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VOLUME SEVEN

BIOLOGICAL IMPACTS OF OIL POLLUTION: ROCKY SHORES

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BIOLOGICAL IMPACTS OF OIL POLLUTION: ROCKY SHORES

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PREFACE

This report is one of a new series commissioned by the International Petroleum Industry Environmental Conservation Association (IPIECA). The full series of reports will represent the IPIECA members' collective contribution to the global discussion on oil spill preparedness and response, initiated by major oil spill incidents during 1989/90.

In preparing these reports—which will represent a consensus of membership views—IPIECA has been guided by a set of principles which it would encourage every organization associated with the transportation of oil products at sea to consider when managing any operations related to the transportation, handling and storage of petroleum and petroleum products:

- It is of paramount importance to concentrate on preventing spills.
- Despite the best efforts of individual organizations, spills will continue to occur and will affect the local environment.
- Response to spills should seek to minimize the severity of the environmental damage and to hasten the recovery of any damaged ecosystem.
- The response should always seek to complement and make use of natural forces to the fullest extent practicable.

In practical terms, this requires that operating procedures for transportation, storage and handling of petroleum and petroleum products should stress the high priority managements give to preventative controls to avoid spillages. Recognizing the inevitability of future spills, management responsibilities should also give high priority to developing contingency plans that will ensure prompt response to mitigate the adverse effect of any spills. These plans should be sufficiently flexible to provide a response appropriate to the nature of the operation, the size of the spill, local geography and climate. The plans should be supported by established human resources, maintained to a high degree of readiness in terms of personnel and supporting equipment. Drills and exercises are required to train personnel in all spill management and mitigation techniques, and to provide the means of testing contingency plans which, for greatest effect, are carried out in conjunction with representatives from the public and private sectors.

The potential efficiencies of cooperative and joint venture arrangements between companies and contracted third parties for oil spill response should be recognized. Periodic reviews and assessments of such facilities are encouraged to ensure maintenance of capability and efficiency standards.

Close cooperation between industry and national administrations in contingency planning will ensure the maximum degree of coordination and understanding between industry and government plans. This cooperative effort should include endeavours to support administrations' environmental conservation measures in the areas of industry operations.

Accepting that the media and the public at large have a direct interest in the conduct of oil industry operations, particularly in relation to oil spills, it is important to work constructively with the media and directly with the public to allay their fears. Reassurance that response to incidents will be swift and thorough—within the anticipated limitations of any defined response capability—is also desirable.

It is important that clean-up measures are conducted using techniques, including those for waste disposal, which minimize ecological and public amenity damage. Expanded research is accepted as an important component of managements' contribution to oil spill response, especially in relation to prevention, containment and mitigation methods, including mechanical and chemical means.

INTRODUCTION

Most people with access to the sea have at one time enjoyed looking into rockpools and searching for crabs under boulders. Rocky shores have a great deal of fascination for people and they are the closest that many of them will get to the mysteries below the low tide mark. They are found, in some form, on most of the world's coasts and their ecology has been the subject of many books, reports and scientific papers.

Rocky shores encompass a variety of intertidal habitats and have a range of vulnerabilities to oil. While some areas are quickly and easily cleaned by natural forces others can trap oil in sensitive sub-habitats which may then be damaged and take many years to recover. Furthermore, rocky shores have an importance in the wider context of marine ecosystems and some provide important local fisheries resources, tourism and amenities.

This report describes the factors that make some rocky shores more sensitive to oil spills than others and considers the most appropriate methods of clean-up. Case histories are used to illustrate the effects of spills and spill clean-up, as well as typical recovery rates.

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THE IMPORTANCE AND VARIETY OF ROCKY SHORES

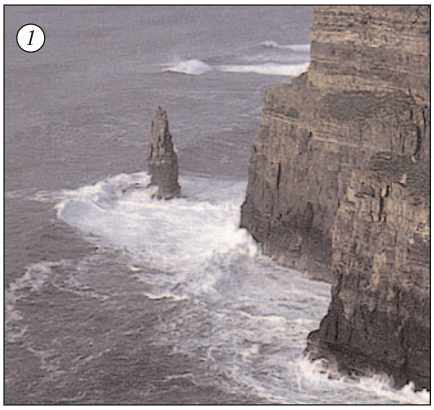
Economic uses of rocky shores. Seaweed harvesting is an important industry in some areas of Scotland (top), and rock oysters are collected from the shores of Goa, west India, for selling in local food markets (bottom).

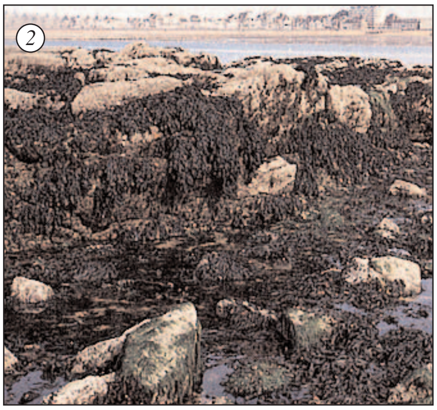
Rocky shores dominate a large proportion of the world's coastlines and although there are regional differences in their form and function they all play important roles within their local marine ecosystem.

Seaweeds, or algae, are a common feature of rocky shores and they are a major source of organic material for other marine life. Many species have an annual cycle of growth and decay, and their productivity can be very high. The rocky shore animals also play a part in this productivity, releasing enormous numbers of eggs and larvae into the sea, which provide part of the food resource for juvenile fish and other species in coastal waters. When the tide is in many fish and other animals also move in to feed directly on the animals and plants of the rocky shore; and when the tide is out, many birds and some mammals do the same.

