced that the tidal flats were in equilibrium, other than the statement that all tidal flats are.

(6) At various stages the alleged mechanism of erosion of the *Spartina* marsh sediments changed three times, from gales as an initial hypothesis, to continuous wetting, dilation and daily grain by grain removal to, thirdly, requiring some major overturning and winnowing mechanism of an unspecified nature. The continuous grain by grain erosion hypothesis directly contradicted earlier anecdotal evidence from the oyster farmer.

(7) Quantities deposited at the trestle site only matched those at the *Spartina* marsh on the assumption that Trench Bay had been defoliated and that no derived sediment had been spread onto surrounding tidal flats.

(8) The hypothesis that the oyster trestles accelerate the currents and prevent deposition is refuted in a more appropriate section later.

The Director of the Shellfish Association of Great Britain gave evidence. The thrust of this evidence was that no precautions had been taken in Ardmillan Bay to prevent sediment deposition around the oyster trestles because it never happened in Britain. Furthermore, first hand experience from the Irish Republic, France, New Zealand *etcetera* where farms of equivalent size to those in Ardmillan Bay occur, was resorted to. These allegedly also never experience silt deposition problems.

This evidence sat uneasily with information familiar to the Defendants from sites at Salcombe (Devon) and Milford Haven (South Wales), where oysters have been grown on fixed structures on tidal flats close to the sites of the nodal point in the estuarine fine sediment circulations of these estuaries. Moreover, the evidence was at variance with discoverable letters to the Plaintiff from insurance companies which explained that the insurer was unwilling to countenance claims for losses due to sediment encroachment "arising from the large number of recent claims" received for such damages. Subsequent to the giving of this evidence, a substantial quantity of long-awaited information from France came into the hands of the Defendants. This evidence would have been contributed during the Evidence in Chief of this author. In summary, SORNIN (1981) has considered sites around the French coast where shellfish cultivation sites are subject to sedimentation problems (Figure 7). Other relevant information is found in the works of AUBIN (1979), DGMM (1979) and LARSONNEUR (1989). One of the most detailed studies is that of NIKODIC (1981). Within this extensive investigation, Nikodic quotes Decree No. 813, p3 of March 17, 1975 related to poche cultivation for the French oyster industry. This establishes six criteria for trestle layout and design:

(1) The overall width including the poche must not exceed 1.2 m.

(2) The total height including the poche must not exceed 1.2 m.

(3) Poche must be no more than one deep.

(4) Lines of trestles in adjacent concessions or within any concession area must be parallel to the current and must lead on one from the other.

(5) Trestles must be placed in parallel rows according to the spacing, no more than four rows of tables per 12 m ground area.

(6) Placement of any vertical elements in the array is prohibited.

A schematic diagram of a typical mud build-up was produced (Figure 8). French work also stresses the importance of routine maintenance, such that weed encrustation and rafting, which otherwise rapidly degrades the hydrodynamic performance of the arrays of trestles, must be kept to a minimum. It was observed that the poche system presently used by Cuan Sea Fisheries is heavily encrusted with *Fucus*. These criteria, 1–6, provide some kind of a yardstick by which to evaluate the layout of the oyster farm at Ardmillan Bay.

The CSF wooden trestle and tray system presented a considerably greater obstruction to the flow than the French metal frames and poche bags in that:

(1) CSF used wooden trestles of 3–4 times greater cross-sectional area.

(2) CSF used vertical stacks of a minimum of two trays plus one lid. These three plus the trestle, provide a solid and vertical obstruction to the flow 40 cm high and 270 cm wide, far in excess of the French recommendations.

(3) CSF trestles in Straiddorn Creek follow the meanders of the low water channel with the consequence that adjacent rows of trestles are frequently at considerable angles one to the next.

