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
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 litoraux 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.


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 Saanich 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.
Contents

Part I: Introduction ................................................. 1

Introduction to the MEEE Project

Summary
P.J. Harrison ......................................................... 7

Part II: Applications of Marine and Freshwater Enclosures .................. 13

Use of rocky-shore mesocosms in pollution research
T. Bakke ............................................................. 14

Benthic mesocosms in the Netherlands
P.A.W.J. de Wilde ..................................................... 26

Bremerhaven caissons — experience and results of experiments with dispersed crude oil in intertidal enclosures
H. Farke, C.-P. Guenther, and W. Arntz ........................... 43

A subtidal soft-sediment mesocosm
J.S. Gray ............................................................... 57

Enclosed plankton ecosystems in harbours, fjords, and the North Sea — release and uptake of dissolved organic substances
U.H. Brockmann ....................................................... 66

Use of enclosures for assessing the effects of pesticides in freshwater aquatic ecosystems
K.R. Solomon, N.K. Kaushik, D. Herman, G.L. Stephenson,
P. Hamilton, K.E. Day, and G. Jackson ............................ 87

Control of phytoplankton blooms in the Subarctic Pacific Ocean — experimental studies in microcosms
M.R. Landry and J.M. Lehner-Fournier ............................ 106

Fate of petroleum hydrocarbons in marine ecosystem enclosures and relevance to marine oil spills
W.J. Cretney ............................................................. 122

Microbial degradation of petroleum in an intertidal beach environment — in situ sediment enclosure studies
K. Lee and E.M. Levy ............................................... 140
Part III: China–Canada MEEE Experiments . . . . . 157

A. Sediments and Heavy Metals

Introduction to the Xiamen marine ecosystem enclosed experiments
Wu Jinping, F.A. Whitney, Hou Shumin, Chen Xiaolin, Zhuang Dongfa, and Wu Shengsan .......................... 158

Application of different types of marine experimental enclosures to study the pathways and fate of chemical pollutants
C.S. Wong, F.A. Whitney, and W.K. Johnson .................. 174

Effect of vertical mixing on ecosystem dynamics in large mesocosms
T.R. Parsons and A.H. Taylor ................................. 186

Phosphate limitation of phytoplankton growth in coastal estuarine waters of China and its potential interaction with marine pollutants
P.J. Harrison, Yang Y.P., and Hu M.H. ......................... 192

Effects of heavy metals and sediment pollutants on phytoplankton and primary productivity in an enclosed ecosystem
Qian Shuben, Chen Qihuan, Tang Senming, Wu Shengsan, Zhang Liangzhong, Hou Shumin, P.J. Harrison, and H. Dovey .... 203

A Gray model for studying the effects of metals on phytoplankton growth in marine ecosystem enclosed experiments (abstract only)
Zeng Jiye and Wu Yuduan ................................. 218

Use of enclosed experimental ecosystems to study the effects of suspended sediments on zooplankton communities
C.M. Lalli .......................................................... 219

Effects of heavy metals and sediment on zooplankton in marine ecosystem enclosed experiments
Chen Xiaolin, C.M. Lalli, and Lin Jinmei ......................... 224

Relationships between particle characteristics and biological activities in controlled ecosystems
Hong Huasheng, Guo Laodong, and Chen Jingqian ........ 230

Biological implications of organic carbon and nitrogen in the Xiamen enclosures
Fu Tianbao, Zhao Rongping, and Yang Yiping .................. 244

Ecological impacts of pollutants on particulate organic carbon, nitrogen, and phosphorus in marine ecosystem enclosed experiments
Xia Zhongfong and Lu Xiankun ................................. 252

Distribution of heavy metals in Xiamen seawater and in the MEEE enclosures
Li Jinxia, Zhang Gongxun, Du Ronggui, Chen Zexia, and Zheng Jihua . 263

Pathways and fates of heavy-metal mixtures in the Xiamen MEEE
Biogeochemical behaviours of heavy metals in marine enclosed ecosystems

