Marine Ecosystem Enclosed Experiments

Proceedings of a symposium held
in Beijing, People's Republic
of China, 9–14 May 1987

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Editor: C.S. Wong and P.J. Harrison

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE
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IDRC-273e

Marine ecosystem enclosed experiments : proceedings of a symposium held in Beijing, People's Republic of China, 9-14 May 1987. Ottawa, Ont., IDRC, 1992. viii + 439 p. : ill.

/Marine ecosystems/, /marine environment/, /marine pollution/, /China/ — /environmental effects/, /experiments/, /toxic substances/, /oceanography/, /scientific cooperation/.

UDC: 551.464 ISBN: 0-88936-543-1

Technical editor: Gilbert Croome

A microfiche edition is available.

Abstract

This symposium on marine ecosystem enclosed experiments (MEEE) consists of nine review papers that describe various types of ecosystem enclosures and a series of papers resulting from enclosure experiments in Xiamen, People's Republic of China, and Saanich Inlet, BC, Canada. The reviews on types of enclosures include benthic enclosures for rocky and sandy shores and the effects of pollutants (primarily hydrocarbons) on bacteria, macroalgae, and invertebrates. The pelagic enclosures were used to study the control of phytoplankton blooms, the uptake and release of dissolved organic substances, and the effects of pesticides on freshwater ecosystems.

Six enclosure experiments were conducted in China and Canada from 1986–87. Some of these experiments examined the effects of contaminated sediments, primarily heavy metals, on bacteria, phytoplankton, and zooplankton and the pathways and fates of these heavy metals in the seawater. Other experiments studied the chemistry and biological effects of chemically dispersed oil.

Résumé

Ce compte rendu du symposium sur les expériences faites en écosystèmes marins comprend neuf communications qui décrivent les écosystèmes retenus et les expériences faites à Xiamen en République populaire de Chine et à Saanich Inlet, C.-B., au Canada. Les communications portent, notamment, sur les écosystèmes benthiques des littoraux rocheux et sablonneux et sur les effets des polluants (surtout les hydrocarbures) sur les bactéries, les grandes algues et les invertébrés. Les expériences sur le contrôle des brutales pullulations ("blooms") du phytoplancton furent menées dans les écosystèmes pélagiques, ainsi que l'absorption et le dégagement des substances organiques dissoutes et les effets des pesticides sur les écosystèmes d'eau douce.

Six expériences ont été faites en Chine et au Canada entre 1983 et 1987. Certaines ont porté sur les effets des sédiments contaminés, principalement par des métaux lourds, sur les bactéries, le phytoplancton et le zooplancton et sur le cheminement et le sort de ces métaux lourds dans l'eau salée. D'autres expériences portaient sur la chimie et les effets biologiques du pétrole dispersé chimiquement.

Resumen

Este simposio sobre Experimentos Marinos en Ecosistemas Cerrados (MEEE) consistió en nueve trabajos de análisis que describen varios tipos de enclaustramientos ecosistémicos y una serie de trabajos derivados de experimentos con estos enclaustramientos en Xiamen, República Popular de China, y en Sannich Inlet, Canadá. Los estudios incluyen enclaustramientos bentónicos para costas rocosas y arenosas, y los efectos de los contaminantes (fundamentalmente hidrocarburos) sobre bacterias, macroalgas e invertebrados. Los enclaustramientos pelágicos se utilizaron para estudiar el control de la reproducción del fitoplancton, la ingestión y expulsión de substancias orgánicas disueltas y los efectos de pesticidas en los ecosistemas de agua dulce.

Se realizaron seis experimentos en ecosistemas cerrados en China y Canadá, de 1983 a 1987. Algunos de estos experimentos examinaron los efectos que ejercen los sedimentos contaminados, fundamentalmente los metales pesados, sobre bacterias, fitoplancton y zooplancton, y el ciclo y destino final de estos metales pesados en el agua de mar. Otros experimentos estudiaron los efectos químicos y biológicos de los aceites crudos dispersados por medios químicos.

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Bremerhaven Caissons — Experience and Results of Experiments with Dispersed Crude Oil in Intertidal Enclosures

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The Bremerhaven Caissons were designed and constructed to enclose parts of aquatic ecosystems for field experiments, especially on intertidal sand flats and mud flats. The constructions are container-like boxes that are open at the top and bottom. Four walls (2 m high × 5.6 m wide × 2.35 m long) enclose an area of about 13 m^2. A Bremerhaven Caisson can operate in a closed, semi-closed, or flow-through mode. Enclosed are both the benthic and the planktonic systems. Long-term experiments (up to several months) on the benthos are possible independent of the operational mode. For plankton, the experimental period depends on the period the water remains in the caisson. Thus, long-term experiments on this part of the ecosystem are only possible when the water circulation is closed.