On grounds of 1, 2 and 3, the CSF trestle array is considered to greatly exceed the recommended maximum density determined by French practical experience. Even worse, however, is the situ-

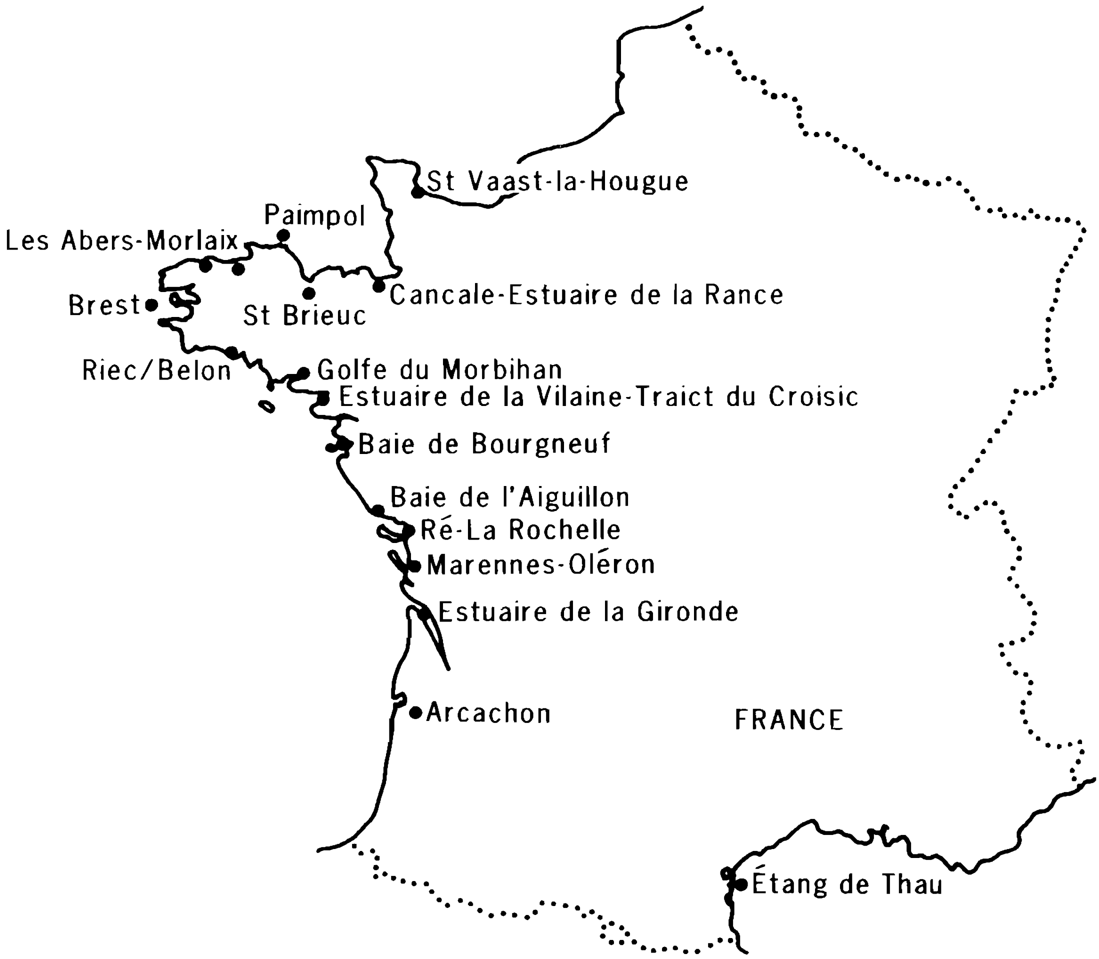

Figure 7. Locality map of France showing sites where shellfish farms are affected by sedimentation. (From SORNIN, 1981, published in AUBIN, 1979.)

ation with respect to ground coverage. French experience decrees a maximum ground coverage of 40% and even this is considered high and to require riders attached. CSF trestles were built sequentially in abutting groups in a continuous stretch of Straiddorn Creek, starting at "Old Area" and working up-creek to "Middle Area", "Top Area" and "Grid". The trestle and tray ground cover was measured and found to be 84%, 65%, 81% and 73% respectively in these four cases. The figures 84–65% assume that the trestles were fully occupied by trays. Air photographs supplied by the Plaintiff taken in 1985 reveal that this is a reasonable assumption. It can be concluded, therefore, that the type of wooden trestle and tray installation, its alignment, and density were all grossly excessive in Straiddorn Creek. This clearly is what led to silt incursion.

