Long term ecological impacts of marine oil spills

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Abstract

Viewed from different perspectives it is possible to be both very positive about the natural recovery potential of most resources after oil spills and very depressed about the chronic long term impacts of oil contamination in some locations and on some resources. Most oil spills result in some acute impacts that are detectable (though not necessarily large) for months or a very few years; but notable impacts that do not show good signs of recovery within two years are uncommon. However, some marine ecosystems, communities and populations are already chronically depleted by human activities and climate change; and oil spills have the potential to cause further long term impacts to the biodiversity and productivity of those resources.

The paper discusses the circumstances that can result in long term damage (including persistent oil, slow growing and keystone species, limited potential for recruitment and severe clean-up actions). Numerous case studies are cited, including some situations where there was surprisingly rapid recovery after severe oiling, and some resources that are becoming increasingly sensitive to damage. It also considers the attributes that provide the most reliable evidence of a negative impact and incorporates these in a revised definition of recovery.

Introduction

Major oil spills always get a lot of public and political attention in the first weeks and months, but interest tails off quickly and is only slightly increased when the summary report on acute effects is published after a year or two. Acquiring funding for studies of long-term impacts (here defined as >5 years) therefore tends to be very difficult. An alternative interpretation of the sparseness of publications could reflect a lack of detectable long-term impacts.

AURIS (1994 and 1995) collated and summarised most of the literature available at that time on spill effects and biological recovery processes in different shore habitats and showed that out of almost one hundred significant spills with available literature there were only 10 or 11 with any documented effects beyond 5 years. A review by Kingston (2002) also highlighted the rapid recovery of most environmental resources after spills, particularly after oil contamination has been removed. However, Carls *et al.* (2001) and Peterson *et al.* (2003) have cast doubt on the ‘old paradigms’ of rapid recovery; claiming that the considerable evidence collected from *Exxon Valdez* studies show long-term ecosystem level impacts. This is similar to the views expressed by Southward (1982) who stated that “the effect of oil…….is to undermine community structure and destabilize the ecosystem, driving it in the direction of monoculture”.

Theoretically, every oil spill will have resulted in some long term effects. A reasonable response might be to suggest that effects can only be considered impacts if they are detectable above the background level of change. However, one might also say that almost any effect can be detected above the background if you take enough samples. As, Shigenaka (2005) discusses, the lines you draw between impacts, effects and background are down to your perspective.

Differences in perspective appear to be at the root of the wide range of 'recovery' definitions given in the literature, and often explain the differences in stated time scales for recovery.

The aim of this paper is to develop a definition of ecological recovery that fits the authors personal perspective and also to review the factors and circumstances that appear to be most important for potential long term ecological impacts to populations and communities. The first step is to review available literature. A summary of some of the most prominent examples of long-term studies following spills, are given below.

Examples of long term impacts

Table 1 Oil spills discussed in this paper

Name	Location	Year	Resources discussed
Torrey Canyon	Cornwall, UK	1967	Rocky shores
Florida (=West Falmouth)	Buzzards Bay, Massachusetts	1969	Saltmarsh
Arrow	Chedabucto Bay, Nova Scotia	1970	Lagoon mud benthos
Metula	Magellan Strait, Chile	1974	Saltmarsh and mixed sediment shores
Amoco Cadiz	Brittany, France	1978	Saltmarsh; seabed sediment benthos
Esso Bernicia	Sullom Voe, Shetland, UK	1978	Sheltered rocky and boulder/cobble shores
TROPICS experiment	Bocas del Toro, Panama	1984	Mangrove
Vivita (and previous spills)	Curacao	1986	Rubble shore molluscs
Galeta (=Bahia Las Minas)	Colon Province, Panama	1986	Mangrove and seagrass
Exxon Valdez	Prince William Sound, Alaska	1989	Various shores, benthos and wildlife
Gulf War	Gulf Coast, Saudi Arabia	1991	Tidal flats, halophytes and mangrove
Haven	Genoa, Italy	1991	Seabed benthos
Braer	Shetland, UK	1993	Deep water mud benthos
Sea Empress	Pembrokeshire, UK	1996	Rocky shores and birds
Estrella Pampeana	Rio de la Plata, Argentina	1999	Brackish water marsh