The highly diverse and productive communities on rocky shores have also provided some human economic benefits. Examples include the many areas worldwide where seaweed is collected for food, fertilizer or alginate production. Alginates are used in the food, brewing and cosmetics industries. There are also many fisheries and aquaculture industries that are based on rocky shore species—e.g. limpets in the Azores, sea-squirts and stalked barnacles in Spain, edible seaweed in Japan and South Korea, and mussels throughout the world. These fisheries can be essential to the economies of some rural coastal communities. Finally, and in marine conservation terms, rocky shores provide the homes for a wide variety of specialized organisms that are not found anywhere else.

Rocky shores are very variable in form. Bedrock shores are common on the wave exposed coasts of all continents but are also found in sheltered marine inlets and some estuaries. Depending on geological formations and oceanographic processes, they range from vertical cliffs to gradually sloping or wave-cut platforms. In many tropical regions they are formed from raised fossil coral reefs. The rock may be pitted, cracked and creviced and sometimes forms rockpools, overhangs, gullies and caves. Some shores are dominated by boulders, particularly in arctic and cold temperate regions where they are often of glacial origin. Many of these boulder shores are very porous, with interstitial spaces that can go deep below the surface. Intertidal boulders in other regions are normally lying on firm sediment without deep gaps. The photographs on the following page show a selection of rocky shores around the world.





1. Extremely wave-exposed Cliffs of Moher, west coast of Ireland.

2. Sheltered rocky platform with rockpools and boulders at St. Malo, France.

3. Sheltered beach rock flat on the Gulf coast of Saudi Arabia.

4. Very sheltered boulder shore in Sullom Voe, Shetland.

5. Very silty bedrock and boulders on one of the few rocky shores in Singapore.

6. Very sheltered rocky shore in Prince William Sound, Alaska.

7. Moderately wave exposed shore formed by raised fossil coral reef on Curaçao.

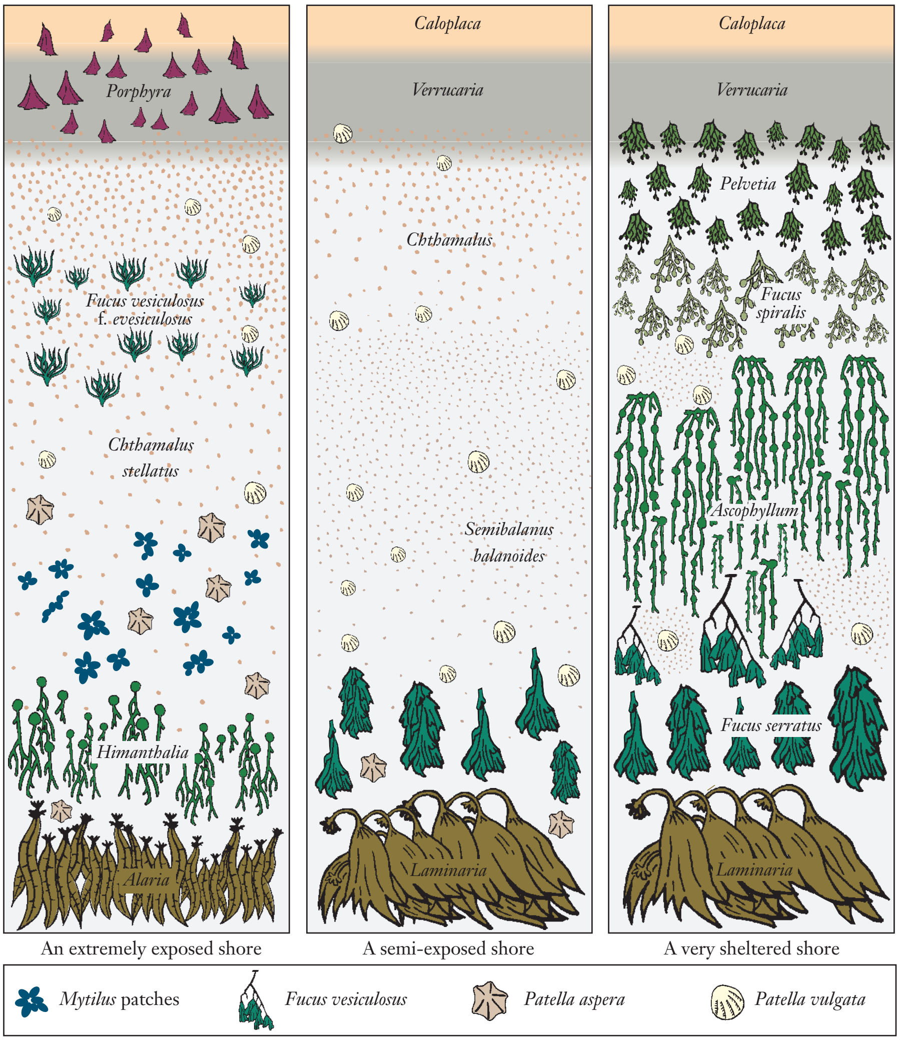
8. Boulder shore in the eastern Strait of Magellan, Chile.

ROCKY SHORE ECOLOGY AND DYNAMICS

A very sheltered shore in the Yealm Estuary, UK (top) and a wave exposed shore at the mouth of the Dart Estuary, UK (bottom). The sheltered shore is dominated by brown macroalgae, while the exposed shore is dominated by barnacles and limpets. Note the sharply defined bands of the different zones. The black band in the splash zone is a natural Verrucaria *lichen—not oil!*

Typical zonation patterns of rocky shores (right): example diagrams from around Dale, UK (from Ballantine, 1961). Pelvetia *is one of the few seaweeds that can survive being almost completely dried out between high tides while* Fucus serratus *and* Laminaria *have to remain moist. Barnacles close their valves to stop moisture escaping while limpets have a 'home' where the shell and the rock form a perfect fit. Soft unprotected animals have to remain on the lower shore unless they can find a moist crevice or pool.*

