EVALUATION AND LIMITS OF PROTECTIVE BOOM PLANS FOR HIGH TIDAL RANGE AND STRONG CURRENT AREAS

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ABSTRACT: *The French organization of onshore oil spill response is defined by specific intervention plans (Polmar plans), established for every coastal department. One of the main elements of these plans consists of detailed plans for deploying booms to protect sensitive areas.*

The Ministry of the Sea, with assistance from CEDRE, carries out exercises every year in different coastal locations to test the feasibility and efficiency of the boom deployment plans and also to train local personnel in handling antipollution equipment. Lessons learned from these exercises enable the improvement of deployment plans and help define new research areas. Within this framework, CEDRE has undertaken a feasibility study for the installation of booms in high tidal range and strong current areas.

This experimental study involved a 15-day period, during the autumn of 1993, of on-site observations on the behavior of booms installed in one of the most difficult sites on the Atlantic shoreline. The main parameters observed were resistance, containment efficiency, and mechanical behavior of booms during the tide cycle, particularly when booms are stranded at low tide. In spite of successful boom installation, the experiment encountered difficulties due to meteorological and instrumentation problems.

Nevertheless, important lessons have been learned.

- *Static boom protection seems to be difficult for such sites, which leads us to question the validity of numerous Polmar plans. We should test alternative response techniques such as dynamic recovery systems set up at the openings to sensitive areas, which will necessitate good coordination between at-sea and on-shore response authorities.*
- *Mooring systems design and installation are jobs for specialists and should be prepared in advance.*
- *Various local means, such as fishing vessels or oyster farm barges, can be used for deploying protective booms.*

As a consequence of the grounding of the tanker *Amoco Cadiz* in March 1978, which spilled 230,000 metric tons (t) of crude oil on the French shorelines, the French Government established a specific entity to face accidental pollutions at sea. In October 1978, the group began work on preventive measures (to increase the safety of maritime navigation) and also on the preparation of antipollution operations and on the antipollution operations themselves. At the same time, the responsibilities and the limits of the different authorities involved in coordinating and conducting the antipollution operations and their preparation were defined.

Improvement in the preparation of the pollution-fighting operations made the redaction of local contingency plans, also called Polmar plans, necessary.

At-sea operations are to be found in the Polmar-Mer plans, onshore operations in the Polmar-Terre plans; their implementation is under the responsibility of the Préfets Maritimes (Ministry of Defense), and Préfets Départementaux (Ministry of Interior). As a result of close cooperation between the administrations, the organizations, and the persons concerned with antipollution operations and the consequences of pollution, the local plans state precisely and concretely the measures to be taken as soon as a risk of pollution exists. For example a Polmar-Terre plan must absolutely include:

- a precise list of the zones to be protected, in order of priority, taking into account biological, touristical, and economical aspects and the technical possibilities for protection;
- an extensive and up to date list of the equipment and products, belonging to both public and private organizations, that are available for antipollution operations;
- the precise plans for setup and maintenance of the booms protecting sensitive areas, including the type and number of necessary booms, access to the site, the orientation, the mooring, and personnel requirements;
- a list of intermediate- or long-term storage sites for the collected oil and waste;
- a list of waste disposal/treatment facilities;
- a program for the transfer of the shellfish cultures;
- a list of the lodging facilities available for personnel; and
- a list of the people having taken a training course.

This new policy decision also made compulsory the organization of exercises implementing these booming plans. Several of these exercises, called Polmar exercises, take place every year with the double aim of training the personnel and of assessing the validity of boom-setting plans and the efficiency of the means selected. They are a precious source of information both at a technical and an operational level. They are carried out under the authority of the Services Maritimes (Ministry of the Sea), with the cooperation of CEDRE which, among other things, establishes the provisional setting of booms (positioning, stress calculations, configuration, type of moorings).

Context of the study

For the past ten years or so, Polmar exercises, apart from their objective of training personnel, have provided a store of information on pollution-combating techniques and their fields of application. However, as the exercises are of fairly short duration, it has not been possible to make the most of these full-scale tests. Several of these exercises have shown the difficulty of an effective protection of any site that is completely uncovered at low tide. In fact, this type of site poses the dual problem of the holding strength of anchoring systems and the efficiency of booms in their role of protection or containment of the pollutant.