In a further parallel between French experience and that reported by this author from Straiddorn Creek, NIKODIC (1981) identifies the severe gales of 1978 as the cause of the tidal flat instability which led to burial of the oysters at Cancale in the Bay of Mont Saint Michel. Similar severe gales in the winters of 1983 and 1984 were the cause of silt liberation from the tidal flats, which in turn smothered the oyster trestles and trays in Straiddorn Creek. It was concluded by the author (KIRBY,

1989) that the cause of the silt incursion at Straiddorn Creek was a combination of:

(1) Interaction of trestles and trays placed rapidly and too close together during calm years 1981, 1982 and early 1983, combined with (2) severe gales in winter 1983 and 1984 which liberated tidal flat muds to be trapped in the densely packed trestles and trays.

D.O.E., D.A.N.I, H.M.(AG) Evidence

General Case

The evidence presented in court fell into two categories: first, contemporary work sheets, diaries and photographs related to the spraying operations. These were maintained by the then warden of the Quoile Centre, Downpatrick, County Down, Northern Ireland. In spite of the passage of an intervening 12 year period, these records were remarkable not only on grounds of the fact that they had been preserved but more so from the fastidious manner in which they had been recorded at the time. These records largely made up for the fact that no rigorous monitoring of the marsh had been carried out subsequent to the spraying. These records permitted retrospective and corroborative proof of the fact that the spray was preferentially taken up in Ringneill Bay, whereas peripheral sprayed areas and the main Trench Bay area had never been defoliated. Furthermore, the records showed that regrowth was most persistent in the wheel tracks, and most importantly, that the marsh had been recolonised by *Salicornia* and *Puccinellia* during 1981 and 1982. The fact that persistent regrowth of *Spartina* had occurred in the wheel tracks demonstrated that these could not have been a focus of erosion as had been claimed by the Plaintiff. Furthermore, the fact that the marsh had become reclothed with native salt marsh species during 1981, 1982 and early 1983 proved that the alleged coincidence of a bare and defoliated *Spartina* marsh and deposition around the oyster trestles was fallacious. In fact, there was a 3–4 yr delay between the small area of marsh being defoliated and the overwhelming of the oysters. Contemporary evidence held by DOE related entirely to the *Spartina* marshes and no observations of the tidal flats or oyster trestles were available. A witness, who had not had the opportunity to testify when the case was settled, had farmed the low-set trestles prior to 1978 and had experienced silt incursions among these following gales.

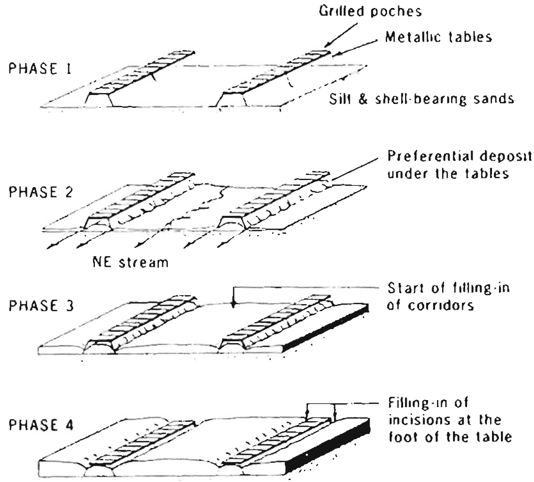

Figure 8. Sequence of oyster trestle burial by mud. Example illustrates a general case, but arises from research at Cancale, Bay of Mont St. Michel (Nikodic, 1981).