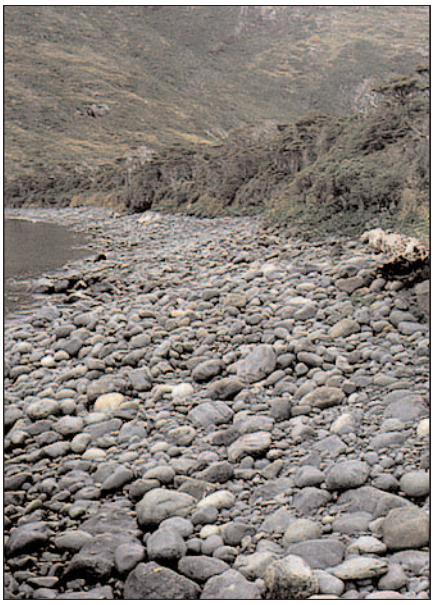
Rocky shores are colonized by a wide variety of marine algae and animals that have adapted to a very stressful environment. But it is a gross oversimplification to describe the rocky shore as *one* environment. Depending on where a rocky shore organism lives it may be subjected to varying levels of desiccation, high and low temperatures, a range of salinities, physical battering by waves, long periods without food and varying levels of predation. In response to these factors the rocky shore organisms have adapted to cope with particular environmental regimes, resulting in distinct vertical zonations and very substantial differences between the communities on wave exposed shores and those on wave sheltered shores.

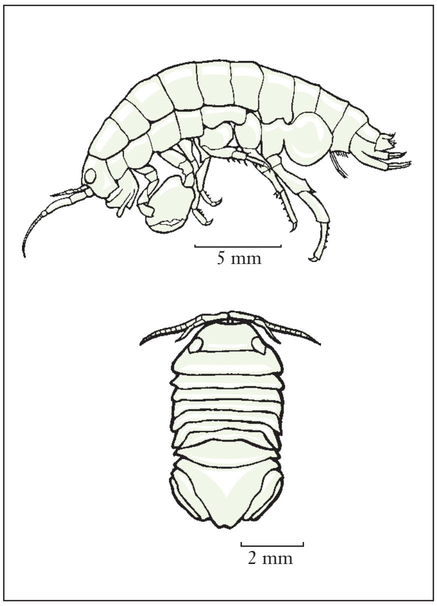


These patterns of zonation and exposure preference are subject to geographical variation but the general trends are usually evident. The lower shore communities are much more diverse and more productive than the upper shore, with more algae and soft-bodied animals. Communities on wave exposed shores have fewer large algae which could be torn off the rock and more filter-feeding barnacles and mussels than sheltered shores. Wave exposed boulder shores are usually too dynamic for anything other than small mobile crustaceans and some ephemeral species which can settle and grow in calm periods.

A rich lower-shore community, including red algae, sea anemones and starfish, on the coast of Oregon, USA (left).

Red Sea snails clustered together in a moist hollow to reduce desiccation. Only a few marine species can survive the harsh conditions of the upper shore zone (right).





On this exposed shore in the Cape Horn archipelago (left), the dominant animals are crustaceans like this amphipod (top) and isopod (bottom). They live in the spaces between the boulders and can cope with their movement.

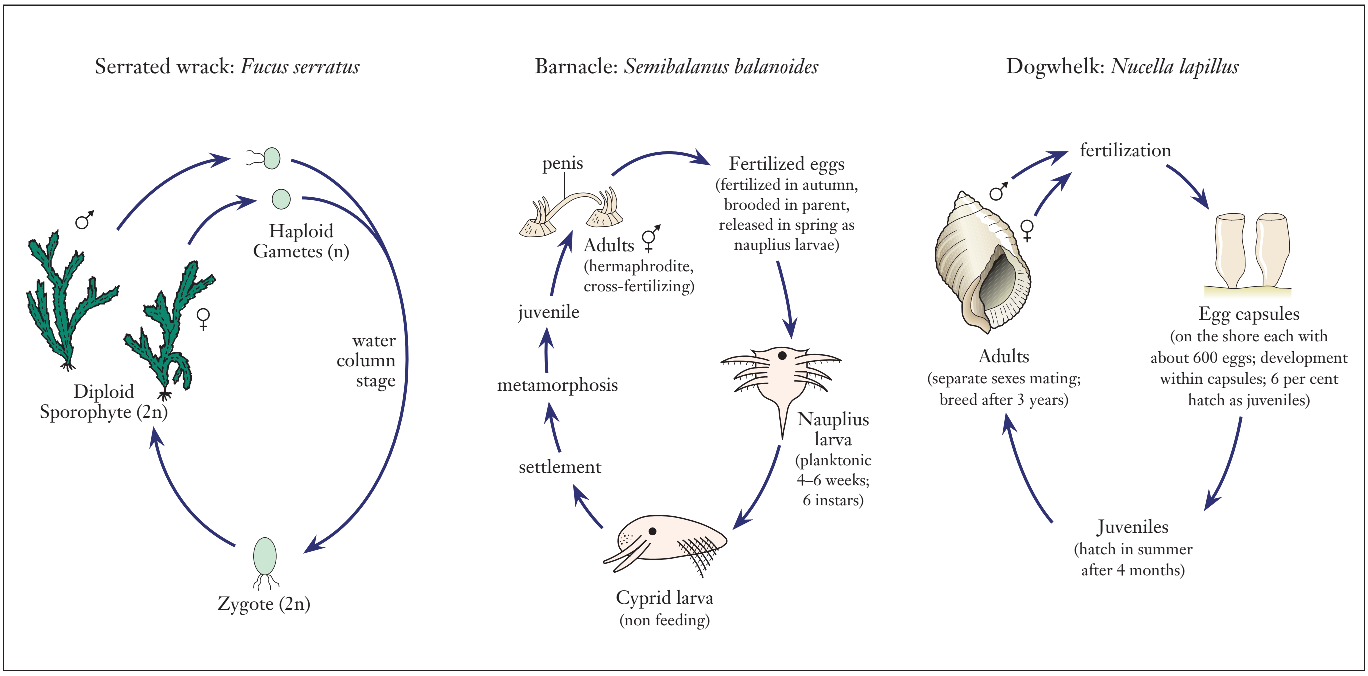
A large rockpool with a wide variety of algae and animals, near Helford, UK.