Many of the sites listed on the French coast as having priority for

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protection are, in fact, uncovered at low tide, and therefore pose the question of feasibility of protection by a static antipollution boom device.

Other studies carried out by CEDRE, at the request of the Ministry of the Sea, on the design and use of anchoring systems have made it possible to update knowledge in this field, drawing conclusions from the various Polmar exercises, and from similar work done abroad. Thus, in 1993, CEDRE evaluated conditions for installing booms in large tidal range and strong current zones on a representative site for a fairly long duration so that all the problems encountered could be observed, and corresponding to the time of utilization in the case of a real-life spill.

The study addresses the conditions for implementation and the efficiency of a plan for deploying an anti-pollution boom in the Traict du Croisic, a zone that is representative of the tidal flats of the Vendée and Charentes, locally subjected to strong currents and almost completely uncovered at low tide. This place is in an area where boom-deployment plans have recently been updated within the scope of the Polmar plan.

The objectives of the study were:

- to define the critical parameters to be taken into consideration, a suitable boom configuration, and one or more strategy(ies) that can be applied to sites with similar characteristics; and
- to evaluate the limit conditions of feasibility and effectiveness of protection on a site totally exposed at low tide, and the efficiency of the various types of booms in the grounding zone.

The study's strong point was the experimental phase on the site, which consisted of observing the behaviour of booms deployed on the Traict du Croisic for two weeks (spring tide—neap tide cycle).

To do this, CEDRE undertook the preparation of this specific exercise by creating a working group with representatives of all state departments involved. This group confirmed the choice of site, defined the boom-laying plan, and initiated the local organization for the exercise. At the request of the Ministry of the Sea, the boom plan was deployed and withdrawn according to the procedure of a Polmar exercise under the responsibility of the local Maritime Service, leaving the responsibility of the experimental study to CEDRE.

Preparation of the trial

Definition of the boom deployment plan. The 1981 Polmar plan scheduled for the Traict du Croisic, a protection plan using antipollution booms with a "double triggering" system (see Figure 1) consisting of a main boom (length 1,700 meters, resting on 10 buoys and 2 anchorings) and a backup boom (length 900 meters, resting on 3 buoys and 3 anchorings). According to calculations, this configuration subjected the booms to forces in the order of 12 tons, making pile-supported anchorings necessary at the channel edges, which is impossible.

The revision of the plan by CEDRE eliminated this configuration, which was too exposed to swell and tidal currents, in favor of a layout located in a more sheltered zone, and mobilizing a shorter boom length (see Fig. 1). Thus, on the basis of these new protection principles (sheltered zone inside the traict), the study focused on producing a layout that considered local constraints (current conditions, space available between anchoring zones and shellfish farms, and naviga-