In pollution experiments, caissons were used to study the fate and effects of chemically and ultrasonically dispersed crude oil and a dispersant on an intertidal benthic system. In different experiments, oil in concentrations between 2 and 40 $mg{\cdot}L^{-1}$ was added to the water inundating the caisson interior during the flood tide (semiclosed mode). The fate of the oil in the sediment (penetration, residence time, etc.) and the effects of both kinds of dispersion and the dispersant on microphytobenthos, bacteria, meiofauna, and macrofauna were studied. The results generally show that oil concentrations below 20 $mg{\cdot}L^{-1}$ have, in most cases, reversible sublethal effects. Higher oil concentrations for a period of several days induced heavy mortality in some groups of the ecosystem, especially in macrofauna species. No difference between chemically and ultrasonically dispersed oil was observed.

In the southeastern part of the North Sea, a spacious intertidal area of about 800 km^2 extends along the Dutch, German, and Danish coasts, forming the Wadden Sea (Fig. 1). As the ground slopes very slightly, this intertidal zone has an average width of about 10 km and a maximum extension of 20 km. The region is characterized by sand flats and mud flats inundated and drained by many tidal channels.

A chain of dune islands and sand barriers forms the seaward border between the Wadden Sea and the subtidal North Sea. This area is of great ecological

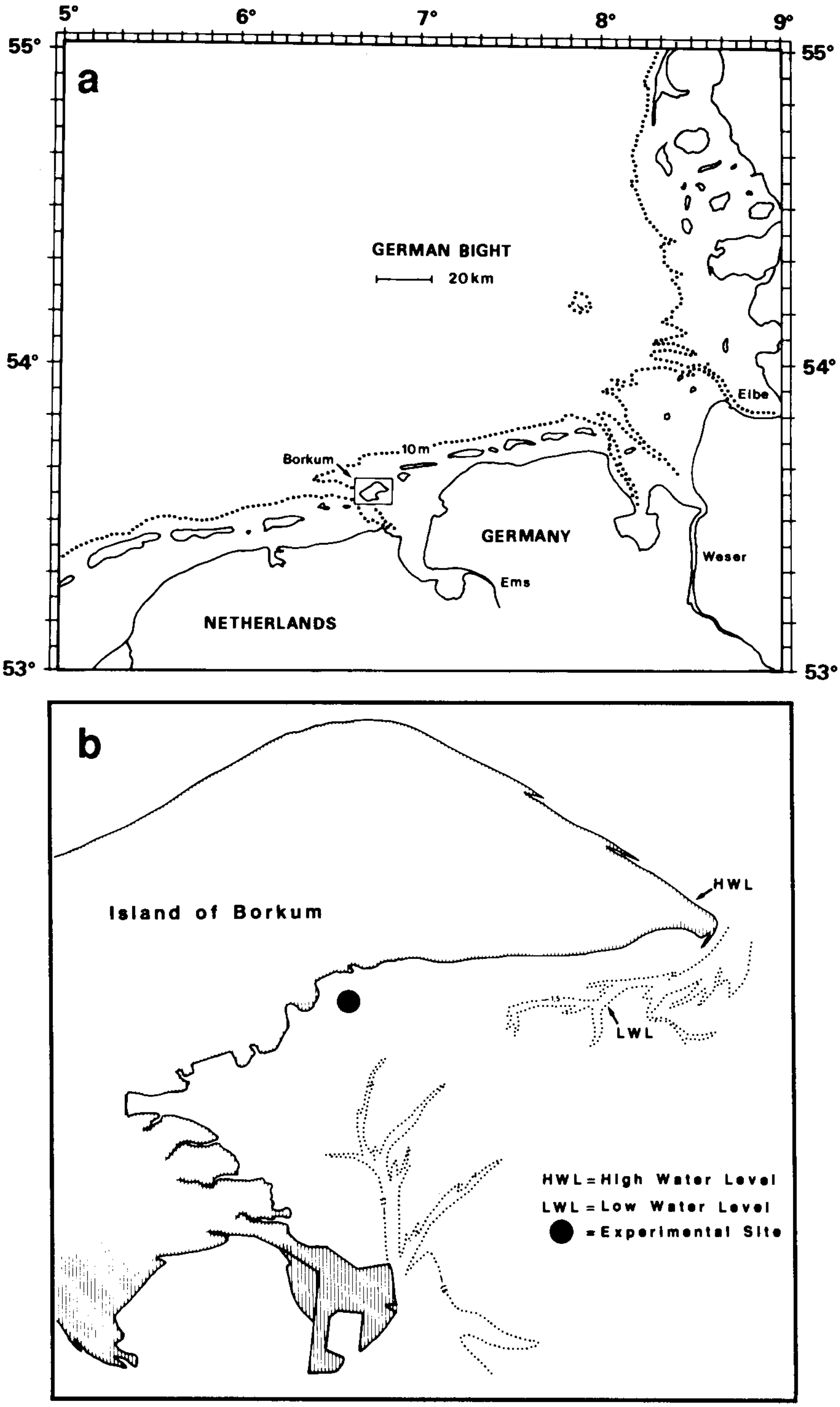

Fig. 1. (a) German Bight and **(b)** intertidal area south of the island of Borkum.

significance. Its high secondary production, based on the rich microphytobenthos of most flats and sedimentation of organic material from the North Sea, provides ample food for a large number of consumers, such as young fish, crabs, and shrimps during the submersion period and birds during the emersion period.