***Torrey Canyon*, 1967** - The impacts of the clean-up of rocky shores following the Torrey Canyon spill are now legendary. The large volumes of highly toxic first generation dispersants caused massive mortality of the shore life and tainted (pun intended!) the name of dispersants to this day. Rapid recovery from the oil was recorded from the un-treated shores, but disruption of the treated shore communities was reported to last at least 10 years and possibly as much as 15 years (Hawkins and Southward 1992). This is all the more remarkable because the disruptions continued in the absence of oil and without any physical clean-up damage to the shore – i.e. only through the natural recovery processes. This is far longer than any other example found, although at least some of the disruptions described were in the form of unusually large fluctuations in abundance of the dominant species. Reductions in biodiversity of the affected shores is only apparent by the very protracted return of one limpet species (*Patella depressa*), which took 10 years. This limpet was at the edge of its geographical range, which will have limited its recruitment potential. Abundances of the other species documented all rose rapidly and many then fluctuated even more than typical natural variability.

***Florida*, 1969** - Although relatively small, this fuel oil spillage caused heavy oiling of significant areas of saltmarsh. After 7 years, oil remaining in the sediment was still having notable effects (poor recruitment, survival and abundance and abnormal behaviour) on populations of burrowing fiddler crabs. Signs of recovery were correlated with sediment naphthalene removal (Krebs and Burns 1978). High concentrations of oil still remain in sub-surface sediments (below 6 cm) at the monitoring sites (Reddy *et al.* 2002) and studies after twenty years (Teal *et al.* 1992) showed that crabs from the heavily oiled sites had much higher oil concentrations in their tissues and that detoxification enzyme indicators (EROD activity) were significantly higher in marsh fish from those sites. Continued ecological effects do not appear to have been studied beyond the first 7 years.

***Arrow*, 1970** - Thomas (1978) describes effects on sediment infauna from a spill of heavy fuel oil into a very sheltered bay. Six years after the spill, toxic levels of oil still remained in the sediment and analysis of clam (*Mya arenaria*) growth rates (from length and weight frequency data) from oiled and unoiled sites showed significant reduction at oiled sites. Lee *et al*. (1999) have carried out bioassay studies in more recent years (last in 1999) on sediments from the same area. They showed that sediments from the oiled sites (which were still conspicuously contaminated by oil) had low toxicity, as measured by bioassays using amphipods.

***Metula*, 1974** - thick and extensive deposits of tar and asphalt pavement still remain on areas of saltmarsh and upper intertidal mixed-sediment beaches at this classic oil spill site (Owens *et al.* 1999). Recovery of the marsh vegetation is likely to take many more decades, but chemical composition of the oil's toxicity is now low and breaking up the deposits would accelerate recolonisation (Wang *et al.* 2001).

***Amoco Cadiz*, 1978** – this very large spill severely affected a wide variety of coastal resources around Brittany, but its ecological impact is now best known for the erosion and slow re-growth of trampled saltmarsh areas; while similarly oiled but uncleaned marsh returned to natural vegetation in less than 5 years (Baca *et al.* 1987). The physical alteration of the marsh was therefore the primary cause of long term effects in this case.

The *Amoco Cadiz* spill also impacted subtidal sediments in the Bay of Morlaix and Dauvin (1998) has suggested that impacts to the benthos lasted for up to 12 years (and in the absence of any oil). He has shown that densities of tubiculous amphipods (primarily *Ampelisca* - which are well known to be extremely sensitive to oil in water) in a fine sand seabed habitat (17m depth) were much reduced for that period, even though they have a high fecundity. He suggests that *Ampelisca* populations in this habitat and location are naturally at a stable 'climax' state but that this state was severely disturbed and that recovery was slow because the population was geographically isolated.