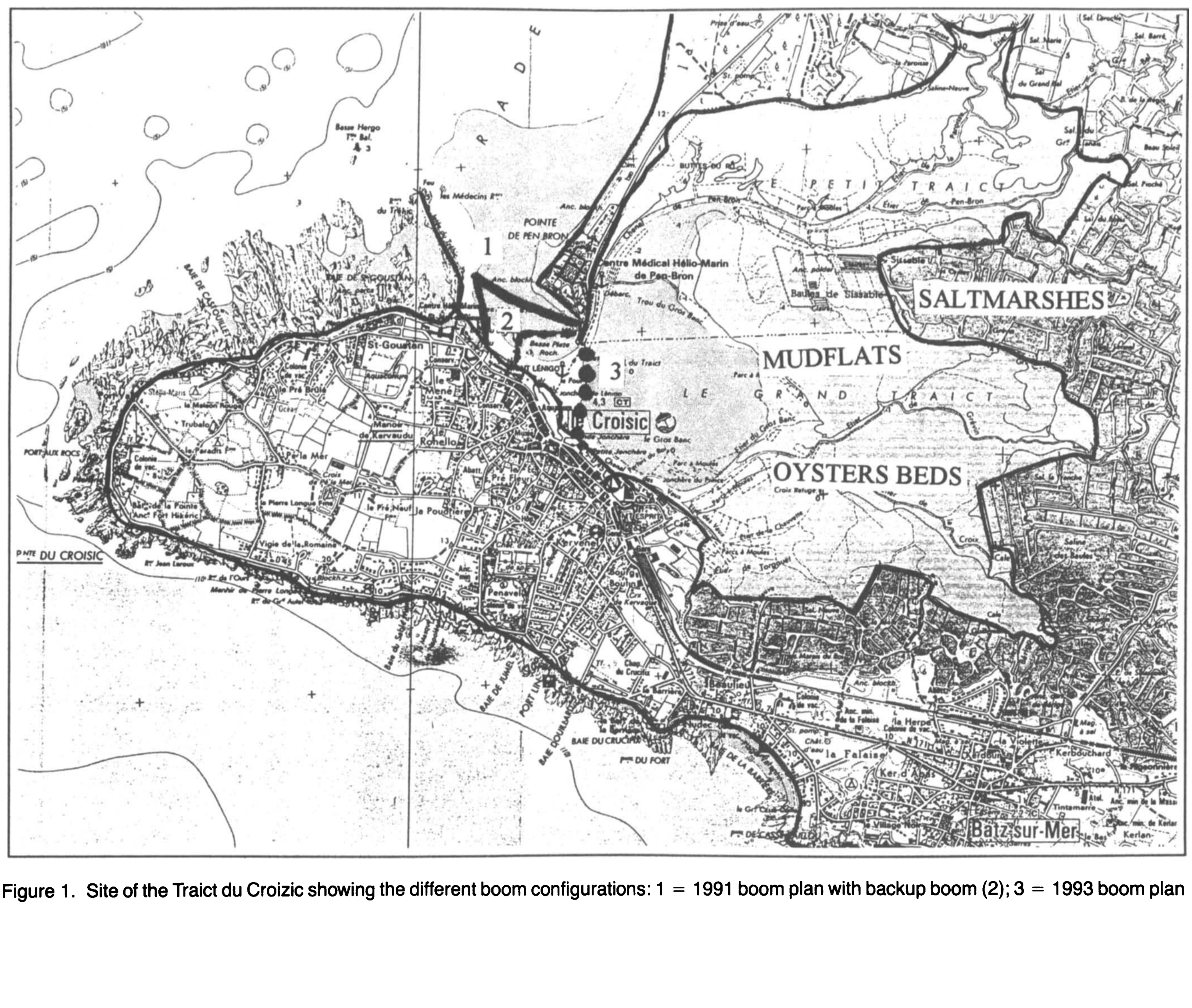

Figure 1. Site of the Traict du Croizic showing the different boom configurations: 1 = 1991 boom plan with backup boom (2); 3 = 1993 boom plan

tional constraints on the waterway such as access to port, fishing boats, and pleasure craft). The layout had the following objectives: optimization of deployment plan (between length and force exerted on the booms and transferred to anchorings), use of many different types of boom existing in the French stockpile, and possible comparison between various boom geometries.

The outcome of this work was a plan (see Figure 2) requiring the deployment of 695 meters of boom between 10 anchoring points. The plan was calculated with FORBAR software and based on the available current data, with the major objective of limiting the forces finally transferred to the anchoring points. The sizing of the anchoring systems was calculated by using the following formula:

$$P_{air} \geq 3 \times F_{resultant}$$

Table 1 gives the calculations.

This sizing resulted, for some of the intermediate anchorings, in providing two mooring blocks, which meant implementation problems.

Experimental study. The experimental study took place from September 24 to October 4, 1993, with the purpose of observing qualitatively and quantitatively the behaviour of the various different types of boom and their anchoring systems. The principal phenomena we had planned to observe were:

- the behavior of booms and their anchoring systems in relation to the grounding and refloating cycles,
- the evolution of hydrodynamic strains exerted on the boom and its containment efficiency according to the water depth (possible local acceleration of the current in shallow water due to reduction of flux cross section),
- the holding of anchorage by mooring blocks, and the
- reliability of anchoring systems on vertical and slanting walls.