Experimental ecosystem research in the Wadden Sea has usually been carried out in the field by direct manipulation of the bottom or by setting up smaller devices, such as cages, to exclude predators (Reise 1985). In the laboratory, benchtop container systems were used to investigate special questions, such as the reproduction, biology, and life cycles of intertidal species (Farke and Berghuis 1979). The Kiel Plankton Tower and the Hamburg Enclosures (Grice and Reeve 1982) were the first German facilities used to enclose marine plankton communities. They were used during the 1970s in the Baltic Sea and a Norwegian fjord. In the subtidal zone of Kiel Bay, a medium-scale experiment on macrozoobenthic colonization, succession, and secondary production, the "Benthosgarten," was carried out between 1975 and 1979 (Arntz and Rumohr 1982, 1986; Rumohr and Arntz 1982). A first enclosure system in the Wadden Sea was set up in the early 1970s for heavy metals studies (de Wolf et al. 1972). In this system, part of an intertidal mussel bed was palisaded for a summer period and the water inundating the interior in the tidal rhythm was contaminated with copper. At the end of the experiment, the timber construction had to be totally demolished. Further experiments employing this enclosure technique were not carried out.

In 1975, "large indoor tidal mud flat ecosystems" (de Wilde and Kuipers 1977) were established at the Netherlands Institute of Sea Research, Texel. Two mesocosms, each containing Wadden Sea sediment covering an area of 20 m^2 and containing 60 m^3 of seawater, circulating between storage tanks and the sediment boxes in a tidal rhythm, were constructed in an aquarium. Using the "indoor tidal mud flat ecosystems," basic research was carried out in an attempt to understand the Wadden Sea ecosystem. Since 1981, the Dutch have used modifications of these mesocosms, so-called MOTIFs (model tidal flats), to conduct research on the effects of oil and dispersants in the Wadden Sea (Kuiper et al. 1986). The MOTIFs are set up on shore in outdoor basins on the island of Texel. As the sediment structure and the benthic community are disturbed as a result of being transported from the tidal flat and introduced into the mesocosms, the large "indoor tidal mud flat ecosystems" as well as the "MOTIFs" need a longer period of stabilization before experiments begin.

Contrary to these on-shore mesocosms, the basic principle of the Bremerhaven Caissons (Fig. 2) is related to the offshore enclosure used in the Netherlands by de Wolf et al. (1972). In both systems, natural areas of tidal flats are enclosed by walls so that experiments can be carried out inside. An advantage of the Bremerhaven Caissons is that they are mobile. They can be brought into position on a flat within one tidal period and can be moved away at the end of an experiment during another tidal period. Neither operation disturbs the experimental site, so the development of the benthos after the experiments can be followed under natural conditions.

The caissons were used at a time when pollution problems associated with coastal North Sea and the sensitivity of researchers to the vulnerability and uniqueness of the Wadden Sea area were increasing. Because little was known about the fate and effects of pollutants under natural conditions on the Wadden Sea ecosystem, the caissons were constructed to fill the gap between benchtop laboratory

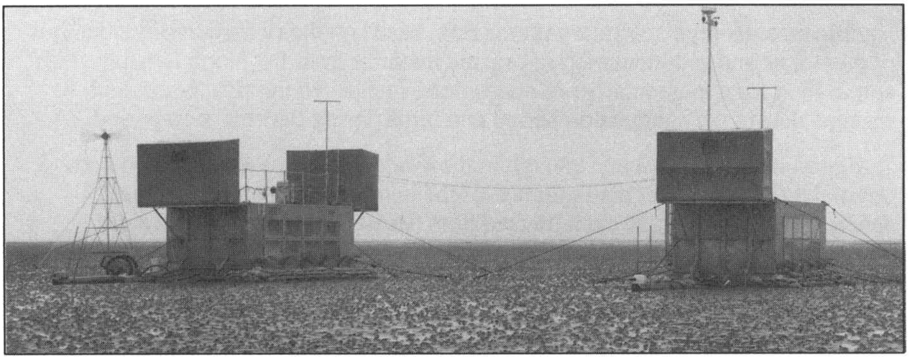

Fig. 2. Bremerhaven caissons on an intertidal sand flat south of the island of Borkum.

experiments and field observations (Parsons 1982). Between 1981 and 1985, 18 long- and short-term experiments on the fate and effects of heavy metals and oil dispersants were carried out in the caissons. Since 1985, the facilities have been used for fundamental research to study interactions between predators and prey, especially juvenile macrofauna, on the tidal flats.

