Helgoländer wiss. Meeresunters. 17, 340–355 (1968)

Scientific consequences of the wreck of the "Torrey Canyon"[1]

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KURZFASSUNG: **Wissenschaftliche Konsequenzen des Schiffsunglücks der „Torrey Canyon".** Einige Gesichtspunkte ozeanographischer und biologischer Untersuchungen, die unmittelbar nach dem Auflaufen des Öltankers „Torrey Canyon" im Englischen Kanal (März 1967) in Angriff genommen worden sind, werden geschildert. Unter anderem werden die Ölverdriftung durch Wind und Fragen der Toxizität der Detergentien, welche zur Dispergierung des ausgelaufenen Öls benutzt wurden, behandelt. Im Großeinsatz hat sich französische Kreide (craie de Champagne) als besonders wirksam erwiesen. Die Beteiligung von Mikroorganismen und des Flagellaten *Noctiluca miliaris* beim Ölabbau wird diskutiert. Auf eine zusammenfassende, von der Marine Biological Association herausgegebene Darstellung der wissenschaftlichen Ergebnisse, welche nach dem Tankerunglück erarbeitet worden sind, wird hingewiesen.

INTRODUCTION

Problems of marine pollution fall into three classes: (a) chronic pollution such as you get from sewage, (b) pollution arising from incidents, such as the disposal of tons of copper sulphate on the Dutch coast described by KORRINGA (1968) and (c) accidents.

I shall speak only about an accident when an oil tanker carrying 117.000 tons of crude oil was wrecked. My country was presented with problems on a scale never known before. We had had oil spillages in our harbours, dealt with by the petroleum companies. Also the Warren Springs Laboratory had carried out much work on treating oil spillages on a scale measured in hundreds of tons. There had been no lack of foresight that oil spillage is a technological hazard of our day. But it had been inconceivable that, with all the aids to navigation which exist to-day, anyone would ever drive a large well-found tanker on to a charted rock in good weather. This was in-

[1] The two papers which I presented at the International Symposium 1967 of the Biologische Anstalt Helgoland were not scientific papers in the usual sense but news reports of much interest only at the time. The colour photographs had all been lent by colleagues. Seven of these in black and white, have been published in "Penn ar Bed" which contains the article by BRUSSON (1967). Close counterparts of others are appearing in the Plymouth Report (SMITH 1968). There seems no point in duplicate publication. The appearance of the Breton publication "Penn ar Bed" (in French) and further information has made it possible to add to some of the interim reports. The paper by BRUSSON (1967) has been especially useful. It has been thought better to give the latest views rather than a verbatim account from the tape recordings taken at the Symposium. The two addresses given at the Symposium have therefore been combined and condensed and then developed with the help of new material.

credible but it happened. What happened was a disaster but one which was much less serious than it would have been if our prevailing winds had prevailed.

The Plymouth Laboratory was never concerned with action but only with observing the consequences of an event, akin to the very cold winter of 1963, which was likely to change the environment which we have under constant study.

GENERAL PROBLEMS OF THE "TORREY CANYON" DISASTER

The wreck occured on March 18th, 1967. On the following day when I read the news I tried to foresee the course of events in the light of my knowledge of our waters. How wrong I was. I tell this story against myself as it illustrates the danger of prediction, even by a so-called expert, in our unpredictable climate. Our winds prevail from the south-west and west not only in direction but in strength, and their effect would be augmented by the current system at the Seven Stones light vessel established by CARRUTHERS, LAWFORD & VELEY (1951). There was a possibility of more southerly winds blowing oil into the Bristol Channel, across to the Welsh coast and that some oil might get into the Irish Sea. It was much more probable that south westerly or westerly winds would blow most of the oil up the centre line of the English Channel, whence small deviations of wind direction would contaminate the north coast of France and the south coast of England. It seemed likely that by the late summer oil would be passing through the Straits of Dover and that by the winter both coasts of the Southern North Sea would be at hazard. Nothing like this happened because northeasterly winds dominated our weather for more than a month. If the Western English Channel is to experience northeasterly winds, then April is the most likely month. Perhaps I should have allowed for that but in most years, even in April, the prevailing winds still prevail from the southwesterly and sometimes northwesterly quadrants. I am not proud of this tale but it needs telling because of the difficulty of foreseeing events accurately in our unpredictable climate.

Contamination was restricted to the coasts of the extreme southwestern tip of Britain, West Cornwall, and of the North Brittany coast in France. It was not the Dutch but the Spaniards who had cause to send a technical delegation to Britain to find out what was happening.