***Esso Bernicia*, 1978** - fuel oil from this spill contaminated shores within Sullom Voe and outside and is still present as patches of tar and asphalt pavement on some very sheltered rocky and mixed sediment shores. Annual monitoring showed rapid return of the communities of epibiota at most of the affected sites except some boulder/shingle shores where aggressive physical clean-up (with bulldozers) caused long-term instability of the substrata (Moore *et al*. 1995). This instability resulted in continued depression of both species richness and abundance of some algae and molluscs on those shores for at least nine years, presumably by reducing recruitment and survival. By 1989 species richness had returned and abundances had also returned to normal levels, but substratum levels were still surprisingly changeable for many more years and abundances still fluctuated greatly (annual reports and personal observations).

The *Esso Bernicia* spill also killed large numbers of wintering birds. Frequent monitoring showed that most of the local populations affected quickly returned to pre-spill numbers except for the great northern diver (*Gavia immer*). Heubeck (1997 and pers. comm.) showed that abundances in Yell Sound were still much reduced from their pre-spill levels. He suggests that the Yell Sound wintering population may also all breed in the same location (somewhere in the Nearctic) and that the cause of the poor recruitment may be due to environmental factors affecting that location.

TROPICS experiment, 1984 - Baca *et al.* 2005 review 20 years of results from this study on the effects of chemically dispersed crude oil on mangroves. They show that the oil did not persist and no long term impacts were detected at the dispersed oil and reference sites; while the undispersed oil site was still characterised by persistent oil residues, significantly reduced mangrove condition (smaller tree size) and substratum erosion.

***Vivita*, 1986** - A tropical example of the long term impacts of tar residues has been shown by Nagelkerken and Debrot (1995). They found that substantial tar cover in rubble shores of Curacao, still present more than 7 years after oiling despite moderate wave exposure, was causing a 35% reduction in species richness of molluscs (snails, limpet and chitons). They suggested that this reduction was in large part due to the loss of micro-habitats (under, between and within the rubble) caused by the cementation of rubble by the tar deposits.

***Galeta*, 1986** - Five years after this crude oil spill there were still severe impacts on biodiversity and productivity of red mangroves (Garrity *et al.*1994, Levings *et al.* 1994) and the structure of the mangrove had been so badly altered that recovery would clearly take a long time, even if oil had not still been present. Relatively undegraded oil was present in the anoxic muds and were expected to remain toxic for at least 20 years (Burns *et al.* 1994). Unfortunately no follow up studies appear to have been published. Recovery of corals on reef edge and reef flat habitats was also very slow (Cubit and Connor 1993), although complicated by natural stresses.

***Exxon Valdez*, 1989** - there is still a lack of consensus between researchers with different perspectives on the impacts of the *Exxon Valdez* spill of crude oil (Shigenaka 2005). Appreciable quantities of oil still persist on and beneath the surface of some sheltered boulder/cobble and coarse gravel shores (Short *et al.* 2004) and elevated tissue concentrations in some bivalves is correlated with oiled shores, but the long-term effect that it is having on ecology, beyond some localised smothering, is confused by conflicting claims. The very limited pre-spill data and many confounding factors has made it difficult to detect impacts in populations of mobile species (fish, birds, mammals), and many studies that link sublethal effects (e.g. biomarkers) to heavily oiled sites may not have taken sufficient account of background oil. Page *et al.* (2004) have shown that substantial background levels of hydrocarbons from a variety of sources, including *Exxon Valdez* oil, are present in seabed sediments. Detoxification enzyme indicators (EROD activity) in coastal rock fish were induced by those background levels but were no more elevated at *Exxon Valdez* contaminated sites than at other sites. There are many ecological studies that suggest that biodiversity and productivity of the majority of affected communities and populations quickly returned to normal levels (e.g. Gilfillan, 1995, Wiens *et al.*, 1999).