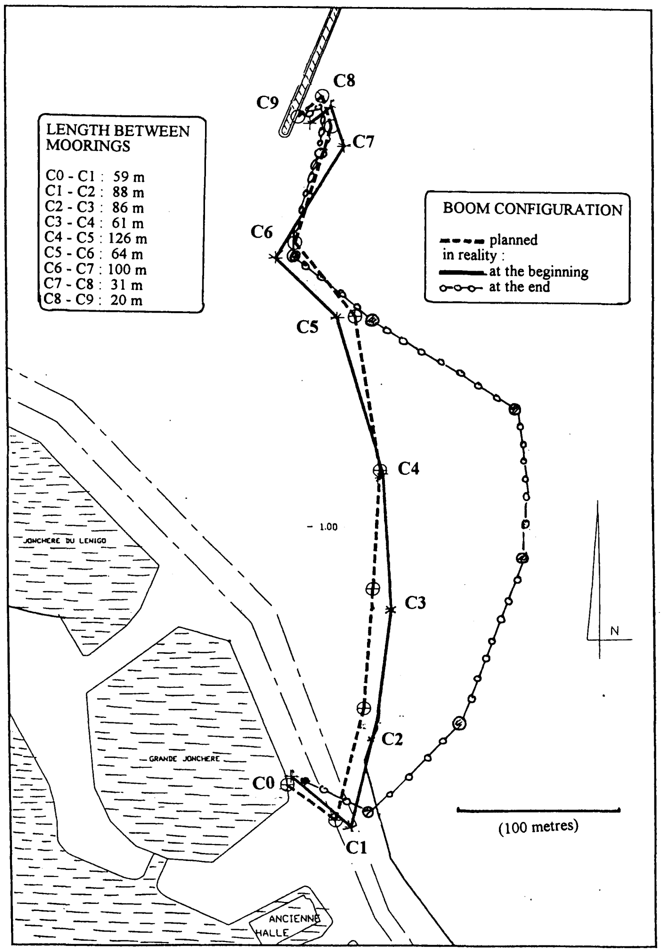

Figure 2. Evolution of the boom configuration

Table 1. Sizing of booms and anchoring

Anchorings	Type of boom	Maximum strength on anchoring[1] (t)	Proposed anchoring weight[1] (t)
C0	TMB Gamspill, 50 m	0.74	3 or 6.7
C1	TMB Gamspill, 100 m	2.83	6.7 + 3
C2	Sillinger TRS 45, 100 m	2.125	6.7
C3	Balear 323, 100 m	2.01	6.7
C4	Sillinger TRS 55, 120 m	2.26	6.7
C5	Sillinger TRS 55, 100 m	2.26	6.7
C6	Balear 335, 100 m	2.9	6.7 + 3
C7	Balear 335, 25 m	4.64	2 × 6.7
C8	Balear 335, 25 m	2.96	6.7 + 3
C9		1.43	6.7

1. according to FORBAR calculations

Measurement material. To achieve this observation program, CEDRE utilized measurement equipment provided by the Ministry of the Sea—a measuring buoy (positioned at the entry of the traict to measure meteorological and hydrodynamic parameters of the zone, and thus to give a reference for measurements on the boom), two dynamometers (and their recording apparatus for measuring the force on the booms at different intermediate anchoring points), a direct-reading current meter, and the associated logistics.

Observation program. A CEDRE team was constantly on site for implementing the observation, and to monitor the boom behaviour.

The testing schedule made it possible to start observations in a period of neap tides suitable for final adjustments of the measurement program and to progress towards mean-coefficient spring tides (maximum 85), with boom withdrawal being implemented under neap tide conditions.

Trial procedure

Implementation of deployment plan

Anchoring. Considering the large number of anchoring points and the fact that work could only be carried out on the selected stretch of water around high tide, the anchors were installed between September 15th and 17th. Three main things were learned during this operation.

- There is an irreducible error involved in the application of the theoretical deployment plan on site. This ultimate error, illustrated by the difference in position between the theoretical deployment plan and the one realized (Figure 2), is the product of a series of uncertainties: imprecision of the theoretical plan on the drawing board (thickness of line and quality of plan background) and imprecision in prepositioning the anchoring points depending on the means used (GPS, by sight, or others) and when installing the moorings.