We quickly realized that we would have to abandon all our research in progress and for a few weeks observe the effects of the oil and of the agents used to deal with the pollution. During the Easter week-end we made contact with the military headquarters at Admiralty House, Plymouth and through them with all the agencies who had been mobilized to deal with the invasion of unwanted oil. Our first task was to collect all records which could have scientific value for the future not only for ourselves but for others. On the first working day after Easter, 28th March everything we had was deployed. Our research vessel "Sarsia" sailed to examine the biological effects of the oil at sea; a group of shore ecologists went to the beaches and cliffs invaded by the oil whilst a group of biochemists tested the toxicity of the detergents being used to emulsify and disperse the oil. A fourth group maintained contact with military headquarters to be briefed on the disposition of detergents, and of command tactics, with the Royal Air Force to learn the results of aerial reconnaissance, and with the Meteorological Office. In spite of the pressure under which all were working we found cordial co-operation wherever we needed it. An information centre and a press office were also established in the Laboratory for which we had reason to be thankful when not only the press but broadcasting and television corporations called us for information. These were answered with authority and at once by men who had the scientific competence to distill an interesting news story from all the facts available to us while remaining within the bounds set by scientific rectitude. It would have been a mistake to have had everyone at work in the field, even though more hands were much needed there. Our relations with the press and television quickly became intimate and frank and worked very well. Any laboratory in a democratic country concerned with a disaster must establish these several liaison organizations or the field work will suffer.

Our organization, normally and necessarily very free, was transformed overnight into an applied laboratory where each man had a set job and each job was clearly understood as the responsibility of one man. The "Torrey Canyon" disaster revealed the value of a laboratory, concerned normally with long term fundamental research, as a reserve available to deal practically and quickly with an emergency.

I was invited to Helgoland as an oceanographer but I ask the privilege of speaking as one who has spent one-fifth of his working life in chemical industry. I can welcome the industrial chemists who are here today because I well remember the occasion when something I did killed many of the beneficent bugs in the Huddersfield sewage works. I can sympathize with the man who has some unwanted industrial waste and sees the sea as the place where it may do least harm. I am like a barrister who according to his brief could state a case either way.

We all desire the benefits which modern technology can bring to the world, not only in goods but in the wealth which our personal investments may bring us. We realize that inevitably technology may create pollution. Kept to itself, guided only by the profit motive, technology could turn our environment into a dreadful slum. What is the use of a wall-paper beautifully printed with a copper-phthalocyanine pigment if our senses are offended by a stench of hydrogen sulphide or we die from eating polluted shellfish.

The industrial chemist must state his problem of disposing of waste products whereas the oceanographer, the limnologist and the ecologist have to state their views for conserving our environment. Environmental scientists feel that the economic guns are loaded against them so that they need to speak the more forcibly.

I would like to state two principles which I think basic, firstly, an industry must bear the whole cost of disposing of its waste products or rectifying the consequences of accidents. No part of the cost should fall on the community. Secondly, industry must always be asked: is there no way by which you can make some money out of your waste? Often, after a little thought, a way to do this may be seen.

I have spoken as an oceanographer but as an industrial chemist I will answer the first thesis. The chemical industry is internationally competitive. If one country should force its industry to bear the cost of suitably treating its waste and rectifying its errors, costs will rise. Prices would be undercut by competitors so that the company with a conscience would go bankrupt. This is a fair reply to which international regulation and enforcement is the only answer. International regulations may be achieved fairly easily whereas enforcement may be much more difficult.

Until recently the United States was the country where technological pollution was most foul; yet with remarkable speed the Americans are transforming their country. Pittsburgh is now again an attractive city to live in and the Federal Water Pollution Control Administration has teeth and is biting to much purpose. A European industrial chemist can no longer plead that an American competitor will undercut him by allowing his waste products to foul the rivers, lakes and seas of the United States. We in Europe have been given a lead; let us follow it.

Marine pollution is an international problem so that the formation of international law is an intergovernmental task. Sound law must be based on sound observations of a kind which only scientists can make. If we, those of us gathered here, can agree then the task of the international lawyers will become much easier.

International law, however good, is useless unless it is enforced. Experience shows that on the high seas, especially at night, it is next to impossible to catch law-breakers red-handed and more difficult still to obtain evidence which will enable a court to inflict a punishment which deters. However complete our scientific knowledge may be, it is of no value unless we can base upon it effective enforcement of law. This must be an aim of research upon marine pollution.

Thought and action are needed about the "fire brigade" problem: how to deal quickly and effectively with a disaster which pollutes the marine environment as did the wreck of the "Torrey Canyon". This disaster occured near a country with a high level of technological competence. Fire brigade action was initiated within hours and from mistakes much has been learned. We can be criticized but is there anyone here who could say that his own country, presented with a similar situation, would have done better?

A similar disaster could occur anywhere along the tanker routes of the world, e. g. on the coasts of Portugal; a country highly civilized but with a lower technological potential. It does not own tankers so that a tanker wrecked there would be flying a foreign flag and owned by nationals of some other country. A country such as Portugal should have the right to call in an international organization to clear up the mess.

To take an example, Portugal might need to draw help from France or Britain. Each would have to mobilize forces which exist but would not be ready for immediate action at a distance. Only an international organization could mobilize quickly the necessary knowledge, people and machinery. Much initiative rests with those of us who possess basic knowledge or know how to get it. Let us use that initiative.