Effects of aggressive clean-up activity (hot water washing) on sheltered shore epibiota were described by Houghton *et al.* (1997). They showed that large fluctuations in abundance of the community dominants were still occurring at the cleaned sites (but were not so great at unoiled sites and oiled uncleaned sites) seven years after the spill. These population fluctuations were therefore similar to those described from the Torrey Canyon spill; but it also seems that the period when species richness and species abundances were continuously reduced was much shorter (apparently only 2 or 3 years).

Gulf War, 1991 - Tar and asphalt pavement still smothers extensive areas of the intertidal sand flats, halophyte zones and mangrove of the Saudi Arabian coast (Michel *et al.* 2005 and personal observations). Ecological impacts (particularly to halophytes and burrowing crab populations) in the upper intertidal and supratidal are severe and there are few signs of recovery (Getter *et al.* 2005 and personal observations).

***Haven*, 1991** - Considerable deposits of soft tar and hard burnt residues from the Haven spill are still present on the seabed off Genoa. Studies on sublethal effects in fish (genotoxic and hepatic tissue damage, Pietrapiana *et al.* 2002) and PAH concentrations in some sediment samples (Amato *et al.* 2002) have been linked to the contamination, but no effects were detected in the macrobenthos (Guidetti *et al.* 2000). Without better evidence of ecological effects (i.e. reduced species richness, population abundance or growth rates) it is not yet possible to show a long term impact, although some small smothering effects are likely just from the presence of the deposits.

***Braer*, 1993** - even acute impacts of the Braer spill were much less than might have been expected from the size of this spill in coastal waters; but the rapid natural dispersal of the oil and strong downward currents did result in unusually high seabed deposition. Very high concentrations (>1000ppm) of oil were found in muddy sediment sinks south of Shetland in deep water (Kingston *et al.* 1997) but impacts were mostly limited to reduced abundance and species richness of amphipods. Follow-up studies did not go beyond 1 year.

***Sea Empress*, 1996** – no significant residues of *Sea Empress* oil remain and a recent review of all available information, on its ten year anniversary, (Moore 2006) found very little evidence of long term impacts. This is not due to a paucity of data, as the local environment of the oil port and extremely rich coastal habitats were already very well described and monitored. However, the review did identify a few notable impacts:

While no significant long-term impacts on local seabird populations were detected, some localised long-term effects did occur, as can be shown from detailed inspection of seabird monitoring data. For example, one small breeding colony of guillemots was apparently wiped out and the site not reoccupied in 10 years – probably because first time breeders are not attracted to empty cliff sites and older birds habitually return to the same nests (Haycock pers. comm.). Of greater significance, Votier *et al.* (2005) have shown that the spill did kill many individual guillemots that they were monitoring in breeding colonies on Skomer Island, and that this had a notable effect on the demographics of the population. The long-term effects of this are unclear. Their results also suggested that available nest sites were reoccupied by a pool of birds that might otherwise not have been able to breed. Productivity and population numbers were therefore buffered by the substantial number of non-breeders in the population.

The spill also threatened the survival of a well studied population of the rarely recorded cushion starfish (*Asterina phylactica*) in shallow rockpools that were severely oiled. Mortality of the cushion stars, which brood their young *in situ* (therefore no recruitment from planktonic larvae), was very high (>95%) and recovery of the population seemed unlikely. However, a return to pre-spill densities was faster than expected (within 6 years, Crump, pers. comm.) due primarily to self fertilisation by the five remaining isolated animals. This is therefore an example of a species that had a greater recovery potential than might have been expected. Although moderately well studied compared to many benthic species, the spill created a situation that highlighted important gaps in our knowledge of its population ecology. It also appears that *Asterina phylactica* is not as rare as it was once considered to be, as many more records have been reported.

Finally, splash zone lichens of rocky shores are very slow growing and long term impacts to some well developed colonies were identified following the spill. Impacts are still evident, with abundance of dominant species and hence productivity (such as it is) is greatly reduced at some sites, but reductions in species richness were not found (Crump, pers. comm.).