The second category of evidence related to data collected during 1988–1989 specifically for the purpose of the defence (Kirby, 1989). The report had to be compiled and written in a format suitable for appreciation by a learned judge who was, nonetheless, a lay person in respect to the physics, chemistry and biology of cohesive sediments. The report began with a historical appraisal of changes in Ardmillan Bay through time. This recognised a number of the key issues concerning the reasons for the oyster trestles being overwhelmed. The report then went on in turn to address three issues:

(1) What is the experience elsewhere when Dalapon and other chemicals have caused a marsh to be defoliated? This was tied to a detailed and specific field study of Ringneill and Trench Bay *Spartina* marshes. The purpose of this was to permit the judge to evaluate whether the Ardmillan Bay marshes behaved in an identical fashion to other treated marshes. It was concluded and demonstrated in the report that the behaviours were in all respects comparable, and no single example of an accretionary *Spartina* marsh being eroded following defoliation has been reported.

(2) What is the long and short term dynamics of tidal mud flats derived from summarising the scientific literature? How does this compare with

Ardmillan Bay? A major field investigation programme involving a number of interlinked facets was carried out between December 1988 and eventually carried through to October 1990. It was shown that the tidal flats of Ardmillan Bay were predominantly erosional in their seaward reaches, whereas deposition was in progress in certain long term sediment sinks and on the peripheral *Spartina* marshes. The short term sediment dynamics showed the same cyclic changes in level that have been reported in the 12–15 scientific papers reviewed and supplied to the court. Over the 22 months period eventually monitored, the tidal flats "waxed" by preferential accretion over the two "summer" periods and "waned" in winter due to the absence of algal binding, combined with the effect of gales. Simultaneous weather records, especially wind speed and direction, were found to fit very closely with the pattern of level change detected. It was concluded that the dynamic behaviour of the tidal flats in Ardmillan Bay was identical with that measured in research investigations carried out elsewhere in the world.

Weather records for the past 15 years were evaluated and it became clear that the period 1981 and 1982, when the oyster farm was expanding rapidly, coincided with unusually calm weather. In contrast, the winters 1983 and 1984 were unusually windy.

Grain size analysis of a suite of samples from various *Spartina* marshes, tidal flat and oyster trestle localities confirmed the similarity between tidal flat and oyster trestle samples and the contrasts with *Spartina* sediment. All this evidence considered together confirms that the mud which smothered the oysters came from the tidal flat.

(3) How do oyster trestles installed on tidal mud flats behave in general? How did the oyster trestles in Ardmillan Bay behave in 1983–1984?

In the absence of access to French literature in the initial report, a theoretical appraisal of oyster trestle behaviour was provided. Later the evidence contained in AUBIN (1979), DGMM (1979), NIKODIC (1981) and SORNIN (1981) was obtained. This shows that a very large proportion of French oyster trestles are affected by siltation and that the problems arise principally due to episodic events (gales). This is what had been proposed independently in KIRBY (1989). The oyster trestles in Ardmillan Bay behaved in an identical fashion to those at Cancale in 1978. They were installed with no consideration to hydrodynamic efficiency, the history of the embayment, or tidal flat dynamics and were installed far too densely. The high density did not assume an importance at initial stages of the expansion programme because the weather was unusually calm and the trestles had yet to reach a critical number and density. In 1983 and 1984, numbers of trestles and their density had increased further and severe gales occurred in both winters. It was the stirring up of local tidal flat sediment around the oyster trestles which led to their burial.

The evidence gathered between December 1988 and August 1989 was already sufficiently robust that the Defence could proceed on the basis that the alleged link between defoliation and trestle inundation was falcial (KIRBY, 1989). This was strongly emphasised by further evidence collected during October 1989–October 1990 (KIRBY, 1990) which would have been presented in the court had the case proceeded. Furthermore, the French experience outlined briefly here, further and inescapably reinforces the case being made by the Defence.

Detailed Evidence

(1) Detailed reviews of changes to *Spartina* marshes defoliated by Dalapon were carried out by WAY (1987) and MCGRORTY and GOSS-CUSTARD (1987). No evidence of erosion was detected in the 15–18 marshes evaluated. Indeed, the major problem is the reverse of that claimed by the Plaintiff. In respect to recreational beaches invaded by *Spartina*, herbicide spraying kills the grass but natural forces are inadequate to remove the underlying mud and rootlet mass necessary to reinstate the sandy beach. Furthermore, sites to dump such material removed by machines are rarely available.