Release of heavy metals from polluted sediment in the MEEE enclosures

$^{65}\text{Zn}$ in the Xiamen MEEE
Zhou Hanyang, Xu Pian, Yao Jiadian, and Zhen Yunfei ................. 314

Biogeochemical processes of mercury in marine enclosures
Xu Kuncan, Wu Liqing, Zhen Changchun, and Zhan Xiumei ........ 323

B. Hydrocarbons

Response of bacterioplankton to Corexit 9527 and Corexit-dispersed Shengli crude oil: marine ecosystem enclosed experiments
Lin Rongcheng, Lin Yanshun, Wu Jinping, K. Lee, and Li Wenquan .... 332

Effects of chemically dispersed crude oil on marine phytoplankton: a comparison between two marine ecosystem enclosed experiments
Lin Yu, Zhuang Dongfa, and Wu Shengsan ................................. 343

Effect of chemically dispersed crude oil on the distribution of primary microfouling organisms
Lin Yanshun, Yao Ruimei, and Liang Ziyuan .............................. 353

Effects of Shengli crude oil and dispersant Corexit 9527 on zooplankton in marine ecosystem enclosed experiments
Chen Xiaolin ........................................................................... 360

Fate of chemically dispersed Shengli crude oil in a marine ecosystem enclosure
Zhuang Dongfa, Wu Shengsan, Lin Yu, Cai Ziping, W.J. Cretney, and F.A. McLaughlin ...................................................... 367

Fate of low-volatility alkanes from chemically dispersed crude oil in a marine ecosystem enclosure
Wu Shengsan, Cai Ziping, Zhuang Dongfa, Lin Yu, W.J. Cretney, and F.A. McLaughlin ...................................................... 378

Use of n-(1-$^{14}$C) hexadecane to study the fate of dispersed crude oil in marine enclosed ecosystems
Li Wenquan, Wang Xian, Wu Jinping, Lin Rongcheng, and F.A. Whitney ................................................................. 388
Part IV: Other China–Canada Enclosure Experiments ........................................ 399

Enclosure study of metal release from dredged spoils and the effect of capping with alluvial materials
C.S. Wong and Vidas Stukas ................................................................. 400

Releasing experiment of mine tailings from Alice Arm, BC, Canada

Effects of Liaohhe crude oil and dispersant on marine phytoplankton in an enclosed ecosystem
Zhu Lin, Shen Liangfu, Huang Wenxiang, Zhang Youen,
Wang Hongyuan, and Zhao Zengchun ............................................ 425

Appendix

Participants list ................................................................................. 436
Effects of Chemically Dispersed Crude Oil on Marine Phytoplankton: A Comparison Between Two Marine Ecosystem Enclosed Experiments

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Two experiments involving the addition of crude oil and dispersant into experimental enclosures were carried out during the Canada–China cooperative marine ecosystem enclosed experiments (MEEE) project. The first experiment (MEEE-83) took place in Saanich Inlet, BC, Canada, and involved the use of Prudhoe Bay crude oil and dispersant Corexit 9527. The second experiment (MEEE-86X) was conducted in Xiamen Bay, People's Republic of China, and involved the use of Shengli crude oil and Corexit 9527. During the Xiamen experiment, the water column was agitated by drastic tidal currents, which promoted dissolution processes and resuspension of settled materials. This changed the fate of the chemically dispersed crude oil compared with results from undisturbed MEEE-83. At the end of the Xiamen experiment, the oil concentration in the seawater was relatively constant. Growth of marine phytoplankton in the Xiamen Bay area could be suppressed when the concentration of oil in the seawater was higher than 1.5 mg L⁻¹.

In 1986, an experiment (MEEE-86X) was carried out in Wutong Bay, Xiamen, to study the fate of Shengli crude oil in marine enclosures and also the effects of crude oil with dispersant Corexit 9527 on marine ecosystems. A similar experiment (MEEE-83) was conducted in Saanich Inlet, BC, Canada, in 1983. This report compares the results of the two experiments and discusses the effects of both the chemically dispersed crude oil and the dispersant Corexit 9527 on local phytoplankton communities.