Bremerhaven caisson

Technical description

A Bremerhaven caisson consists of a rectangular container that is open at the top and bottom (for technical details, see Farke et al. (1984)). The walls, made of seawater-proof aluminum, are 5.6 m long (sidewalls), 2.35 m wide (front walls), and 2 m high. About 13 m^2 of a tidal flat are enclosed. Instruments and the electric power supply are contained in two canvas shelters mounted on platforms at the upper outer edge of the front walls. Researchers can find shelter there during their stay on the caissons. A gangway connects the two platforms. Inside the caisson, about 0.5 m above the sediment surface, a movable working bridge allows researchers to sample the sediment and benthos without walking on it. Windows in the sidewalls reduce shading (Fig. 3).

Equipment

Scour protection and mooring on the ground

Protection against scouring is indispensable if caissons are to be operated in the field. Synthetic mats, as used in aquatic engineering, provide effective scour protection. They are fastened inside at the lower edge of the walls and run underneath to the outside so that the caisson rests on them. These mats are 1 m wide and cover the sediment around the caissons. Their outer edges are dug into the ground, providing a smooth transition between the sediment and mat. As an additional safety measure, two layers of densely packed sandbags surround the walls of the caisson (Fig. 2).

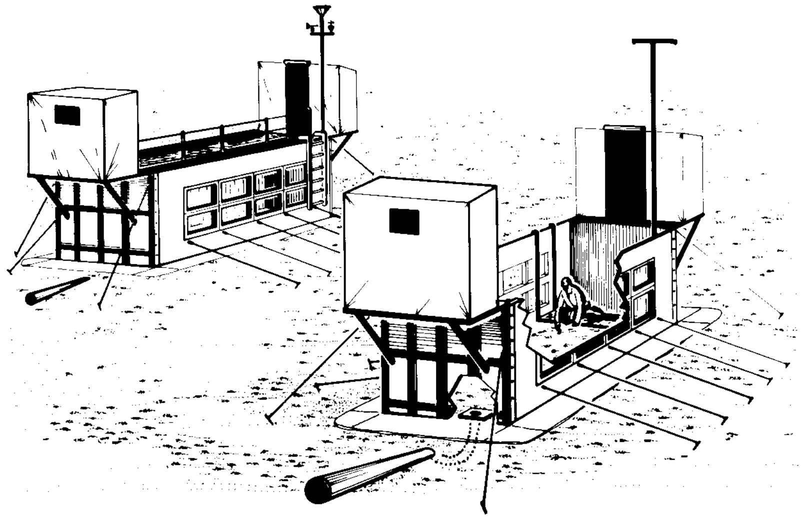

Fig. 3. Caissons on an experimental site (from Farke et al. 1984).

To prevent any movement, each caisson is moored by 16 guy ropes that are fixed to iron pins screwed about 1 m into the ground.

Inundation systems

The caissons can be operated in three different ways: as a flow-through system, semiclosed, and closed (Fig. 4). The flow-through mode (Fig. 4a) is used for predator–prey experiments. In this case, water from the flats is continuously pumped into the caisson during the submersion period. The incoming water, which is filtered through 1-mm meshes, is dispersed by a tube system close to one end wall. At the opposite wall, an outlet system equalizes the water surplus from the pumps so that the same water level is maintained inside and outside the caisson.

The semiclosed mode (Fig. 4b) is used for pollution experiments. In this case, one inundation system functions as a water inlet during the flood period and as an outlet during the ebb tide. Within one submersion period, no water exchange between the interior of the caisson and the ambient flat takes place and the contamination can be confined to the water volume inundating the caisson during the flood tide. For long-term pollution experiments, the total water exchange within the tidal rhythm necessitates contaminating the incoming water for each subsequent flood.

In the semiclosed mode, a water-circulation system must be installed inside the caisson to avoid oxygen depletion in the water close to the bottom. For circulation, the caisson water is pumped to a row of horizontally fixed outlets near one end wall. On the opposite end wall, a similar pipe system functions as an inlet leading the water back to the pumps.

Operating the caisson in a closed mode (Fig. 4c) seems possible but has not yet been tried. In this case, a tank should be installed on a ship anchored near the caisson to store the caisson water during periods of emersion. Inundation and drainage