Defoliated *Spartina* marshes were also studied by the Defence with no material evidence of erosion.

(2) In respect to Ringneill Bay *Spartina* marsh, not only are wheel tracks preserved 12 years after the spray campaign but the lips either side of the wheel ruts remain in several localities. This indicates a complete lack of surface erosion at the site.

At the front of Ringneill Bay *Spartina* marsh, as at many localities elsewhere, areas of "*Spartina* stubble" are to be found. These are areas where the dead rootlet system and stem bases are preserved and only the aerial foliage has been removed. The presence of the stubble and specifically the fact that the stem bases are at a higher level than the rootlet system, prove that this is the original sediment level and no sediment has been removed from the surface.

(3) The long term history of the intertidal zone was elucidated from the geological literature and field work in the area. Following sea level recession at least 2,500 years ago, only between 0 and 3 m, but generally about 30–50 cm of modern sediments overlie the older Flandrian succession. This 30–50 cm may itself be, in part, relict. The area must therefore be either non-depositional or erosion-dominated. Old peats outcrop in the intertidal zone in one area. Chalkified *in situ* valves of the species *Ostrea edulis* are scoured out in life position high on the intertidal zone in sites such as Ringneill Creek. This species only lives close to or below low water mark and must indicate both sea level recession in the past and the fact that the shore upon which it is exposed is eroding. The history of the last 150 years has been reconstructed from old maps, charts and air photographs. Ardmillan Bay has a rural location and has been minimally affected by man. The two major influences on the sedimentary regime during the last 150 years have been the construction of fords and causeways joining the various drumlin islands and the effects of the *Zostera* disease. Ford and causeway construction altered the hydrodynamic regime, strengthening tidal currents in the outer bay, and reducing water circulation in the inner bay. This may have caused or at least exacerbated the erosion of the outer tidal flats and the transference of derived sediment to the high water mark. The tidal flats are evidently steepening at present. Subsequent to these changes, formerly sandy inner embayments such as Trench Bay began to be veneered by mud. It was in an attempt to stabilize and firm this mud in 1942 that a farmer misguidedly introduced *Spartina*. The fact that mud deposition could and did become established early this century on the inner shore and showed no tendency for erosion is certain proof that a defoliated immature *Spartina* marsh, especially with the enhanced stability of its dense binding rootlet system, would not tend to erode, as the Plaintiff was at pains to try and establish.

Until about 1930, the outer shore muds were loosely bound by the plant *Zostera marina*. From this time onwards, a disease eradicated the entire species from the shore of Ardmillan Bay as well as from much of the British coast (LYNN, 1936). As a direct result, in the early 1930's, this outer zone was heavily eroded and a proportion of the derived sediment transported inshore onto the new intertidal sinks established close to the shore following causeway construction.

The construction of the causeway at the head of Straiddorn Creek rerouted its drainage and led to its steady atrophication. Clearly a creek which is steadily silting-up is an unsuitable site for oyster cultivation using fixed structures.

Evidence for the present long term erosional nature of the outer shore, in addition to the exposed fossil *Ostrea edulis* shells, comes from three separate lines of evidence:

(1) Aerial photographic evidence of the progressive exposure of drumlin cores in the outer bay.

(2) The presence of extensive zones of scour topography in the outer bay muds.

(3) The widespread occurrence of valves of the boring bivalve *Pholas dactylus* and the burrowing bivalve *Mya arenaria*, (Figure 9). *Mya* lives in a burrow up to 60 cm deep and its discovery as paired valves projecting from the tidal flat in life position is inescapable evidence that up to 60 cm of tidal flat sediment has been lost from on top since the animal was living. Furthermore, the recognition of some valves with an epiflora of filamentous algae, some with an upper epifloral zone and a lower bare zone and other exposed shells entirely uncolonised by algae, is proof that the erosion is progressing at the present time.