  In addition to this error inherent to the laying of anchorage, swinging of the anchorage systems also contributes to a discrepancy between the theoretical deployment plans and their practical application.
- The deployment catamaran allows double mooring blocks to be installed by straddling with no serious technical difficulties.
- If it is properly prepared, the installation of anchoring systems by mooring blocks can be very quick. The local team, working only around high tide, installed nine anchorage points in two days—a total of 14 mooring blocks, 10 of which were installed by straddling.

Booms. Deployment of the booms was done in compliance with the Polmar exercise program on September 22nd and 23rd. This exercise showed the value of calling on local resources (shellfishing barges and small trawlers) for boom deployment and towing.

Experimental study. On September 24th, the experimental study took over from the Polmar exercise with a first day of general observation of the boom configuration on the stretch of water and the preparation of measuring apparatus. The measuring buoy was anchored at the mooring head, near the entry of the traict, and the VHF receiver and data processing station were installed nearby in direct line of sight of the buoy. The floating barge was fitted out as a mobile measuring platform that could be moored at the various intermediate anchoring points where the dynamometric measurements were programmed.

There were difficulties from the very first day with these measurement facilities. Problems of calibration and electrical supply of the dynamometers on the one hand, and failures at the acquisition unit of the measuring buoy on the other, limited the number of usable data. Then the spring tides and meteorological conditions deteriorated and broke up the boom system, meaning that the team had to abandon the measuring program to give priority to saving the site (shellfish farms and pleasure boats) and withdrawing certain lengths of boom.

Wednesday, September 29. At mid tide, the boom started to be shifted into the traict, in particular sections C2 to C5. Two pleasure crafts were threatened by the boom, which drifted into the middle of the traict and had to be displaced. It was decided to withdraw boom sections C1-C2, C2-C3, and C6-C7. The boom between C1 and C2 was torn, and section C6-C7 could not be withdrawn due to excessively strong ebb currents.

Thursday, September 30. The teams on the spot noted the considerable displacement towards the interior of the traict of the boom device; moorings C1 to C4 had turned upside down, and section C3-C4 overlapped the shellfish beds. The decision was taken to withdraw boom sections C3-C4 and C6-C7.

Thus, at the end of the week, it was possible to measure the extent of damage and to make a qualitative observation of the behavior of the few sections of boom that remained on the stretch of water. Figure 2 shows the displacement and final positioning of the anchorings. Finally, withdrawal operations, shortened by partial withdrawal implemented the previous days, progressed well, in spite of fairly difficult meteorological conditions.

Observations

In spite of the fact that the experimental program was not a complete success, this study offered the opportunity to make several observations concerning the limit principles of floating protective booms.

Behavior of the booms on the water. One of the booms used had a clear tendency to submerge in the current. This is related to the boom design, the taunting element being the ballast chain at the base of the skirt. Under the action of hydrodynamic forces, the boom tends to lie down in the current swivelling around the chain. Thus, in a current of approximately 1 knot, the boom starts to keel over; and in currents reaching 3 knots, it is submerged by the mass of water.

Such behavior has two consequences: the air draft is reduced, facilitating flooding over the top, of the boom, especially in the case of choppy water; and the hydrodynamic forces exerted on the boom are increased, resulting in cross stresses on the mooring blocks.

- The inflatable booms used had no particular problem; their high floatability prevented them from being submerged, and the ballast chain kept the skirt fairly vertical.
- The small self-inflatable boom was beyond its utilization limits on this stretch of water due to its small size and its very small floatability reserve. The mere weight of the mooring accessories made it sink partially, and the air draft was much too small for the choppiness of the surface.

Limits of containment. Sorbents were spread to simulate the arrival of floating polluting slicks along the various types of boom. Whatever type of boom was used, it was noted that, for currents of 1 knot or more, the containment limits are exceeded; vortexes develop opposite the boom, which suck the floating product in and expell it a few meters farther back.