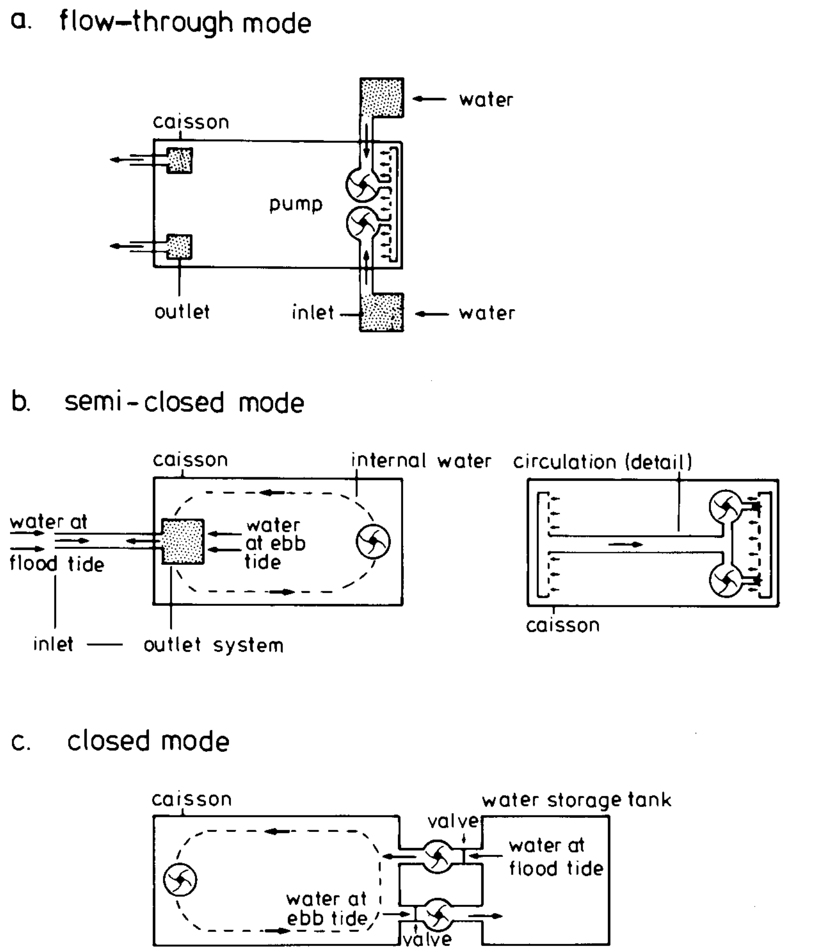

Fig. 4. Operational modes of the caissons.

of the caisson's interior must be regulated by valves and pumps corresponding to the tidal regime on the flat.

Electric power supply

Electric power is mainly used for pumping the water inside the caisson (flow-through mode) and for water circulation (other operational modes). Electricity is also needed for the tide-gauge controlled automatic addition of soluble pollutants (Farke et al. 1984) developed for heavy metal experiments. To diminish risks, only low voltage electricity (12-V direct current) is available on the caisson, so all pumps and other electric facilities must operate under this condition. Eight special batteries for slow discharge, each with a capacity of 60 A-h, are installed. They are recharged by a wind generator and during periods of low wind velocities by a small 12-V generator. A sophisticated electronic unit controls discharging and recharging the batteries and switches off the generator or the consumer in case of overcharging or undercharging. In this way, the batteries and the whole electric-power system are protected from destruction.

Environmental and meteorological data

Various environmental and meteorological parameters — salinity; sediment, water, and air temperature; tide-gauge data; water turbidity; radiation; precipitation; and the direction and speed of the wind — are continuously recorded (every 5 min) and stored on magnetic tape.

Operation of the caisson

At present, the Bremerhaven caisson is the only mobile mesocosm capable of enclosing the benthos. Using two rubber floats attached to the sidewalls, it can be towed to the experimental site when the flat is submerged (Fig. 5). With a draft of only 0.3 m, the caisson can reach even very shallow parts of the Wadden Sea. When the tide recedes, the caisson rests on the flat. After detaching the floats and extending the scour-protection mats, the device is moored to the ground. Exact positioning on an experimental plot is possible within a 0.3-m limit, so that the site can be prepared before the caisson is settled. The caisson can be remobilized by reattaching the floats to the sidewalls, which lift the device from the bottom during the next flood period. Even after standing in one place for 2 months, the floats are sufficiently buoyant to lift the caisson with the attached scour-protection mats. The caisson can then be moved to another site nearby within one submersion period.

Field experience

Between 1980, when the devices were constructed and the first field trial took place, and 1987, the Bremerhaven caissons have proven their practicability for ecological research in 21 field experiments carried out during the period from May to September each year in different parts of the German Wadden Sea. During these periods, the caissons were used for 9 short-term (1 week) and 12 long-term (1–2 months) experiments on the fate and effects of heavy metals (Prosi et al. 1983; Rehm and Schulz-Baldes 1983; Schulz-Baldes et al. 1983; Farke et al. 1985a,b), oil and dispersants, and benzpyrene and to study predator–prey interactions in the intertidal ecosystem.

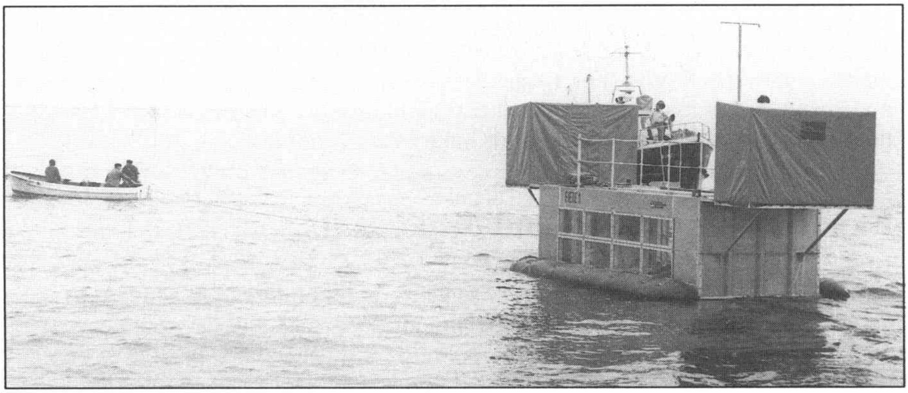

Fig. 5. Caisson being towed to an experimental site.