THE MOVEMENT OF THE "TORREY CANYON" OIL AT SEA

The data for our calculations all came from aerial reconnaissance by the Royal Air Force. For several days it was very difficult to see any pattern in events. The observations proved to be very good but interpretation depended on the weather and lighting conditions at the time and upon standardization of the meaning of the words improvised to describe a new phenomenon. After about five days when much oil had reached position C (Fig. 1), the pattern became clear. Later we were fortunate in that Professor E. J. Denton, was able to take up the study of the movement of the oil in terms of the wind measured at nearby land stations and of the daily isobaric weather charts. He found that the oil had drifted before the wind at a speed 3.3 % of the wind

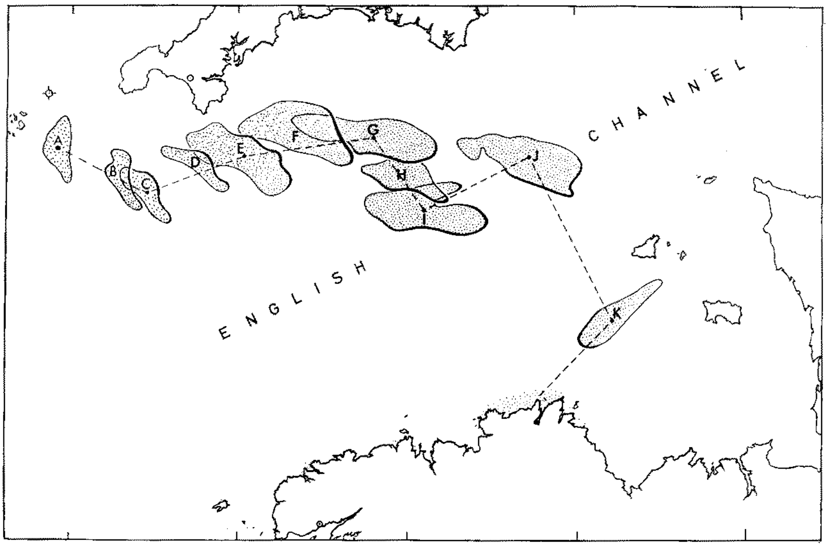

Fig. 1: A diagram, based on observations made by Royal Air Force Coastal Command of the drift of oil liberated when the tanker "Torrey Canyon" was wrecked in March, 1967; position A, 20 March 0700 h; position K, 8th April about mid-day

speed, agreeing with the figure obtained by Hughes (1956) from the drift of plastic envelopes. By the time the calculations were concluded, much oil was actually ashore near Treguier in Brittany, but close to the date and place predicted.

However a very large amount of oil was later liberated when the ship broke her back on the evening of 26 March and up to the time when she was bombed – possibly as much as 48.000 tons. This oil quickly was lost from sight. Professor Denton calculated where this oil should be. It should first have moved towards mid-Channel. About 5 April the wind direction changed from northwesterly to northeasterly so that by about 10–11 April, this very large amount of oil should have lain northwest of Ushant, having nowhere touched land. On 12 April the oil was seen from R. V. "Sarsia" but about 20 miles short of the calculated position.

It is interesting to compare Professor Denton's calculations with a report not available when I spoke at Helgoland, that of Capitaine de Frégate Brusson (1967) on the French observations.

The oil was first seen by the French on 11th April at a position about half way between the positions calculated for 10th and 11th April. The agreement is good but thereafter the calculated positions and the positions observed by the French began to separate; the calculated wind-drift suggests that the oil should have travelled 60 nautical miles in 5 days whereas the observed drift of 60 miles occupied 13 days.

Clearly the southward movement of the oil was slowed down by an opposing steady residual surface current of about 0.3 knots running northwest of Ushant. At the time the discrepancy with the positions reported by Professor P. COURTOT much concerned us but in retrospect it seems reasonable to believe that residual currents must be vectorially added to or subtracted from the drift computed from the meteorological isobaric charts.

Nevertheless starting from the position of the oil reported by the French on April 17th, the 3.3 % factor was applied to the drift during the next fortnight. The calculated position on 1st May was very close to that where the French observed it. A forther deduction, again with the 3.3 % factor, suggested that oil would enter the Baie d'Audierne about May 20th, which it did.

Consequently, the 3.3 % factor failed to predict correctly only for about a week while the oil lay northwest of Ushant. We know that often a strong residual current there enters the English Channel from southwest or south so that our calculations have given us a measure of the residual current in mid-April at the surface around 48°50'N, 5°30'W of about 0.3 knot (0.15 m.p.s.).

Other evidence supports the view that the factor 3.3 % is about right. On 29th April oil patches were observed off the Lizard and marked with surface drifters. On 8th May some oil came ashore at Wembury a few miles east of Plymouth. The wind-drift calculation, based only on the 3.3 % rule, would have brought the oil ashore well to the west of Plymouth. We then used Admiralty tidal data to correct the calculated wind drift for the effect of residual current. The landfall now agreed with that observed. A member of the Plymouth staff was asked to search for the surface drifters and found two. There is little doubt that the oil cast ashore east of Plymouth was that marked off the Lizard by R. V. "Sarsia" and that allowance for the residual current had to be made.