All of this detailed evidence demonstrated that the outer tidal flats around the oyster trestles were erosion-dominated and a likely source of the mud which buried the oysters. Furthermore, it showed that Straiddorn Creek had a marked tendency to silt-up from the time of causeway construction.

The final key to the source of the mud covering the oyster trestles was a detailed and intensive study of short term tidal flat dynamics. This was undertaken by regularly remeasuring a series of 56 stakes placed in 10 traverses, 7 stakes in 2 traverses on the Ringneill *Spartina* marsh and 49 in 8 traverses on the open mud flat. The stakes were remeasured every two weeks wherever possible and the total period of measurement eventually extended to almost 2 years. To assist in interpreting the changes in level and also to permit hindcasting back to prove the dynamic instability back in 1983 and 1984, records of wind strength and direction from a nearby site were obtained.

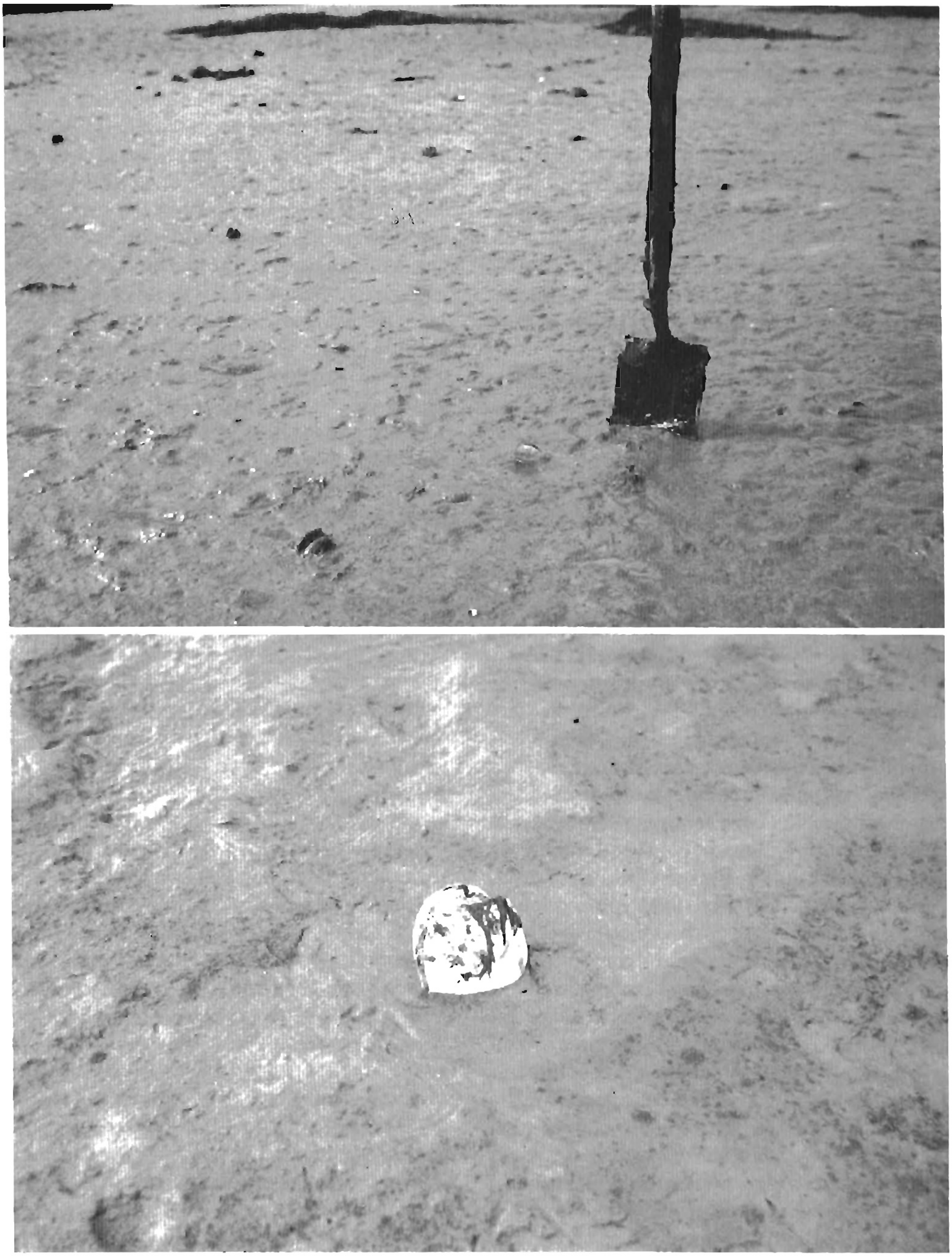

Figure 9. (Upper) Scoured out pairs of *Mya arenaria* valves in life position from Ardmillan Bay tidal flats demonstrating long term erosional trend. Locality is a broad open area, not a meandering creek bank. Large *Myas* burrow to 60 cm. (Lower) Close-up of exposed paired *Mya arenaria* valves in life position.

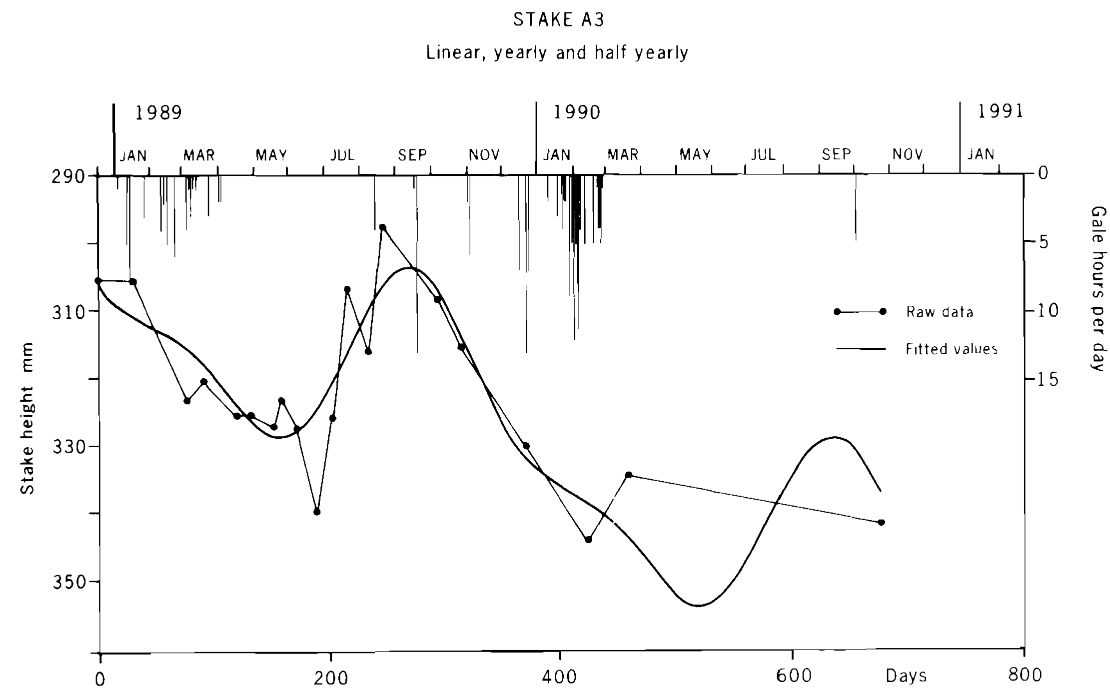

Figure 10. Time/height curve for one of the 49 tidal flat stakes in Ardmillan Bay monitored frequently over a 22 month period. Coincidence of individual gales and tidal flat lowering and also general relationship between curve and wind pattern over 22 months is apparent. Data exhibits a statistically valid linear and yearly (cyclical) trend.