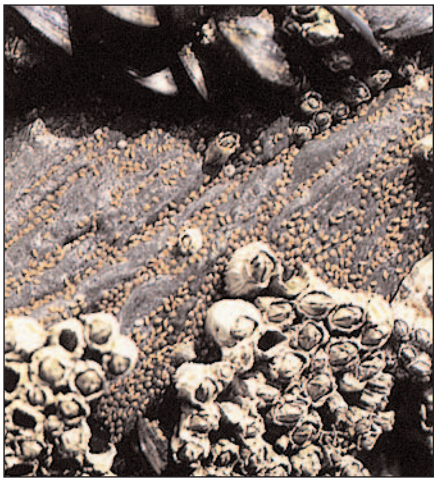
The basic zonation patterns described above become more complex when the rocky shore is broken up with cracks and crevices, rockpools, overhangs and other shaded areas. These moist areas are often a haven for soft bodied animals such as sea anemones, sponges and sea-squirts, and rock pools often contain species or communities of nature conservation importance. Unfortunately, these specialized sub-habitats are also the places where oil can become concentrated. The same is true on stable boulder shores where the rich animal communities underneath the rocks are also the most vulnerable to oil pollution.

Most rocky shore organisms reproduce by producing large numbers of planktonic larvae (animals) or spores (algae). Only a few animals (for example some snails) produce young by direct development. Planktonic development involves an element of chance but has the advantage of distributing the species over larger areas and colonizing new shores. It is therefore likely that they can recolonize shores affected by oil spills fairly rapidly, as long as there are healthy populations on other shores in the region. Direct developers, however, have the certainty that the young will grow up in a suitable habitat, but if the population is severely reduced by a spill it may take a long time to recolonize the shore. Direct developers are therefore more vulnerable to the effects of oil pollution and other impacts. There are more direct developers on the cold rocky shores of high latitudes than in temperate or tropical areas.

The structure of the rocky shore community is influenced by more factors than just habitat preferences and reproduction. Interactions between the different organisms are very important. An example is the balance between grazers and algae. In essence the algae are kept under control by the grazers, e.g. limpets, which remove the microalgae and spores of large algae before they can grow. This provides space

Life cycle diagrams for some typical rocky shore species. The seaweed and the barnacle produce planktonic spores and larvae respectively, while the dogwhelk produces young by direct development. Adapted from Hawkins and Jones (1992).





Recently settled mussel spat in the gaps between adult barnacles, mussels and limpets (left). The planktonic larvae of this bivalve will have spent about 4 weeks floating in the coastal waters.

Limpets, mussels and algae on a shore in Victoria, Australia (right). The algae have only been able to grow on the mussel shells, out of reach of the grazing limpets.

for other animals such as barnacles, mussels and other filter feeders, which may themselves be kept in check by predatory snails and shorebirds. The densities of grazers therefore have a controlling effect on the rest of the community and they are sometimes very sensitive to oil pollution.

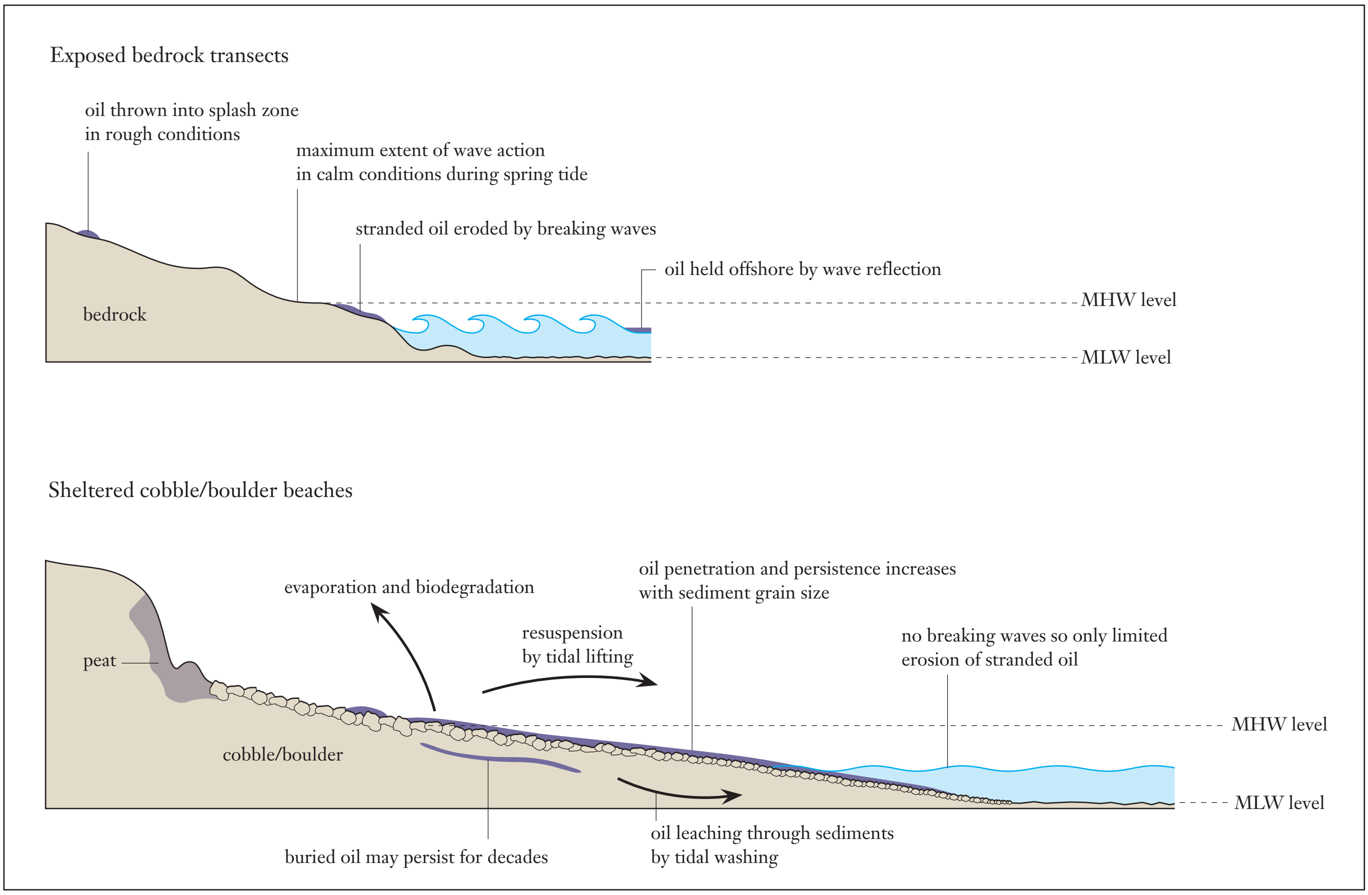
The constant interactions between unpredictable and patchy larval settlement, algae and barnacles competing for space and the grazing patterns of snails, on top of the complex nature of the habitat and all its sub-habitats, result in a very dynamic and patchy community. It is very rare to find a uniform distribution of any species, and the annual variations in density on a particular patch of rock can be large. This has severe repercussions for monitoring programmes or research studies, particularly when trying to separate natural variability from some of the less obvious effects of a spill.