Methods

Three plastic bags (2.4 m in diameter × 16 m deep) were used in MEEE-83. Each bag enclosed about 65 m³ of seawater from the site. The first bag (C1) was used as a control, receiving neither oil nor dispersant. The second bag (C2) was treated with 20 g of Corexit 9527. The third bag (C3) was treated with a mixture of
200 g of Prudhoe Bay crude oil and 20 g of dispersant. Except for during sampling periods, the enclosures remained relatively undisturbed throughout the experiment. At the beginning of the experiment, the enclosures were supplemented with nutrients (N:Si:P = 10:10:1 µg·L⁻¹) to induce phytoplankton blooms.

In MEEE-86X, several fortified polyethylene bags (2 m in diameter × 6 m deep) were used to enclose about 14 m³ of seawater. The first bag (C1) was used as the control. The second bag (C2) was treated with 15 g of dispersant Corexit 9527. A mixture of 150 g of Shengli crude oil and 15 g of dispersant Corexit 9527 was added to bag C3. At the beginning of the experiment, nutrients were also added to each enclosure to arrive at initial N:Si:P ratios of 15:15:0.5 µg-at·L⁻¹. A phosphate-limiting condition occurred during the experiment because seawater from Xiamen Bay is usually deficient in reactive phosphorus.

Both experiments employed the same sampling methods. Samples were analyzed for the following parameters: water temperature, salinity, nutrient concentrations, chlorophyll a, primary productivity, number and species composition of phytoplankton, number and species composition of zooplankton, bacteria and heterotrophic production, settling rate, and concentration of oil components. Analytical methods used in the two experiments were also similar, details of which are described in Parsons et al. (1984a), Wong et al. (1984), and Whitney (1984).

Results

On day 4 of MEEE-83, diatom blooms were observed in bags C1 and C2 (Fig. 1). Species of plankton were similar in these bags throughout the entire experiment. No diatom bloom was observed in bag C3 and abundance of plankton decreased gradually. These observations indicated that diatom growth in bag C3 was significantly suppressed. However, microflagellate growth was fairly conspicuous.
At the end of the experiment, the abundance of microflagellates reached its maximum, at more than 30 times its initial value. Corresponding with the plankton blooms, amounts of chlorophyll $a$ in bags C1 and C2 also reached their peak values.

**Fig. 2.** Changes in chlorophyll $a$ and primary productivity in MEEE-83.
on day 4. These amounts decreased to their lowest values after day 11. In bag C3, the amount of chlorophyll a remained fairly stable until the end of the experiment when its value increased slightly because of the prolific growth of microflagellates. Trends of primary productivity for bags C1 and C2 paralleled that of chlorophyll a, i.e., maximal values were reached on day 4 and minimal values occurred after day 11. In bag C3, the primary productivity decreased at the beginning of the experiment, but rose slightly at the end of the experiment (Fig. 2).

All of the above results indicated that Corexit 9527 alone does not affect the growth of diatoms (Parsons et al. 1984a; Harrison et al. 1986). However, the oil-dispersant mixture in bag C3 suppressed the growth of diatoms, but not the growth of microflagellates. Primary productivity of phytoplankton was inhibited initially by the oil-dispersant mixture, but gradually recovered later.

In MEEE-86X enclosures, the species composition of phytoplankton was basically the same, although the abundance of each species varied over the course of the experiment. In bag C1, a plankton bloom dominated by centric diatoms occurred on day 8, followed by a slight decrease in the number of phytoplankton over the next few days. After day 14, phytoplankton increased rapidly due to tremendous growth of pennate diatoms. Results from bag C2 were similar to those from bag C1, with a plankton bloom occurring between days 2 and 11. No dominant species was observed in bag C3. A small decrease in the total number of phytoplankton in bag C3 occurred after the addition of crude oil, but numbers increased slightly near the end of the experiment.