Dr. TOMCZAK has studied similar drifts in the Helgoland Bight and consistently found that oil was driven forward at about 4.2 % of the wind speed. The difference between 3.3 % and 4.2 % would matter in practical applications. It is relevant to quote BRUSSON (1967) who used a figure of 2.5 % of the wind speed to account for the drift northwest and west of Ushant. The percentage discrepancy is almost the same but in the other direction. Coastal currents in the northern hemisphere tend to run with the coast on the right. The Plymouth results and those of HUGHES (1956) were evaluated well away from land, TOMCZAK's with a coast on the right and BRUSSON's with one on the left. This cannot be the whole of the explanation but for the present would be a useful guide to observers who may have to contend with a future emergency and do not have exact knowledge of residual currents. Well away from land polluting oil is likely to move ahead of the wind and at about 3.3 % of the wind speed. Where the wind drift flows closely parallel with a coast on the right, the factor may be 4.2 % or even more but when the coast is on the left the factor may be as low as 2.5 %. It will be noticed that the EKMAN spiral seems not to have application to this problem.

A number of other slides presented at the Helgoland symposium are presented in the Plymouth report on the "Torrey Canyon" pollution (SMITH 1968, Chapter 8).

CRAIE DE CHAMPAGNE

So far as Britain was concerned the very large mass of oil drifting towards the Bay of Biscay, of the order 40.000 tons, had been completely lost to sight. All oil at sea was believed to have been destroyed. But as a result of Professor Denton's calculation we sent our research vessel "Sarsia" to look for oil and found it within 20 miles of the predicted position. There was evidence that the French had found it before us and had

Fig. 2: Bay of Biscay, 12th May, 1967. Craie de Champagne, used by the French to sink oil at sea, associated with which is a swarm of *Noctiluca miliaris.* (Photo: R. Swinfen)

taken action. A white powder was spread upon the floating oil (Fig. 2) and fortunately for us they had thrown overboard a bag marked "craie de Champagne" and still containing inside some dry white powder. Since this powder seemed inert when treated with hydrochloric acid we deduced that it was not calcium carbonate and that it might be fuller's earth, which occurs in Champagne. The material was somewhat hydrophobic and oleophilic. Professor Courtot gave us the answer: Craie de Champagne is French blackboard chalk, consisting of calcium carbonate treated with 1 % sodium stearate. (British blackboard chalk is made from gypsum.)

At Plymouth and at other British laboratories, untreated chalk and ground limestone had been tried for dispersing oil and found to be not at all efficient. Clearly the 1 % of sodium stearate is all important, not only in protecting the chalk for a while from the attack of hydrochloric acid but in making it disperse in oil rather than in water.

The French used about 3.000 tons of this treated chalk upon about ten times the weight of oil present as oil-in-water emulsion having a density only slightly lighter than sea water. Our calculations suggest that all this oil would otherwise have come ashore on the Atlantic coast of Brittany. The inference is that they had been completely successful in treating a very large amount of oil as 70 % oil-in-water emulsion with no more than 3.000 tons of craie de Champagne.

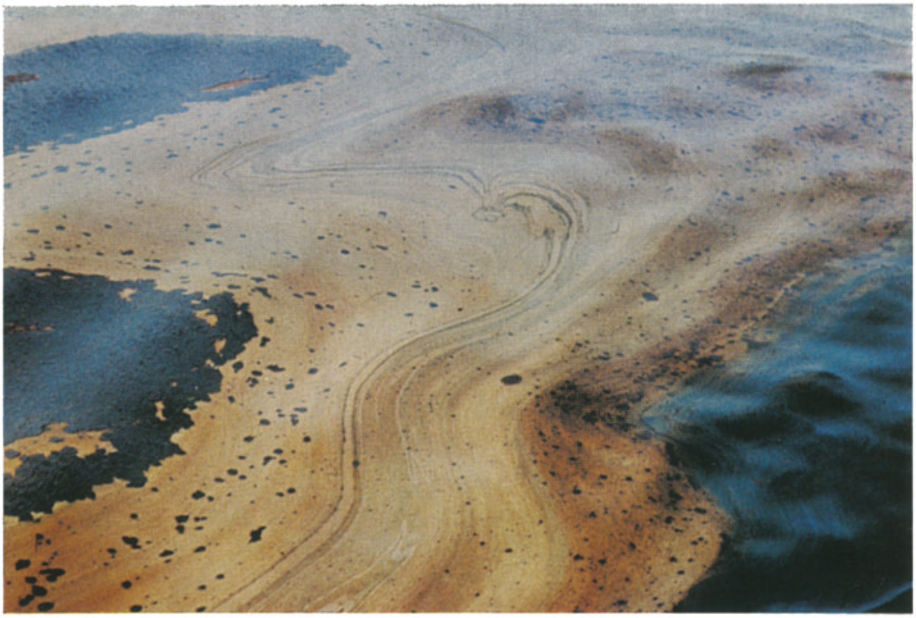

Fig. 3: Bay of Biscay, 47° 55′ N, 05° 19′ W, 12th May, 1967. Swarms of *Noctiluca* associated with oil. (Photo: R. SWINFEN)

It would seem that the main purpose of the French treatment was to sink the oil so that there was a risk that the underlying fishing grounds would have received a coating of treated oil sufficient to have been noticed by the many fishing vessels which work the area. Our own research vessel dredged a few bottom samples from the area where the oil was "sunk" and found no trace of oil. However, the hauls were too few to support an assured conclusion. More to the point we have no reports that fishing vessels have been inconvenienced. It seems a fair conclusion that little oil reached the bottom of the sea.