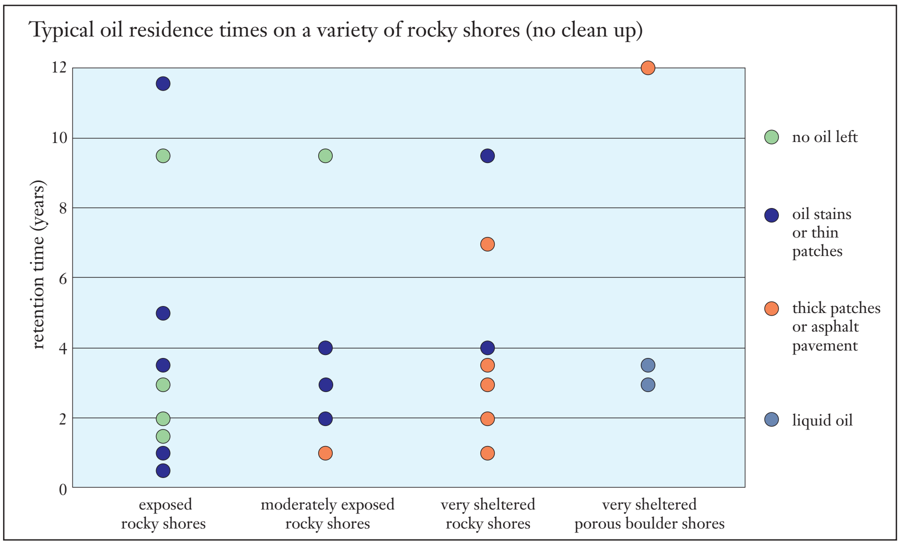
This mosaic of algae, limpets, barnacles and predatory dogwhelks can change from year to year.

FATE OF OIL

The vulnerability of a rocky shoreline to oiling is dependent on its topography and composition as well as its position. At one extreme, a vertical rock wall on a wave exposed coast is likely to remain unoiled if an oil slick is held back by the action of the reflected waves. At the other extreme, a gradually sloping boulder shore in a calm backwater of a sheltered inlet can trap enormous amounts of oil which may penetrate deep down through the substratum. The complex patterns of water movement close to rocky coasts also tend to concentrate oil in certain areas. Some shores are well known to act as natural collection sites for litter and detached algae and oil is carried there in the same way. On exposed coasts these sites are usually boulder/cobble beaches at the backs of bays or gullies which act as traps for the oil. As on all types of shoreline, most of the oil is concentrated along the high tide mark while the lower parts are often untouched. Oil tends not to remain on wet rock or algae but is likely to stick firmly if the rock is dry.

Weathering processes affecting the persistence of stranded oil on exposed and sheltered rocky shores in Sullom Voe, Shetland. Adapted from Shears (1990).





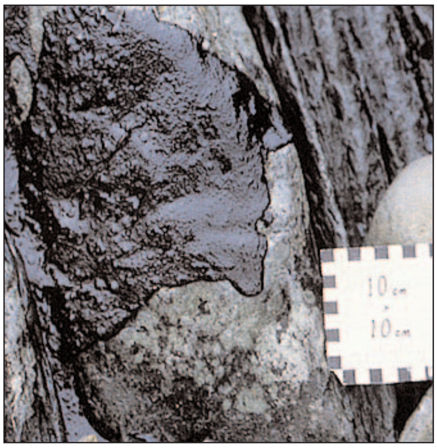
Typical oil residence times on a variety of rocky shores where no clean-up has been attempted. Liquid oil only persists deep within sheltered boulder shores, but thick tarry deposits can last for many years on the upper shore of sheltered rocks. Thin oil stains can persist on the upper shore, even on exposed shores. Data compiled from various published and unpublished records.

It is not long before the waves and tides that carried the oil onto the shore are gradually removing it again, but the rate of such weathering is dependent on many factors. The wave exposure, weather conditions and the shore characteristics are most important. Clearly, a patch of oil on a rock exposed to heavy wave action is not going to remain there for long. However, it could take many years for the limited water movement in a sheltered bay to remove oil trapped under boulders or in gullies and crevices. Gradual leaching of this oil could result in constant low level pollution of, for example, a rockpool. Other important factors include the water temperature, since microbial breakdown of the oil is slower in cold environments, and the presence of silt and clay particles which can remove oil by a process of flocculation. Grazing animals such as marine snails may also remove significant amounts of oil.

As the oil is weathered it becomes more viscous and less toxic, often leaving little but a small residue of tar on upper shore rocks. This residue can remain as an unsightly stain for a long time but it is unlikely to cause any more ecological damage.