During all of these operations and the long periods in the field, the caissons have been exposed to manifold weather conditions. Although experiments usually start after the stormy period in spring and normally end before the autumn gales occur, the caissons have to withstand heavy weather conditions nearly every year. Thunderstorms with violent gusts as well as storms up to 9–10 Beaufort wind speed (75–100 $km \cdot h^{-1}$) were endured for one or two tidal periods without having any major affect on the experiments. Only extreme high tidal water levels, which in the German Bight result from strong northwesterly winds, and storms may cause problems. A few times, water levels as high as the upper edge of the caisson and waves endangered the platforms and canvas shelters, but the scour-protection mats, sandbags, and moorings prevented sediment erosion around the walls and any dislocation of the caisson. Although no operation failed, such events mark the limits of caisson experiments. As the devices are only 2 m high, the mean water depth at high tide at the experimental site should not exceed 0.8–1 m because storm tides with water levels about 1 m above mean high tide level sometimes occur in the German Bight even during summer. Thus, caisson experiments in deeper parts of the Wadden Sea, near the low-water mark, could only be carried out under stable weather conditions and special security measures.

Effects resulting from enclosure by caissons have been mentioned in Farke et al. (1984) and current experiments confirm former appraisals. Reductions of light by the caisson walls results in lower primary production of microphytobenthos at the beginning of an experiment, but this seems to be normalized after a period of adaptation. Generally, primary production of the microphytobenthos in the Wadden Sea is unstable, with marked differences within a few days. Inside the caisson, the bottom temperature is only 1–2°C higher than outside the caisson, even on hot sunny days, and extra sedimentation is limited to an extent that is not obvious because of sediment reworking by bioturbation activities.

Operating the caisson in the semiclosed mode without water circulation results in a marked reduction of oxygen in the enclosed water body, which may lead to mortality of benthic macrofauna. The system of water circulation prevents such effects, and oxygen measurements of near-bottom water show an oxygen decrease of about 10% only during the ebb period when the influx of seawater from the flats is stopped.

Measurements of algal chlorophyll in bivalves can be used as an indication for the feeding activity of these animals (Farke and Gunther 1984). A comparison of the chlorophyll content in *Cerastoderma edule* from the flats and from a caisson during a period of 9 days (Fig. 6) shows no major differences. Species composition and abundance of macrozoobenthos between the control caisson and the flats did not differ markedly, even after periods longer than 1 month.

Experiments with oil and dispersants

The Wadden Sea ecosystem is very sensitive to oil pollution. In addition to acute toxic effects after an oil spill, sandy and muddy sediments will incorporate stranded oil and become a source of chronic oil pollution for many years. In spite of this, highly frequented shipping routes exist only a few kilometres away from the Wadden Sea. Difficult navigational conditions and often stormy or misty weather enhance the risks of collisions or tankers becoming stranded and leaking oil.

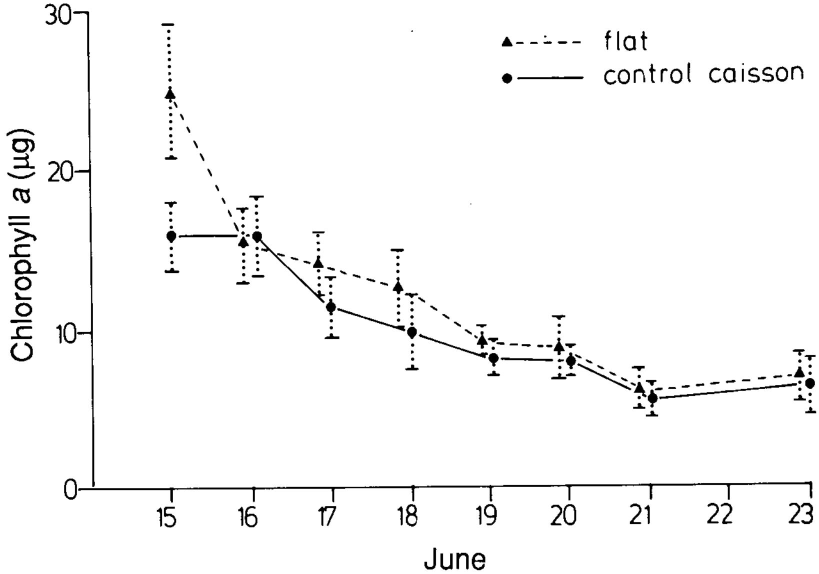

Fig. 6. Feeding activity of *Cerastoderma edule* from an uncontaminated caisson and from the ambient flat. The amount of algal chlorophyll *a* ingested by the bivalves is indicated.