These limits are reached all the faster as, in spite of the angles of incidence between the boom geometry and the principal direction of the current field, it remains extremely difficult to avoid the formation of pockets in each section where the boom lies perpendicular to the current. This inadequate geometry of each section of boom is due to the uncertainties inherent in the on-site application of the theoretical deployment plan: the imprecision of plans, positioning error of anchoring systems, uncertainty in the length of booms and mooring accessories, swinging of anchoring systems, and various degrees of elasticity of all these elements.

Table 2. Calculation of the lifting angles and resultant maximum horizontal holding strength of anchorage

Anchorage	Water height at mid tide (m)	Anchorage line length (m)	Lifting angle (degrees)	Resultant maximum horizontal holding capacity of anchorage (t)
C1	2.7	15	3	3.82
C2	1.8	10	5	2.42
C3	3	10	13	2.27
C4	3	10	13	2.24
C5	5.1	20	5	3.84
C6	6	20	8	4.06
C7	4	20	2	5.03
C8	3.5	15	6	4.72

Complexity of current fields. According to the level of filling or emptying of the basin formed by the Traict du Croisic during tidal movements, extremely complex currents develop, related closely to the geomorphology of the site. These complex current fields with changing velocities and direction, depending on the tide, make it very difficult to predict the behaviour of the protective booms on the stretch of water and limit the plan's performance regarding mechanical strength and containment efficiency.

Displacement of the deployment plan. Figure 2 gives the displacements of the intermediate anchorages between the boom plan as initially implemented and that measured after displacement towards the interior of the traict. The mooring blocks that had moved the most (C2, C3, and C4) had tilted, and were found upside down in their final position.

Mooring lines and mooring blocks holding strength. With the purpose of limiting swinging of intermediate anchorage around low tide, the length of lines has been limited to 2 or 3 times the water depth at high tide. This short length of the lines may have had detrimental consequences on the holding strength of the anchorage due to the reduction of their horizontal holding capacity, and also by increasing the tipping torque of the mooring blocks.

Table 2 shows, for each anchorage, the lifting angles of the chain at the level of the mooring block and the reductions of horizontal holding strength of the mooring block corresponding to an applied force of 1 ton at mid tide on September 29, 1993. From the table, we see that anchorages C2, C3, and C4 were particularly vulnerable, which confirms that they played a predominant role in the general displacement of boom. This vulnerability was due to the sizing of the mooring blocks, the short length of lines, and the lifting angles reached by the lines which reduced the horizontal holding capacity and increased the risk of tipping.

Currents and water depths. The possible increase of strain exerted on the booms in shallow water that resulted from reduction of the flowing cross section of the flux of water under the boom (water depth ≤to 5 times the water depth of the boom) was not revealed by the measurements taken during this study.

Provisional FORBAR calculations and real measurements. Table 1 shows that the calculations of strength given by FORBAR vary between 2 and 3 tons for all but one intermediate anchorage from C1 to C8, with a maximum of 4.6 tons for C7. If we assume that they are reliable, the measurements at our disposal for the Traict du Croisic site never exceed 1.5 tons—at best only 75 percent of the strains calculated on C3.

Conclusion

Although the Polmar exercise phase proceeded smoothly and in extremely favorable conditions (neap tides, good meteorological conditions), the experimental phase soon met with considerable problems related to meteorology and instrumentation. The configuration of the boom was modified and the mooring blocks were displaced, without it being possible to quantify the forces and strains undergone by the booms and anchorages.

However, several interesting facts were brought to light.

- The objective was certainly too ambitious and, in the future, it would be preferable to run experiments on smaller and less-complex sites (regarding the seabed and currentology) and to have available a suitable and reliable instrumentation.
- The design and implementation of the anchoring systems is an affair for specialists and deserves preliminary studies.
- Numerous local means such as trawlers and shellfish barges may be extremely useful for placing the booms; and it is certainly worth arranging for their assistance in the case of pollution;
- For the protection of sites uncovered at low tide, it is often best to position the booms in the high-water zones, even if this means harsher sea conditions if in the open, or only protecting a part of the sensitive site.
- Alternative solutions to static protection configurations, such as dynamic trawling in the open for sensitive sites, should be studied and perhaps be given priority in the future.