Fresh and weathered fuel oil (below left and centre) on upper shore rock.

The trails left by the rasping tongue of a grazing limpet (below right). These marks are sometimes found on patches of weathered tar.

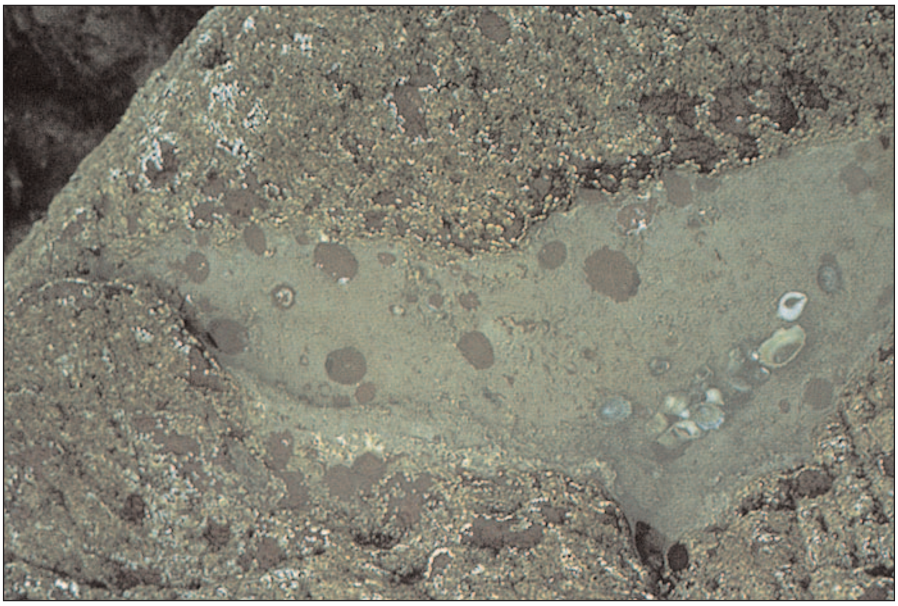


IMPACTS OF OIL SPILLS

The immediate impact of oil on any marine organism depends on the toxicity, viscosity and amount of oil, on the sensitivity of the organism and the length of time it is in contact with the oil. There have been a number of spills where rocky shores have been coated in a large amount of oil that caused very little discernible effect. There have also been spills where a moderate amount of oil has caused wide scale mortality of sensitive species. However, even where the immediate damage has been considerable it is unusual for this to result in long-term damage and the communities have often recovered within 2 or 3 years. This is because oil is not normally retained on rocky shores in a form or quantity that causes long-term impacts and also because most rocky shore species have a considerable potential for re-establishing populations. Nevertheless, long term effects can occur in certain circumstances, for example, if large quantities of viscous oil land on a wave sheltered upper shore area and form an asphalt pavement.

The sensitivity of rocky shore organisms is not easy to predict, but there are some clear trends. The brown seaweeds, for example, are relatively insensitive to oil due to the slimy mucilage which coats all their surfaces. Even after a

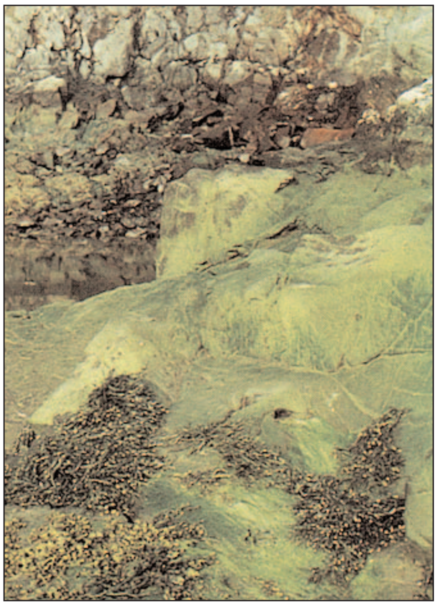
Dead limpets and marks of other limpets recently killed by a gasoline spill.



heavy oiling most of these seaweeds are washed clean by the next high tide and remain largely undamaged. Many rocky shore animals have also been found to withstand heavy oiling. Barnacles and intertidal sea anemones are typically only killed after being smothered by a viscous oil for a few tides. Limpets, littorinid snails and other grazing molluscs, however, are usually more susceptible, and a particularly toxic oil may cause the death of large numbers of them. This may be a direct effect or through the narcotic effect of the oil which causes the animals to lose their grip on the rock and become available to predators or die of desiccation.

The extent of the effect on susceptible organisms is strongly related to the toxicity and freshness of the oil. A weathered crude oil may have very limited effects, even if it is present on the shore for a long period. A fresh diesel or gasoline, however, can cause acute toxic effects to molluscs and bleaching effects on red algae in the short time before it weathers away.

The removal of large numbers of grazers is often followed by a rapid proliferation of microalgae covering the normally grazed rock in a 'green flush'. This is a