After the addition of crude oil, the number of centric diatoms decreased significantly, remaining below initial values for the rest of the experiment. However, a small increase in the number of pennate diatoms occurred during the last part of the experiment (Fig. 3). Variations in amounts of chlorophyll a in bags C1 and C2 with time followed basically the same trends. In bag C3, after the addition of the oil-dispersant mixture, the amount of chlorophyll a decreased rapidly and stayed mostly at a low value. All the results for primary productivity followed the same

Fig. 3. Changes in centric diatoms (open), pennate diatoms (solid), and microflagellates (shaded) in the three enclosures of MEEE-86X.
trend as chlorophyll $a$ with very low productivity in bag C3 throughout the experiment (Fig. 4).

**Discussion**

Results from MEEE-86X revealed that variations in the abundance of phytoplankton and the amount of chlorophyll $a$ were almost identical in the control bag (C1) and the bag treated with dispersant (C2). The structure of the plankton community in each enclosure was fairly stable during the experiment. It can be assumed that the addition of Corexit 9527 to the experimental ecosystems did not affect the structure of the diatom community. This result agreed completely with the results of MEEE-83.

In enclosures treated with chemically dispersed crude oil, suppression of phytoplankton in bag C3 of MEEE-86X was much more severe than that observed in MEEE-83. At the end of the experiment, the abundance of centric diatoms did not recover to its initial value, the number of microflagellates remained low, and there

![Graph](image)

**Fig. 4.** Changes in chlorophyll $a$ and primary productivity in MEEE-86X.
was only a small increase in the number of pennate diatoms; this increase should not, however, be considered as an indication of recovery from oil pollution.

In the later stage of MEEE-83, the number of diatoms increased tremendously, there was a large increase in the number of microflagellates, and primary productivity and amounts of chlorophyll a increased. The difference in the degree of plankton suppression between these two experiments was attributed mainly to the total oil concentration (particulate and soluble) in the water column, the concentration in MEEE-86X being much higher than that in MEEE-83. Even at the end of the experiment, the total oil concentration in MEEE-86X was about 1.5 mg L⁻¹, i.e., about five times the concentration of 0.3 mg L⁻¹ measured in MEEE-83. The quality of the crude oil and the field conditions under which the experiment was conducted probably contributed to the high concentration of oil in the seawater (Fig. 5).

The percentages of nonvolatile alkane in Prudhoe Bay crude oil and Shengli crude oil were 10 and 14% respectively. Total numbers of particles within 3–4 μm diameter, counted before the experimental treatments, were about 20 000 particles mL⁻¹ for both experiments, and the size distribution of the particles was almost identical (Fig. 6). One day after the addition of crude oil in MEEE-83, 51% of the oil was adsorbed on the particles. In the case of MEEE-86X, 80% of the oil was found on the particles and 20% of the total was in soluble form. The crude oil in MEEE-86X was dispersed as an unstable suspension system in the water col-

![Fig. 5. Oil concentrations.](image-url)
umn. In this system, the concentration of particulate oil could not be lowered quickly. Two weeks later, it was still at a level of 0.85 mg·L\(^{-1}\) in contrast to 0.1 mg·L\(^{-1}\) in MEEE-83. From day 3 onward, the level of soluble oil remained at about 1 mg·L\(^{-1}\) (Fig. 5). Here again, another difference between the two experiments must be taken into account — the water column in the Xiamen enclosures was considerably disturbed.

The Xiamen area experiences semidiurnal tides. The maximum current at the site is about 1.5 knots. Between high and low tides, experimental bags were observed to be bumped around by the tidal currents. These bags were only 6 m in depth and when they were subjected to strong current action, resuspension of settled materials and associated particulate oil in the bags was unavoidable. Results of the \(n\)-(1\(^{14}\)C) hexadecane-trace experiment (Fig. 7) also indicated inconsistent radioactivity levels in the water phase. This was most apparent between days 3 and 4 when radioactivity increased from 101 to 498 dpm·L\(^{-1}\) with a concomitant decrease in radioactivity in settled materials. On day 4, the settling rate of particulates was significantly reduced.