Over the two-year period, the *Spartina* marsh sites showed a tendency for either negligible or very slow sedimentation, consistent with the sheltered location of Ardmillan Bay. There was a statistical tendency in the data for summer lowering and winter rise in level. This was believed to be due to desiccation and wetting respectively. In contrast, a large number of the tidal flat stakes showed a statistically valid tendency for a summer rise in level and a winter fall in level. This mirrors closely findings elsewhere. December 1988 to November 1989 coincided with a generally very calm weather period. Monitoring was sufficiently frequent and gales sufficiently infrequent that the impact of specific gale events on the height versus time curves can be distinguished. Gales on April 1-2, 1989, August 8, 1989, September 20-21, 1989, and November 1–2, 1989, all caused a distinguishable drop in tidal flat level on a large number of stakes (Figure 10). In contrast, from November 1989 to March 1990, an unusual number of very severe gales occurred. These scoured the flats to an exceptionally low level, in addition to winnowing the muddy sand substrate to the extent that a number of areas were converted to sand flats over this period.

The gales caused in the region of 27,000–52,000 m^3 of tidal flat sediment to be redistributed on a number of occasions. It is such material which is believed to have been trapped within the oyster trestle area in winters 1983 and 1984. The wind data for 1983 and 1984 proved that conditions were as severe as during the 1989–1990 winter, increasing confidence that sediment burying the trestles came from the tidal flats and not from the tiny *Spartina* marsh, as the Plaintiff had alleged. Grain size analysis of sediment still smothering the oyster trestles showed a bimodal muddy sand virtually indistinguishable from the local tidal flat. Sediments within the buried trays were slightly finer, arising it is thought, from the filtering activities of the oysters when still alive and the fact that they were initially higher in the water column.

JUDGEMENT AND SETTLEMENT

In the case of Loch Ryan Oyster Fishery versus British Railways Board, the court found in favour of the Defence. The whole of the Defence sedimentological evidence was accepted but a very small financial settlement amounting to less than £30,000 after costs, in respect to "oyster-accounting procedures" was paid. Shortly afterwards, the fishery went into liquidation.

In the case of Cuan Sea Fisheries versus DOE(NI), DANI and HM(AG), the two parties met on day 85 of the hearing. At this stage, it was calculated that the case was likely to run for another 120 days in order to reach completion. The author's own evidence had been estimated to require 60 days in Chief, in Cross-examination and Re-examination. Neither side wished the case to run for this further period and a compromise settlement was reached on the understanding that no liability was admitted or attached. The settlement was widely regarded in legal circles as a victory for the Defence.

CONCLUSIONS

The complexity of the two examples given demonstrate the importance and desirability of a learned judge having access to appropriately qualified assessors. These would not only assist the judge in reaching his decision but could also shorten the process of giving evidence.

The two examples demonstrate also the necessity for undertaking any marine operation on the basis of a sound knowledge of the physical environment in the area.

Regarding dredging operations, the case demonstrates the importance of choosing the appropriate plant, not only in relation to its primary role, but also in account of secondary impacts. Furthermore, not only is careful monitoring during operations required, but also continuous-reading instruments, capable of measurements in the nearbed layer, are essential. Campaigns to eradicate *Spartina* or other noxious weeds should only be undertaken on accreting coastlines. In a large number of areas, *Spartina* has been deliberately planted as a inexpensive coast protection measure. Defoliation of areas with a pre-existing erosional long-term trend is inappropriate. Spraying to return a habitat to a former use is most effective where defoliation operations are applied to young and immature marshes and the plant has had little opportunity to modify the substrate in which it has taken root.

In respect to "sedimentation engineering", the discipline involved in placing oyster trestles, the case demonstrates the need for a site investigation survey and thorough knowledge of the natural environment and of how it will be affected by the structures planned. Furthermore, it is evident that in the United Kingdom and Eire there are presently no design criteria of any kind to which the shellfish industry have recourse for advice in establishing fixed structures. Should large scale shellfish cultivation proliferate in these countries on a scale approaching that in France such criteria will be essential. At present there are five large farms using fixed structures in the U.K. and Eire, none of which have been laid out in response to sedimentological design criteria, one of which has already suffered extinction and was the subject of this dispute.

Not only near-field criteria, as applied in France, but also far-field criteria need to be taken into account. Such criteria have been formulated from experience gained during this case by the author.

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