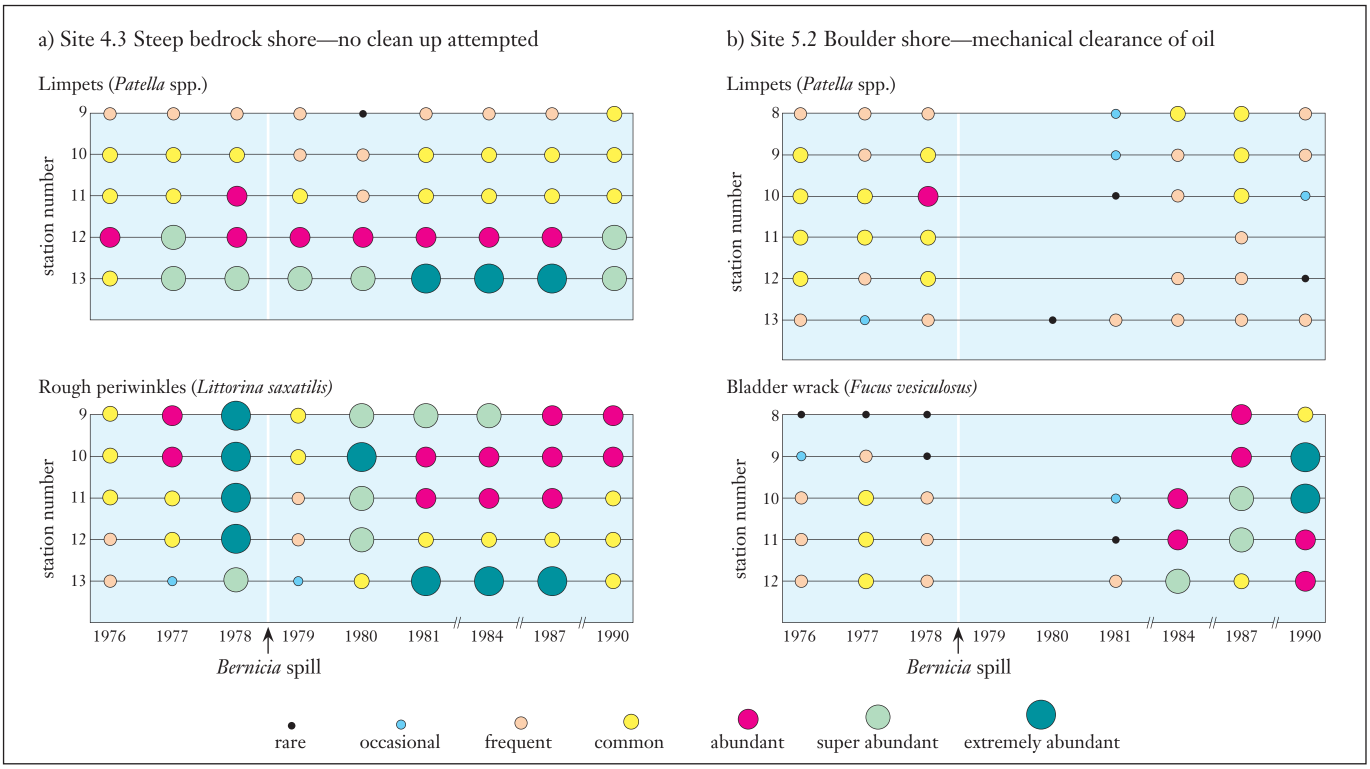
'Green flush' on a Shetland shore polluted by oil from a tarmac plant (left). All of the grazing limpets were killed, but the macroalgae survived intact.

The same shore 6 years later (right). A healthy community of algae, limpets and other animals was re-established within 4 years.

characteristic sign of a stressed environment, but it is also the first stage in a well recognized path to recovery. As long as the shore is not contaminated by further oiling the spores of macroalgae also settle and grow resulting in an abnormally dense cover of seaweeds. At the same time the juvenile limpets and snails, which settle and develop in damp and protected sub-habitats, move out onto the open rock to gradually repopulate the vacant areas. They grow quickly on the large quantities of food and gradually reduce the seaweed cover to normal levels. The whole process may take less than two or three years for the shore to look 'normal', although in some cases the balance between algae and grazers may take longer to stabilize.

Although effects on grazers are often the most obvious impacts of a spill there may also be effects on other species. Small crustaceans, such as amphipods,

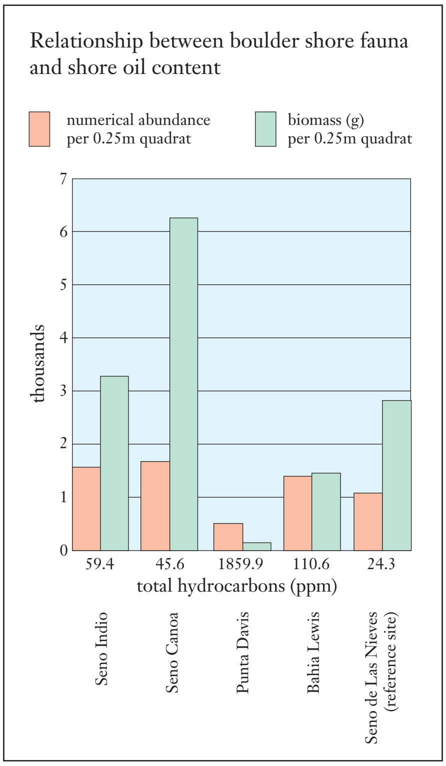
Effects of a fuel oil spill and subsequent clean-up on rocky shore populations in Sullom Voe, Shetland, UK:
a) Populations of limpets and periwinkles were temporarily reduced at shores where there was no clean-up.
b) Long term impacts on limpets, algae and other species have been recorded from shores which were mechanically cleaned.
(Abundance categories are applied from defined scales for different species. See Moore et al. *(1995) for details).*



which live amongst the seaweed and under boulders, are often killed, slowing down the important process of detritus breakdown. Crab and starfish populations may also be affected, thus reducing predation on snails and mussels. However, most of these populations will return to their former abundances very quickly and usually within a year. Exceptions can occur when oil is trapped on the shore for a long time and if long-lived slowly repopulating species are affected.

Sublethal effects of oil pollution, including reduced growth rates, loss of reproductive functions and other changes in the organisms' biochemical systems have been observed and studied in a variety of rocky shore species. However, the extent of their effect on community ecology and productivity after an oil spill is not known.

Effect of the Cabo Pilar *spill on boulder shore fauna in the western Strait of Magellan (below left). Species living under the boulders were particularly affected. The graph (below) shows the relationship between the boulder shore fauna and shore oil content. The five sites are arranged in geographic order from NW to SE. See Guzmán* et al. *(1991) for details.*



CLEAN-UP METHODS

Before any clean-up measure is attempted there should be an assessment of the net environmental benefit. It should be clear from the above that natural weathering will rapidly remove the oil from most rocky shores and that recovery will probably be complete within a few years. The clean-up response must therefore be designed to significantly reduce the recovery time or be driven by over-riding economic, amenity or wildlife concerns that can stand up to criticism. The choice of technique and the extent to which it is applied should not be decided in haste.