It may also be inferred that the French received unforeseen help not only from the 1 % of sodium stearate in the commercial craie de Champagne, the value of which may not have been appreciated, but from the presence at the time of helpful micro-organisms in the sea.

The colour of most of the patches treated by the French with craie de Champagne and observed by us was pink (Fig. 3). The colour was due to the flagellate, *Noctiluca miliaris*. That is the limit of our factual knowledge.

One may surmise that micro-organisms were essential for the success of the French treatment. Each particle of craie de Champagne was able to collect about ten times its weight of oil from the oil-in-water emulsion. Bacteria probably began at once to feed on these particles but may or may not have been an essential link in the chain. From discussions after this paper was read it would seem that *Noctiluca miliaris* is phagotrophic and would have no difficulty in engulfing the dispersed oil on chalk, providing that the particles were of suitable size.

The inference, far from proven, is that *Noctiluca miliaris* ate almost all of the oil which the French dispersed for them. During the symposium Dr. UHLIG (Biologische Anstalt Helgoland) mentioned our knowledge, or lack of knowledge, of *Noctiluca miliaris* so that this idea was presented solely as a basis for further research. The problem has many aspects:

(a) Would the French have been so successful in dispersing so much oil so completely without the help of *Noctiluca?*

(b) Would silicone-treated power station fly-ash or any of the other dispersing powders that have been suggested, be as successful as craie de Champagne?

(c) In areas such as the Thames Estuary where *Noctiluca* occurs rarely, if at all, are there other phagotrophs able to grow rapidly and discharge the same function?

(d) "Red tide", which was produced, is often very toxic. Is there any risk that dispersion of oil by craie de Champagne, or by other oleophilic fine powders, might produce a toxic environment?

(e) In nutrient poor water, would an admixture of fertilizer augment the ability of dispersed oil to support a phagotrophic population?

(f) Would the creation of a hypereutrophic situation to destroy oil do more harm than good to the sea as an environment, especially for shellfisheries.

(g) Stated in another way, the French treatment was carried out in a mass of clean sea water more than 100 m deep and with strong currents. Would the treatment have been so successful if it had been carried out on a shallow sea (such as the Thames Estuary or Helgoland Bight) where previous pollution had already reduced capacity for self-purification of the water?

(h) Crude oil and the oil-in-water emulsion are very different things. Would craie de Champagne or a similar powder be as successful in dispersing crude oil with a specific gravity of 0.85 as first released from a wrecked tanker? The French carried out a fascinating experiment in economic ecology. We must learn from it all we can.

AMENITY VERSUS THE ENVIRONMENT

The "Torrey Canyon" disaster has highlighted the conflict which exists between the interests of amenity and the interests of the natural environment. The county of Cornwall lives upon the holiday industry. Apart from china clay (Kaolin) all other industries take second place. Since crude oil and holiday makers are incompatible, detergents were used on a vast scale to make the beaches fit for the holiday season. Some of the amenity and ecological problems are illustrated by Figures 4 to 9.

Fig. 4: Porthmeor Beach, St. Ives. 28th March, 1967. Beach polluted with untreated oil, deposited by the receding tide. Prior to any cleansing operations. In the foreground the reflection of the sky on the oil makes it appear blue. (Photo: R. Swinfen)