In addition to mechanical cleanup, which is favoured in Germany, chemical dispersion of oil is now being discussed in light of the modern dispersants of low toxicity that have been developed. The Bremerhaven Caissons have allowed researchers to contaminate a defined water body with dispersed oil and a dispersant. In different experiments, chemically and ultrasonically dispersed oil and a pure dispersant were added to the caisson water to study and compare the fate and effects of the contaminants in the benthic ecosystem. The experiments were conducted to provide information about the ecological consequences on tidal flats when chemically dispersed oil enters the Wadden Sea with the incoming flood.,In the case of a near-shore oil spill, the results may help in deciding whether dispersants should be used to combat the oil.

During the period 1982–1984, nine experiments involving various concentrations of dispersant and dispersed crude oil were carried out (Table 1). The oil was dispersed either chemically or ultrasonically. In all experiments, the contaminant was added over several succeeding tides to the water inundating the caisson during the flood period. The results of the 1982–1983 experiments have been published (Farke et al. 1985a,b) and a detailed report including 1984 data is in preparation. Thus, only the main results are reported here.

Accumulation of oil in the sediment

In all experiments, even at the highest concentration of oil, 40 mg·L^{-1} of seawater, the dispersed oil accumulated only at the surface of the sediment, with little penetration into deeper layers. As a consequence, the period of oil contamination of the benthic system was short, because after refloating the caissons the natural water movement (waves and currents) and biological degradation eliminated the oil from the surface sediment within 1–3 months. Only in the experiment with oil at

Table 1. Oil dispersant experiments with Bremerhaven Caissons, 1982–1984.

Experiment	Contaminant	Concentration (ppm)	Contamination period (d)
82–1	AL/Fi	4	3
82–2	AL	2	3
82–3	Fi	0.4	3
83–1	Fi	1	6
83–2	AL/Fi	10	6
83–3	AL	8	6
84–1	St/Fi	40	6
84–2	St/Co	20	6
84–3	St/Fi	20	6

Notes: In experiments with oil and oil-dispersant mixtures, the values refer to the oil concentrations actually measured in the caisson water during high tide (mean) of each contamination period. In experiments with pure dispersant, nominal concentrations have been calculated.

Abbreviations: AL, Arabian light crude oil; St, Staffjord crude oil; Fi, Finasol OSR5; and Co, Corexit 9527.

40 $mg{\cdot}L^{-1}$ of seawater were slightly increased oil concentrations measured even 90 days after the contamination period. However, compared with the real-world situation after an oil spill, where large areas are polluted, only an area of 13 m^2 was contaminated during these experiments. Thus, elimination of oil from the entire Wadden Sea region would be much slower. Because no deep sediment layers were seriously contaminated, a state of chronic pollution may be avoided by dispersing the oil.

Biological investigations

Various biological disciplines were involved in the experiments. Investigations were carried out on microphytobenthos, bacteria, meiofauna, and macrofauna; thus, the response of important parts of the Wadden Sea ecosystem to oil and the dispersants was studied. Generally, no biological effects were observed when adding the dispersant alone, and different reactions could not be found between the chemical and ultrasonic dispersion of the oil. In all of the experiments, the measured effects depended on the concentrations of the dispersed oil in the water and the time of exposure.

The gross photosynthetic rate of microbenthic algae (mostly diatoms) calculated from oxygen production and consumption measurements was used as an indicator of algal activity. At oil concentrations of 2–4 $mg{\cdot}L^{-1}$ of seawater, the gross photosynthetic rate increased, but at 10 $mg{\cdot}L^{-1}$, an increase in algal activity was partially inhibited compared with the control caisson. At 40 $mg{\cdot}L^{-1}$, no algal activity could be measured.

Microbiological investigations showed no toxic effects of the dispersions on oil-degrading bacteria even at the highest concentrations. Compared with the controls, their numbers increased by a factor of 10–100. An adaptation of the bacterial populations occurred within a few days. Biological oxygen demand (BOD) measurements showed that biological degradation of the oil plays a role in the elimination processes.

For nematodes, the most abundant meiofaunal group, the number of species, abundance, and diversity were studied. Generally, nematodes seem to be less affected by oil, and the parameters mentioned were not very helpful for indicating effects, especially when the data referred to the nematode group as a whole. Shifting dominances could be found only at higher oil concentrations.

Clear effects at all levels of contamination with oil were observed in macrobenthic animals. Oil concentrations up to 10 mg·L^{-1} of seawater caused mainly sublethal effects, such as a reduction in the feeding activities of bivalves and polychaetes (Farke and Guenther 1984; Farke et al. 1985a,b). Only a few species showed decreased abundances. At 20 mg·L^{-1}, *Cerastoderma edule* and *Mytilus edulis* stopped digesting algal chlorophyll, and some polychaetes and bivalves appeared at the sediment surface. However, no mass mortality occurred, and most of the animals dug again when the contaminant were removed.