It is generally accepted that the ecological impacts of an oil spill may be compounded by aggressive clean-up methods. This has been shown on rocky shores in a number of cases. The use of large volumes of toxic chemicals to disperse the oil from the *Torrey Canyon* spill (Southward and Southward, 1978), the mechanical scraping of boulder shores during the *Esso Bernicia* spill (Moore *et al*., 1995) and the high pressure hot water flushing technique used during the *Exxon Valdez* spill (Houghton *et al*., 1993), all resulted in greater impacts and longer recovery times for shore organisms. The main cause of these impacts was the extensive removal of long-lived keystone species which take many years to become re-established.

Clean-up techniques which remove bulk oil without causing severe physical or chemical damage are preferable. They do not always result in enhanced ecological recovery, but impacts may be indistinguishable from oiled shores where clean-up

Hot water washing of a beach in Prince William Sound, Alaska, that had been oiled by the Exxon Valdez *spill in 1989. Much of the shore life could not survive temperatures that reached 60°C.*

was not attempted. Furthermore, by removing this bulk mobile oil it will not be able to move off and contaminate other shores. A brief summary of the main techniques is given below, and it is clear that the way in which a technique is used can be as important as the technique itself.

High pressure cleaning of a rocky shore during a spill in Milford Haven, UK, during 1981. The blast is removing limpets and seaweed that had survived the effects of the oil.

Suction devices

Pooled oil in gullies, rockpools and between boulders is likely to be removed only slowly by natural means and may cause more ecological damage than surface oiling. If suction devices can reach these pools they can significantly reduce the pollution without doing much physical damage. Unfortunately many suction devices are heavy and cannot easily be carried over rough terrain. The environmental advantages of the method need to be continuously weighed against the damage caused by trampling.

Low pressure flushing with ambient temperature seawater

To use this technique properly requires a coordinated effort of many workers and a lot of equipment. There are obvious advantages to washing bulk oil off the shore without causing physical damage, but the oil needs to be held within a containment boom and picked up with skimmers before it can oil other shores. It is also preferable that oil is not washed down across the more sensitive lower shore areas, so operations should be carried out while the tide level is almost up to the level of the oiled rock. The pressure and volume of water should be constantly regulated to achieve the desired result.

High pressure cold or hot water flushing and steam cleaning

These methods are very destructive and should only be used if concern about the complete destruction of the natural rocky shore community and its impaired recovery rate is overridden by other factors. If they are used on small upper shore areas to remove tar or oil stains they should be carried out during high tide or in such a way that the oily water can be trapped and removed.

Dispersants

Modern dispersants have a low toxicity and are unlikely to do any more harm than the oil. However, since the oil will become dispersed into the water it may contaminate areas below the water level that were previously unaffected, unless it can be trapped and removed. The main advantage of dispersant use is to enable some oils to be removed more easily, i.e. without harsh physical methods, but they are not effective on very viscous oils and a lot of preparation is required (IPIECA 1993).

Dispersants being used at a spill in Milford Haven, UK, in 1986. The coffee-coloured dispersed oil impacted lower shore and subtidal areas which had not been previously oiled. The effects were minimal, but this technique would not be used now without a considered assessment of net benefit.

Sorbents

The use of sorbents has very limited application, and only for liquid oils in small areas like rockpools. In the absence of a suction device a sorbent pad can quickly remove oil from the surface of a pool. This should be a simple manual technique and sorbents should not be left unattended but quickly removed and then suitably disposed of.

Council workmen manually bagging oiled weed and debris following a spill in Bantry Bay, Ireland, in 1990.

Manual removal

Detached oiled seaweed and tarballs that are washed up on the strandline of some rocky shores may be removed by hand or with the aid of a fork with suitably spaced tines. The main advantages are for human amenity rather than ecology and the benefit analysis might consider the impact of intensive trampling by the workers.

The choice of clean-up response will also need to take into account a number of other practicalities. The most important is the ease of access. Many rocky shores are inaccessible from the land, due either to remoteness from access roads or because of topography, and may only be accessible from the sea in good weather. Even if clean-up workers can reach the shore safely it is another matter to provide them with the clean-up equipment and storage facilities they will require to do anything useful. When that has been achieved the progress of the clean-up over difficult rocky terrain will still be painfully slow. If the period when the tide is out is at an awkward time of the day, the progress will be even slower.

CONCLUSIONS

Rocky shores comprise a wide variety of different habitats and communities and vary greatly in their sensitivity to and recovery from oil spills. In general, the least sensitive shores, and those with the greatest potential for natural recovery, are found on wave exposed coasts. Attempts to clean these shores are normally unnecessary, but are also unlikely to do long-term damage unless harsh physical or chemical measures are used. Conversely, rocky shores in wave sheltered areas are more sensitive to oil spills and they are also more sensitive to damage from clean-up measures. Both of these statements are generalizations and there are few other rules of thumb until one looks at specific rocky shore habitats.

Rocky shores also vary greatly in their value, be it economic, amenity, education, conservation or their role in the marine ecosystem. Some deserve a considerable effort to protect them from oil spills. Due to their inherent variability in sensitivity, recovery potential and value, it is essential that oil spill contingency plans are adaptable enough to tailor the response to the particular shore. A pre-requisite for a good plan is a good set of sensitivity maps, shoreline access details and clean-up guidelines and good communication between the environmental advisors and the clean-up managers.

A deep water channel flanked by rich rocky shores allows oil tankers access to terminals in Milford Haven, UK. Well developed oil spill contingency plans and sensitivity maps are essential elements in the management of this busy port.

ACKNOWLEDGEMENTS AND FURTHER READING

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