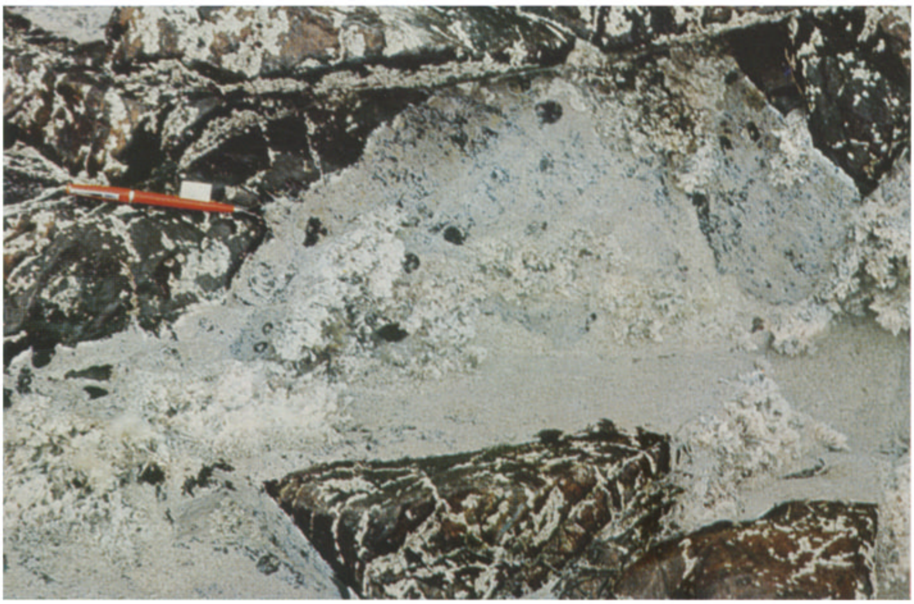

Fig. 5: Kynance Cove. 22nd April, 1967. Rock pool on reef which had been heavily sprayed with detergent. The pool is lined with an encrusting coralline alga, which has been bleached by detergent, as have the tufted corallines. The dark oval patches mark sites previously occupied by limpets *(Patella)*, all of which had died. (Photo: N. A. Holme)

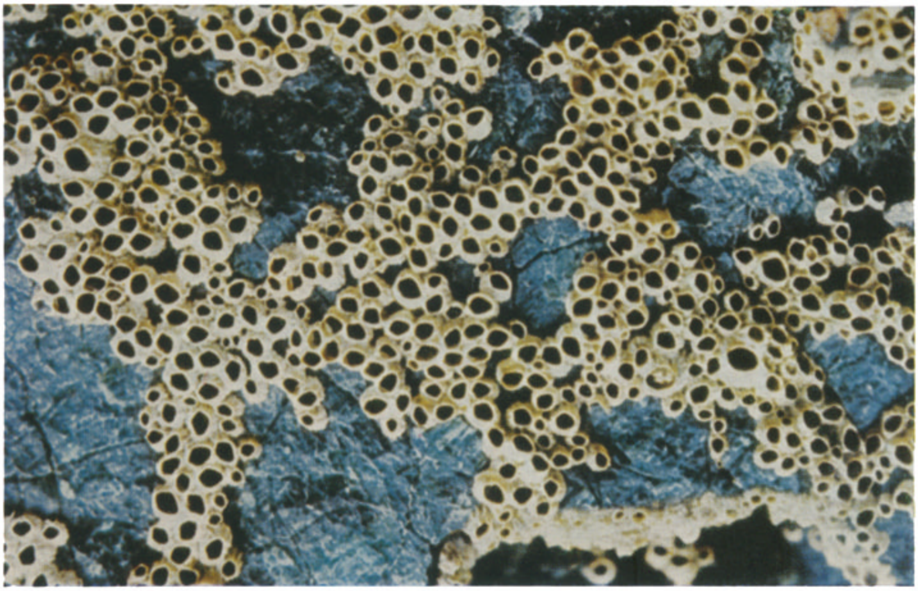

Fig. 6: Kynance Cove. 25th May, 1967. Barnacles *(Chthamalus)* killed by detergent spraying. (Photo: N. A. Holme)

Fig. 7: Porthtowan, North Cornwall. 12th August, 1967. In the foreground rocks sprayed with detergent. On these limpets had been killed so that as a result the green weed *Enteromorpha* had multiplied prodigiously. In the background no detergent spraying had been carried out, and the limpets keep the green weed in check by their foraging activities. (Photo: N. A. Holme)

Fig. 8: Oil cleansing operations in Porthleven Harbour, 28th April, 1967. Bulldozing the harbour floor and detergent spraying the heavily polluted harbour wall. (Photo: P. E. Gibbs)

Fig. 9: Mouth of Porthleven Harbour. Detergent emulsion drifting out to sea following heavy detergent spraying in the harbour. 28th April, 1967. (Photo: P. E. Gibbs)

Ecologists and chemists, concerned with the marine environment as a place where a balanced population of plants and animals lives, see the problem very differently. To them the very toxic detergents were wholly bad. The natural environment would have suffered much less if the oil had been left alone. Limpets on the rocks, bacteria in the sand and bacteria and phagotrophs at sea would in time have dealt with the oil, except possibly for some asphaltic residues. Oiling of sea birds is a special problem.

Of all the methods used, treatment of the oil at sea with "craie de Champagne" seems to have been most effective and to have done least damage but even with this one is worried that toxic products might in other circumstances result. If the oil cannot be removed by physical means, is it not best to leave it alone?

SUMMARY

1. The re-deployment of the resources of the Plymouth Laboratory required to observe the consequences of the "Torrey Canyon" disaster were described. Some excerpts were taken from the report (SMITH 1968) to be published by the Marine Biological Association of U. K. on 18 March, 1968.
2. Field studies were made at sea and on the polluted shores, as well as laboratory studies of the toxicity of the detergents employed to disperse the oil.
3. The drift of the oil, established by aerial reconnaissance, was found to be directly ahead of the wind at 3.3 % of the wind speed.
4. Now that the 3.3 % factor has been established by direct observation at sea, a limited aerial survey of the area where the oil was predicted to be would have been of more value than the blanket survey of a limited area close to the coast.
5. When known, strong surface currents should be added vectorially to the calculated wind-drift. Two examples are quoted, one explaining the differences between calculated drift and the drift observed by the French while oil was northwest of Ushant. The results in the Helgoland Bight were compared.
6. The value of craie de Champagne used by the French to sink the oil at sea and the possible part played by the phagotrophic flagellate, *Noctiluca miliaris*, were discussed.
7. Implications of the "Torrey Canyon" disaster affecting international law and enforcement were developed. The need was stated for an international fire brigade ready to deal with pollution of the sea by an accident on the high seas or on a coast.