Doubling the amount of oil to 40 mg·L^{-1} of seawater caused severe effects on macrobenthic animals (Table 2). After the second contamination, all *C. edule* appeared on the sediment, but regeneration experiments showed that all of these animals were able to dig again after being kept for 1 day in clean seawater. After four contaminations, only 35% of the cockles could regenerate; after eight contaminations, none of the cockles could regenerate. Another bivalve, *Macoma balthica*, appeared on the sediment at the end of the contamination period, but the percentage that could regenerate was low. Higher numbers of the polychaete *Arenicola marina* were found on the sediment after the second contamination. After six additions of oil, its regenerating ability dropped to 57% and none were able to dig after eight contaminations. *Nereis diversicolor*, another polychaete, was more sensitive. Only 50% regenerated after two oil additions.

About 90% of the macrofauna was killed during this experiment. Of the 500

Table 2. Effects of Staffjord crude oil (40 mg·L^{-1} of seawater) dispersed by Finasol OSR5 on four endobenthic macrofauna species.

	Contaminations						
	1	2	4	6	8	10	12
Cerastoderma edule							
No. of individuals[a]	250	676	658	606	676	588	—
Successful regeneration (%)	—	100	35	13	0	—	—
Macoma balthica							
No. of individuals	0	0	0	0	14	29	1 102
Successful regeneration (%)	—	—	—	—	30	20	—
Arenicola marina							
No. of individuals	0	2	100	180	208	177	—
Successful regeneration (%)	—	100	100	57	0	—	—
Nereis diversicolor							
No. of individuals	Many	Many	Many	Many	Many	—	—
Successful regeneration (%)	100	50	—	20	0	—	—

[a] Number of individuals appearing at the sediment surface.

lugworms living in the caisson area at the beginning of the contamination period, only 25 survived. Other species, such as *Nereis diversicolor* and *Cerastoderma edule*, were totally absent after the experiment. Recolonization started soon, however, and after about 6 months the abundance of most species at the experimental site was comparable to the uncontaminated flats. Again, the surrounding unaffected areas provided a large reservoir for resettlement. In the case of a real oil spill, however, regeneration of an entire intertidal region would be expected to be much slower.

Conclusions

As noted by Giesy and Odum (1980), short-term single-species laboratory tests are, in most cases, insensitive to important interactions or compensatory reactions between the organism and its abiotic and biotic environments. As the complexity of natural systems can be realized to some extent in micro- or mesocosms, they may function as operational bridges between simple laboratory tests and complex field situations.

On the other hand, unavoidable impacts, spatial and temporal limitations, and changes in the abiotic and biotic environments affect the comparability of micro- and mesocosms with natural ecosystems and produce different kinds of stress (Pilson and Nixon 1980). In pollution studies, the stress caused by the experimental system itself and additional pollutant stress may have synergistic effects or they may alleviate each other. Thus, enclosures of natural ecosystems, the more complex they are, may provide decreasing possibilities to isolate cause and effect (Steele 1979).

Inherent impacts of the system differ from one experimental setup to another and depend on the type of enclosure. As shown by the response to copper pollution of two large plankton enclosures at Saanich Inlet and Loch Ewe, pelagic ecosystems may be critical variables themselves, limiting their use in pollution research (Steele 1979). Benthic organisms, especially macrofauna, seem to be better pollution indicators than plankton (Banse 1982). With a mainly sedentary lifestyle and longer life spans, macrobenthos might integrate environmental effects more significantly than planktonic organisms. The Bremerhaven Caissons are mainly designed for benthos research, and in the pollution experiments only this part of the intertidal ecosystem was studied. Plankton and seston, which are transported into the caissons twice a day, develop outside under natural conditions. Thus, caisson- or pollutant-specific plankton do not establish, diminishing the risk of artifacts. Before the experiment, the sediment as well as the benthos can develop under natural conditions; thus, the historical component of the ecosystem is kept intact in caisson experiments. After refloating the caisson, the experimental area is returned to natural conditions again; thus, loss and degradation of pollutants and regeneration of the benthic system can be studied.

At present, two Bremerhaven Caissons have been constructed: one is used for experimental manipulations; the other is used as a control system. A team of about 10 people can install the caissons on the flat within one emersion period and then operate the two devices in the field. To adequately replicate experiments would double or triple the work and costs involved, thus going beyond practical limits for most tidal areas and most research institutes.

To avoid pseudoreplication (Hurlbed 1984), inferential statistics cannot be used to validate the results of caisson experiments. On the other hand, the oil–dispersant studies show that repeated experiments on the same subject, even with a slightly different experimental design, such as increasing oil concentrations, allow conclusions to be drawn on the behaviour, fate, and a great variety of effects of such substances in the natural environment.

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