All of these results indicated the existence of resuspension that minimized the action of sedimentation. In MEEE-86X, the average settling rate of particles after
oil treatment was 3.2 g·d⁻¹, with a maximum of 7.3 g·d⁻¹; whereas in MEEE-83, the average was 8 g·d⁻¹ and the maximum was 24 g·d⁻¹. At the end of the experiment, the percentage of settled oil was 14.7% of the total added for MEEE-86X; and 21.4% of the total added for MEEE-83.

One of the important pathways for oil removal is adsorption of oil droplets on plankton or other suspended organic particles followed by their sinking to the bottom to reduce particulate oil in the water column (Lee et al. 1985). In MEEE-86X, oil droplets were also found clinging to the surface of plankton when observed under a fluorescence microscope. Thus, settling of oil adsorbed on suspended organic matter should be occurring in the enclosures. In this experiment, however, the maximum number of phytoplankton was only 600 cells·mL⁻¹, which is only 4% of the maximum number in MEEE-83 and even less than the initial abundance (900 cells·mL⁻¹) of the latter. The relatively low number of phytoplankton in the enclosures would reduce the chance of the particulate oil sinking. Furthermore, the settling process was also offset by the turbulence-induced resuspension. This reduced even further the already weakened scavenging process.

In MEEE-86X enclosures, those particles adsorbing a high concentration of oil are likely to possess a stronger coalescing ability than particles absorbing lower amounts of oil. As the enclosed water column is agitated, the chance of collision among the particles increases, which, in turn, enhances the coalescing ability of the particulate oil. The large particles would then float to the water surface and cling to the inner wall of the bag. Results from MEEE-86X revealed that coalesced particulate oil observed clinging to the inner wall of the bag near the waterline.
Table 1. Fate of chemically dispersed crude oil in the MEEE-83 and MEEE-86.

<table>
<thead>
<tr>
<th></th>
<th>MEEE-83</th>
<th>MEEE-86X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>Percentage of oil added</td>
<td>Weight (g)</td>
</tr>
<tr>
<td>Oil in sediment</td>
<td>42.8</td>
<td>21</td>
</tr>
<tr>
<td>Oil on bag wall</td>
<td>4.1</td>
<td>2</td>
</tr>
<tr>
<td>Particulate oil</td>
<td>5.0</td>
<td>3</td>
</tr>
<tr>
<td>Oil in seawater</td>
<td>19.5</td>
<td>10</td>
</tr>
<tr>
<td>Others</td>
<td>—</td>
<td>64*</td>
</tr>
</tbody>
</table>

* Approximate values.

amounted to 40.6 g or about 27% of the total oil added. In the case of MEEE-83, only 4.1 g of coalesced particulate oil, or 2% of the total oil added, was found clinging to the inner wall of the bag.

Another important phenomenon was observed during MEEE-86X. Three days after the addition of crude oil, the concentration of soluble oil in the water columns leveled off at about 1 mg-L⁻¹ (Fig. 5) even with all the transfer and degradation processes in action. This was mainly caused by the high concentration of particulate oil in the water columns, and when the water columns were disturbed, the dissolution process of oil would increase. A laboratory experiment also corroborated that the solubility of crude oil in seawater increases with agitation.

In summary, the disturbed water columns of MEEE-86X enclosures resulted in lower settling action and, therefore, a reduction in oil removal by the scavenging process. At the same time, resuspension of particles enhanced dissolution of particulate oil, resulting in a much higher concentration of oil in the water columns. In other words, disturbing the water in the enclosures altered the transfer and fate of the crude oil in the water columns (Table 1). The biological effect of this alteration is that phytoplankton growth found in the area around Xiamen would be suppressed by dispersed crude oil at a concentration of about 1.5 mg-L⁻¹.

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