Acknowledgements: The report on the effect of the "Torrey Canyon" pollution upon marine life is to be published by the Marine Biological Association (1968). It was a truly combined operation from which it has been impossible to dissect the contributions by individuals. I drew on the experience and observations of many and express my indebtedness to all my colleagues.

Most cordial co-operation between the French and British Scientists concerned with the "Torrey Canyon" pollution has developed but this has been due to one man alone, Prof. P. COURTOT of the Faculté des Sciences, Brest. Prof. COURTOT telephoned to the Plymouth Laboratory the information freely given by the French Marine and organized the contacts from which so much else has developed. Our Laboratory and others in Britain are most grateful to him. Even fuller co-operation would have developed if telephone communication had been

easier. Most calls between Plymouth and Brest required many hours to complete and were not lightly undertaken.

Views expressed in this paper are my own and do not necessarily represent those of the Marine Biological Laboratory.

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Discussion following the paper by COOPER

RAMSTER: What was the source of the wind data?

COOPER: Six-hourly wind records from the nearest land stations were first used. Later the wind speeds were deduced from the isobaric charts published in the same British Daily Weather Reports. Agreement was good for all English meteorological stations used, for Guernsey and Cap Fréhat in France. The Ushant wind records did not give a good fit; better agreement was found using winds deduced from the isobaric charts. (Much of the discrepancy was due to the residual current. See revised text.)

RAMSTER: Are you, Dr. COOPER, not surprised by the idea that Woodhead sea-bed drifters, moving along the bottom of the sea, give the same type of result as the movement of surface drift envelopes?

COOPER: I was guilty of a slip of the tongue (corrected in the revised script). Only surface drifters were used.

KOHNKE: Ich möchte darauf hinweisen, daß die unterschiedlichen Windfaktoren auf physikalische Ursachen zurückgeführt werden können.

COOPER: Yes. The surface tension and viscosity of oil differ from those of water and will change as crude oil is converted to the "chocolate mousse" emulsion, consisting of 70 % water and 30 % oil.

KOHNKE: Welche Restströme herrschen im Englischen Kanal?

COOPER: We have far too little quantitative knowledge of the residual currents in the English Channel, although qualitatively they are well understood.

NEUMANN: Der Faktor L = 4,2 % hängt wesentlich mit den Meeresströmungen zusammen. Wir haben tatsächlich eine Menge der Rechnungen mit dem Faktor L = 3,8 % durchgeführt, haben dann aber bei den Auszählungen den Faktor L = 4,2 % bestätigt gefunden. Selbstverständlich haben wir keine Möglichkeit, die tatsächlichen Meeresströmungen mit Strommessern nachzuprüfen, so daß die erhaltenen Strömungen nur im Zusammenhang mit dem Faktor L = 4,2 % anerkannt werden können.

COOPER: Without doubt the difference is largely due to residual currents which in the English

Channel are in part consequent on variable preceding winds and in part are due to tidal forces which we do not understand. We have no variations in the distribution of masses as large as those in the German Bight. For future emergencies air force personnel will need manuals to advise them how best to follow the drift of surface pollutants at sea.

POSTMA: As *Noctiluca miliaris* is lighter than seawater it is often very much concentrated along lines of convergence. The same can also happen to oil. Is it therefore not possible that the concentration of oil and *Noctiluca* on the same spot is caused by an identical behavior?

COOPER: Yes, it is possible. We are able only to report what was seen and offer no assured explanation.

UHLIG: Ihre Vermutung, daß *Noctiluca miliaris* möglicherweise an der Vertilgung des Öls beteiligt war, hat mich außerordentlich fasziniert. Unsere bisherigen Experimente deuten darauf hin, daß *Noctiluca* keinerlei Nahrungsspezifität aufweist, eine Ölvertilgung seitens *Noctiluca* wäre daher durchaus denkbar. Darf ich fragen, ob einer Ihrer Mitarbeiter entsprechende Untersuchungen durchgeführt hat?

COOPER: No, there is no work in progress on this subject at Plymouth.

TOMZCAK: Ich möchte Dr. COOPER gratulieren zu diesen Untersuchungen. Es ist eine gute Gelegenheit gewesen, den Driftfaktor in der Praxis zu bestimmen. Die Diskrepanz zu den Ergebnissen unserer Driftkartenmessungen könnte daran liegen, daß die Restströme eventuell nicht genügend berücksichtigt wurden. Wir hatten in Deutschland zweimal Gelegenheit, den Faktor in der Praxis nachzuprüfen. Bei der Strandung von „Gerd Maersk" in der Elbmündung ergab sich durch Schiffs- und Flugzeugbeobachtung der Wert 4,3 %. Bei dem Unglück der „Anne Mildred Brøevig" nordwestlich von Helgoland erwies sich durch Meldungen des Eintreffens von Öl an der dänischen Küste bei Esbjerg und später in der Jammerbucht im Norden von Dänemark die Richtigkeit unserer mit 4,2 % durchgeführten Rechnungen. Wir sind gern bereit, zur Klärung der Frage beizutragen und Driftkarten – sofern noch genügend bei uns vorhanden sind – zu Vergleichsmessungen zur Verfügung zu stellen.