***Estrella Pampeana*, 1999** – severe trampling during operations to remove oiled vegetation from brackish water marshes, resulted in substantial oil being pressed down into marsh sediments and extensive damage to root systems (personal observations). Ecological monitoring showed a rapid recovery of unoiled and oiled-but-not-cleaned sites, but delayed recovery of the 'cleaned' marsh (Moreno *et al.* 2004 and personal observations). The worst affected of the 'cleaned' marshes were still not fully recovered in 2003.

Defining ecological recovery

Two key attributes are considered to best represent the ecological value and function of communities and populations:

- *Biodiversity* – often simply measured in terms of species richness, but often derived from calculated indices of species number and abundance. Levels of biodiversity within a particular habitat are naturally very stable if reliably monitored by the same methodologies, although species composition of some communities can change dramatically over time. A return to normal levels of biodiversity, but not necessarily the same composition, after a reduction related to a spill may therefore be used to define recovery. The maintenance of biodiversity is widely considered to be the most important measure for ecosystem 'health'.

- *Productivity* – best measured as the primary and secondary production of organic material (which feeds other species and ecosystems), but more often assumed to be correlated to species abundance and growth rates. Levels of productivity for a particular population naturally fluctuate greatly between seasons and years, but some characterization of the typical natural range can sometimes be made. A return to typical levels of productivity after a reduction induced by a spill may therefore be used to define recovery. However, as shown by some of the spill studies above, it is not unusual for this recovery to be confused as the population goes through a further period of oscillating high and low abundances which dampen over time. Nevertheless, it is considered here that the most important *primary-recovery* processes are those which bring the productivity back from a period of continued reduction; and that any ongoing periods of unusually pronounced fluctuations are usually relatively unimportant and are here termed *secondary-recovery* fluctuations. This position is similar to that given in reviews by Baker *et al.* (1990) and Kingston (2002), although distinguishing them into separate stages does not appear to have been done before.

While these two attributes may not provide a thorough description of population, community or ecosystem function, and standard methodologies are difficult to define, they are universally applicable to all biological communities. Also, while many people will not fully agree with the relative unimportance of secondary-recovery fluctuations the concept will be implicitly understood by all biologists. There are of course many measures of sublethal effects that are showing great promise for assessment of environmental impacts, primarily as initial screening tools (Kirby *et al.* 2000). However, our understanding of ecological function and natural variability is still too limited to utilise them for reliable assessment of impacts in the absence of ecological effects data. Furthermore, the increasing analysis of enzyme activity (e.g. EROD, MFO, P450, CYP1A), which can be induced in animal tissues by PAH contamination of their environment, can give misleading results if they are not related to baseline conditions (Lee and Anderson 2005).

Continually depressed biodiversity or productivity is therefore considered to provide the most reliable evidence of a negative impact; and therefore (modifying the definition given in Baker *et al.* (1990)) recovery can be defined as:

> *Ecological recovery is marked by the re-establishment of a biological community in which plants and animals characteristic of that community are present and functioning normally – this function being manifest primarily by normal levels of both biodiversity and productivity.*

Factors that can lead to long-term ecological impact

A review of the spill studies summarised above shows that the most important factors are often predictable. These factors are discussed below:

The persistence of oil - Exposure to wave action greatly reduces the persistence of oil and it is the lack of water movement in very sheltered (usually <20km fetch) environments that is the main cause of most of the long-term ecological effects described above. While oil characteristics and environmental conditions can significantly influence the fate of oil that reaches very sheltered habitats, the potential vulnerability and sensitivity of those habitats is very high. Preventing oil contamination of such areas is the best way of minimising long-term impact.

The persistence of oil in habitats that are more exposed to wave action is considerably less (unless supplied from a chronic source above the shore), such that it is unusual for substantial amounts of chemically toxic or smothering oil to remain for many years. However, this can happen if heavy oiling occurs during a sufficiently long period of calm seas for tar to form intractable residues; particularly on mixed sand/shingle shores where asphalt pavement can form.

It is apparent that it is the physical smothering by tar residues, which effectively reduce habitat diversity by binding substrata and filling spaces, that demonstrates the most conspicuous long-term impacts on biodiversity and productivity.

The chemical toxicity of weathered tar is much reduced by physically locking it up inside the deposit. Many such deposits (particularly in upper shore rock and shingle habitats) have very little ecological effect, and I have seen limpet grazing marks and algae colonising the surface of old tar residues. Young deposits are clearly not completely benign and long term sheening can even occur from old deposits (personal observations of *Esso Bernicia* oil); but the physical presence of the oil has the main impact.

However, hydrocarbons trapped in sheltered sediment habitats can be more bioavailable and cause more long-term impacts through chemical toxicity, as shown by some bioassay tests and some biological effects studies. Degradation and reduction of the toxicity takes place over time, but in the most sheltered anoxic muds it can remain toxic for at least 20 years.

It was expected that subtidal deposits of ‘non-floating’ oils could have long-term ecological impacts on benthic communities. However, the few studies to date (c.f. *Haven* spill above and National Research Council 1999) have not yet identified any notable effects.

Slow growing, long-lived and keystone species - Mortality of slow-growing long-lived species is likely to cause at least some longer term effects on population structure, even if remaining oil residues and recruitment are not limiting. Particular concern is for affected species that have a major structural role in the community they live in (by physical size or other strong ecological influence) – often termed ‘keystone species’. Vulnerable groups of species with life spans over 10 years include lichens, encrusting coralline algae, mangroves, corals, some crabs and lobsters, some snails (particularly limpets), some shallow water clams and burrowing urchins and many species of birds, reptiles and mammals.

Of these species, the most significant long-term impacts have been described for mangroves (c.f. also NOAA 2002), which, even if oil disappeared after killing them, new recruits would take many years to grow to the size where they were supporting associated epibiota and other wildlife. Long term impacts on corals have also been described; and while their vulnerability is often low and their recovery potential generally high, the potential consequential impacts on biodiversity are also high.

However, apart from lichens, the spill studies do not provide any examples of long-term effects due to slow growth of the other species listed, although this may often be due to limited data collection on population age/size structure. Given the scale of seabird deaths after some spills, it is apparent that those populations must have considerable recovery potential. The studies on limpets and birds suggest that demographic effects may occur, but that reserves in the population quickly buffer impacts on productivity.

The slow recovery of a subtidal amphipod population after the *Amoco Cadiz* spill is of interest here. Data in Dauvin (1998) show that the amphipods were present in much reduced, but still moderate, densities throughout the sampling period, so, given the potential reproductive rate of amphipods, geographical isolation seems an inadequate reason. Personal observations of similarly dense *Ampelisca* populations in other locations (where the extremely dense tubes form a mat that clearly influences the structure of the seabed) suggests an alternative to this explanation. It seems likely that once these populations reach a critical density they form the self sustaining stable ‘climax’ state described by Dauvin, but that it takes time and particular environmental conditions to reach this density. It is suggested that this is an example of a species that gains ‘keystone’ status when it forms these dense mats, and that it is the slow development and longevity of the mats that makes long-term effects possible. Studies of *Ampelisca* populations (not forming mats) before and after other spills (e.g. Nikitik and Robinson 2003) have shown acute impacts followed by a return to pre-spill densities in 3 or 4 years.

Limited potential for recruitment - It is unusual to get widescale loss of any species, because oil distribution is normally very patchy and much less than the scale of dispersal of most species. However, some species have localised populations that are geographically isolated from sources of outside recruitment or are otherwise characterised by limited recruitment. Factors include - physical barriers, distance, edge of distributional range, strong linkages between breeding and feeding sites, limited dispersal mechanisms for spores, larvae, juveniles or adults, or other features of reproduction that limit local recruitment.