COOPER: Discussion of this matter has been incorporated in the text revised in the knowledge of the French observations (BRUSSON 1967).

GUNKEL: Ich finde die angedeuteten und möglichen Beziehungen zwischen *Noctiluca* und Öl äußerst interessant. Darf ich hierzu vielleicht ein Ergebnis anführen, das wir bei einigen Abwasserversuchen erhalten haben. Mit Anreicherungskulturen von ölabbauenden Bakterien beimpfte Öl-Wasserumsätze zeigten zu bestimmten Zeiten keinen Abbau mehr, die Anzahl ölabbauender Bakterien nahm sehr stark ab. Bei mikroskopischer Kontrolle ergab sich ein Massenauftreten bakterienfressender Protozoen.

NEUMANN: Welche Schichtdicke hat das Öl? Man muß berücksichtigen, daß der Faktor bis 40 cm Tiefe auf L = 2,0 % abnimmt, was zur Erklärung des Faktors L = 3,3 % beitragen könnte.

COOPER: The thickness of oil well away from the "Torrey Canyon" probably rarely exceeded 5 cm. Most estimates of thickness are guesses. BRUSSON (1967) states that the red brown sludge (boue) seen by the French was 2 to 3 decimetres thick.

BROCKIS: May I compliment Dr. COOPER on his very wide-ranging paper and also on the excellent photographs with which he illustrated his remarks. I should like to emphasize that the best method of cleaning oil from a beach when using detergents is to plough furrows parallel to the water front and then to apply detergent so that the advancing tide mixes the oil, sand and detergent as soon as possible, and certainly within one hour of detergent application. This will materially assist in preventing the deep penetration of oil and detergent into the beach, which Dr. COOPER mentioned earlier in his presentation. The author made a plea for further steps to be taken internationally to prevent discharge of oil at sea from all types of shipping. Such steps are already in progress and in May of this year, the 1962 amendments to the 1954 Convention for the Prevention of Oil Pollution of the Sea came into force, although they do not of course form part of international law. The restrictions which these amendments place on all new ships of 20.000 gross tons and over will in due course go a long way towards meeting the undoubted need that Dr. COOPER stressed at the conclusion of his paper.

COOPER: The method of ploughing furrows parallel to the water front was widely practiced, also a herring bone method. It so happens that a slide of the first method was available. The problems of chronic, as opposed to accidental, oil pollution arise largely from cargo ships of intermediate size which discharge asphaltic residues from their fuel tanks, often at night.

PEARSON: Have you any information on the relative rates of dispersal of the oil, and of the oil and detergent mixtures in the sea?

COOPER: Nothing quantitative.

PEARSON: Is anything known of the resistivity of the oil-degrading bacteria in the natural marine environment to the presence of detergents?

COOPER: No, but one may guess that the aromatic fraction is not likely to help.

SIMPSON: I would like to make a few brief remarks on the observations on the effects of the "Torrey Canyon" incident on fisheries, that were made by our staff at the same time as those made from the Plymouth laboratory. The damage to commercial fish was negligible and the trawl fishery resumed normal fishing as soon as the oil had cleared from over the fishing grounds. Mackerel fishing continued uninterrupted and in many areas mackerel were being caught on the edge of the water whitened by the detergents. There were considerable numbers of crabs and some lobsters killed in the immediate vicinities of about four bays where the largest quantities of detergents were used, but it is considered that the numbers killed were very small compared even with the local stocks of these species. The catches of lobsters and crabs during the 1967 season do not appear to have been significantly affected. There was some tainting of lobsters in one area by the detergents and the fishing was stopped in this area for about 3 weeks to protect the market. The tainting was found to be lost if the lobsters were kept in clean water for about 2 weeks. The small damage to fisheries must not, however, be taken to mean that fisheries would be so little affected in other areas, such as where the sea is less deep and where dilution and dispersal would be less rapid, etc.

COOPER: I am grateful to Mr. SIMPSON for supplying this information. Our two laboratories worked closely together and there was little overlap.

BAARS: May we assume that the detergents used were of the "soft" (biodegradable) type?

COOPER: "Detergent" is a misnomer. "Emulsifying agent" is a better term, since they are non-ionic and designed for the purpose of emulsifying oil at sea. I am not at liberty to divulge the formulation beyond saying that the best usually consist of two non-ionic surfactant substances dissolved in an aromatic carrier solvent.

BAARS: Could you give an idea about the total amount of detergents used during the whole operation of cleaning?

COOPER: The amount used was very large indeed, but I cannot quote a figure from memory.