The spill studies provide a few examples of long-term effects that are at least partly due to some form of restricted recruitment potential, although the unexpected recovery of the *Asterina* starfish following the *Sea Empress* spill also highlights that we need to be cautious about predictions of the vulnerability of most species.

Severe clean-up actions - The removal or dispersal of bulk oil that is causing acute impacts can also reduce long-term impacts. However, it is well known that physical clean-up actions can cause long-term impacts if applied very severely.

The spill studies provide examples of long-term impacts from severe clean-up in marshes, but the examples from rocky and boulder shores (*Torrey Canyon* and *Exxon Valdez*) suggest that the *primary-recovery* processes can be rapid and that the long-term effects are mainly just *secondary-recovery* fluctuations. It is interesting to compare results of the latter two studies with those from the detailed studies of limpet communities at West Angle Bay following the *Sea Empress* spill, which were not cleaned. More than 50% of limpets were killed in the Bay (almost 100% in some places), but apparently full recovery, with no obvious *secondary-recovery* fluctuations, occurred in less than 5 years. It is assumed that the enhanced fluctuations at the *Torrey Canyon* and *Exxon Valdez* sites was due to the greater mortality and disruptions to all shore species from the clean-up actions.

Note: no examples have been found of long-term impacts resulting from the use of second or third generation dispersants (i.e. deliberately excluding the first generation products used in 1967 during the Torrey Canyon spill). However, available data is very limited and it is possible that chemically dispersed oil could become deposited in muddy sediment sinks (with potential long-term ecological effects); especially if used on waters with high sediment loads and low flushing rates (National Research Council 2005).

Conclusions

Oil which persists in the marine environment clearly has the greatest potential for long-term ecological impacts. Once oil has been removed, recovery of most communities and populations is rapid as long as the habitat has not been physically damaged by clean-up actions. Biological characteristics of some species can also slow recovery, but most documented examples of such effects are of populations that are more affected by long term oil contamination. Even those examples which do describe slow recovery in the absence of oil are complicated by high levels of natural fluctuation and natural stresses.

Very little in the views expressed above is new, and readers may recognise issues discussed over twenty years ago (Clark 1982). Many developments have since been made in hydrocarbon analysis, sublethal stress indicators and techniques for describing community disturbance; but these developments do not seem to have resulted in improved consensus between biologists with different perspectives. From the authors perspective the most useful post-spill studies have provided insight into ecological processes at a local scale, but they have not greatly improved our insight into impacts on the wider ecosystems. This is in contrast to the insights that studies on fisheries and diffuse pollution, for example, are now providing (GESAMP 2001a). Indeed, GESAMP (2001b) ranks oil pollution as a low priority, and at a local scale, in its assessment of global priorities for action. To study ecosystem effects of oil spills it is necessary to consider them in association with other impacts.

Notwithstanding the above, it is likely that many subtle long-term ecological impacts are caused by spills; and are not detected because data is inadequate and natural fluctuations mask the effects. For example, it is suggested that small losses in biodiversity, due to mortality of sensitive species naturally occurring at low abundance in isolated pockets with poor recruitment potential, are likely after large spills. On the other hand, the creation of space in a habitat provides a potential opportunity for colonisation by different species.

Finally, it is likely that chronic impacts from other human activities and stresses from climate change could make some ecological resources more vulnerable to oil spill impacts. The recovery potential of any population can be weakened by other forms of pollution, fisheries or many other damaging activities. For example, if another spill on the scale of *Braer* were to occur in the same location and time of year, but in current conditions, much greater and potentially long term effects on birds are considered likely. Fisheries impacts, on top of climatic effects, on seabird food availability in the north of UK have had a devastating effect on many seabird populations over the last few years (JNCC 2005). In their weakened state populations subject to further mortalities from oil would be unlikely to have the reserves to recover quickly. The vulnerability of coral reefs around the world may also be much greater now, due to effects of climate change, coastal developments etc. (Waddell 2005).

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