Establishing the true environmental impact of a spill

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Abstract

Most public reactions to an oil-spill are dramatic – horror is expressed, hands are wrung, anguish is expressed. Large sums of money are then thrown around in attempts – usually focussed on public spectacle – to "clean-up" the oil. Alarm is announced about environmental impacts. Where the concerns are about issues of human health or about socio-economic issues such as tourism, this is all very well. In terms of ecological consequences, however, much of it flies in the face of known, objective information about oil-spills. Where spills occur in open, coastal waters, on hard rocky substrata, they have virtually no long-term effects. In contrast, attempts to clean-up after a spill are often sources of long-term damage.

In soft-sediments, such as mangrove forests and mud-flats, issues are more complex and there can be long-term consequences of the spill for animals and plants, but the effects of cleaning up are also potentially very damaging.

These issues will be very briefly introduced with demonstration of the sort of ecological work that needs to be done to measure the short- and long-term consequences of a spill and of attempts to clean it up. Examples from "Torrey Canyon", "Exxon Valdez" and "Laura d'Amato" will be illustrated.

Introduction

Oil-spills command considerable attention from the media – because they are often large, usually dramatic and undoubtedly very ugly. Nothing seems worse than a mass of toxic hydrocarbons smeared over the natural habitats of some foreshore. As a result, there is massive public response, a frenzy of activity by agencies, community groups and politicians. There are demands for "the environment to be saved". Often, as in the case of large spills such as "Torrey Canyon" or "Exxon Valdez", very large sums of money change hands in order to mobilize whatever resources can be found to clean up the mess. This is all done in the name of saving the environment.

For many spills, however, the ecological issues are different from those being touted in public discussion. There is, in fact, plenty of evidence that for many marine organisms large, dramatic sudden impacts are not really the issue that public opinion would have everyone believe. Long-term, chronic, low-level contamination of habitats is, almost without exception, much worse in terms of environmental outcomes. Destruction, deterioration and fragmentation of habitat are considerably greater threats to long-term sustainability of coastal biodiversity. In some habitats, attempts to clean-up a spill are potentially (and sometimes known to be) much more damaging than the oil itself.

The issues, from the central point of view of marine ecology, are briefly considered in this paper. The point is to get three major points into sharper focus:

1. oil-spills in many marine habitats do not represent the most important problems for ecological sustainability;
2. attempts to clean-up an oil-spill need much more careful planning and decision-making in order to prevent possibly greater impact than due to the spill itself;
3. the information needed to ensure clear-headedness about w hat do to can only come from detailed and carefully planned experimental analysis – so this sort of scientific work needs to be planned and funded in a coherent and co-ordinated manner.

Oil-spills are undoubtedly terrible things. They are unsightly, smelly, can represent a huge hazard to human health, damage to property and various other risks. They cause short-term and major disruptions to ecological processes and to numerus populations of marine and coastal species. Nothing discussed here is an excuse to ignore the problems or to abdicate responsibility for safe transport and handling of toxic materials.

It is, however, the case that the large sums of money put into clean-up, the appropriate sums exacted by penalties, fines and because of guilty feelings by those responsible, could all be much better spent. Far better, wider-reaching, longer-term sustainable ecological outcomes would be achieved by realism, rather than media-generated public emotion as responses to spills.

Short-term versus long-term ecological changes

Sensible and coherent ecologists long-ago abandoned the concept of a ‘balance of nature’. There is not – there cannot be – any such thing (see the summary in Botkin (1990) for some of the arguments against this nonsense). Yet, it is alive and well in the offices of journalists, community groups and many managers of environmental issues – let alone planners of environmental curricula in schools.

Marine organisms, in particular (although they share these life-histories with most insects and many terrestrial plants), have dispersive larval stages. Their eggs or offspring are released into the sea to float about in the plankton while they develop. They are consumed in large numbers by predators. The time taken to develop and then find a suitable habitat varies with weather, currents, availability of food. The numbers eaten vary with numbers of predators and the period spent in the plankton. So there is a very great variation in the numbers surviving from place to place and time to time (Underwood and Fairweather, 1989; reviewed by Underwood and Keough, 2001). This, alone, causes great fluctuations and differences in numbers of animals or plants arriving into any habitat.

Processes killing and removing animals are also very variable – notably the effects of storms and weather. Given intrinsic variability in numbers of animals, mortality due to competition for food and space and due to predation must also be very variable (see review in Underwood, 1979).

This has two relevant conseque nces for understanding oil-spills:

(i) designing sampling and experimental studies to understand the effects is very complex and requires skill, training and experience;
(ii) numbers of animals and plants are always fluctuating; fairly rapid recovery from short-term disturbances is a usual feature of the ecology of coastal habitats (although there are notable exceptions, e.g. Underwood, 1999).

There are always exceptions and the slow recovery of large birds and mammals following the "Exxon Valdez" spill has had numerous long-term (10 years) effects on intertidal and subtidal invertebrates (reviewed by Peterson, 2001).

Types of disturbances

The general theory of ecological disturbances has therefore focussed on two classes (or ends of a spectrum) of disturbances. This was well-illustrated by Bender et al. (1984). Short-term disturbances – called "pulses" – do not provide permanent causes of change. Many populations will recover rapidly once the disturbance is gone. In many habitats, oil spills arrive, but weathers quite quickly; the toxins are rapidly driven off (that is why the "Laura d'Amato" spill was so smelly!), or denatured. Natural processes remove the residues. Animals and plants can quickly recolonize the newly-cleared habitats.

In contrast, "press" disturbances – such as hydrocarbons from roads washing into an estuary every time it rains, or building a port, or daily harvesting of intertidal animals and plants for food, or recreational fishing - are very different. Although the effects may be quite small in any short period of time, there is no way that anything can recover. The disturbance persists or recurs too frequently. Some oil-spills are potentially presses. For example, in mangrove forests, burying oil can put it below the layer of bacterial decomposition, so it keeps leaching to the habitat for many years (see the long-term studies in Panama by Burns et al., 1993).

Of course, nothing is ever this simple and pulse (or press) disturbances can also cause press (or pulse) responses (Glasby, 1997). For example, a short-term disturbance that causes destruction of a mangrove forest will have very long-term consequences in the long period for trees to grow again. Also, some disturbances cause no response at all – the ecological system is inert to them (see Underwood (1989) for a discussion of this in the context of environmental impacts.)

In general, however, oil-spills are classical pulse phenomena relative to the longevity and life-histories of assemblages of marine species. Understanding them and managing them is all about understanding how to measure and predict the effects and how to prevent them from becoming long-term.

Consequences of clean up after an oil-spill

It has been well-known for a very long time that much of the oil from a spill on rocky surfaces will be removed naturally over relatively short periods (e.g. Boehm et al., 1995). In contrast, radical attempts to clean, using emulsifiers and other chemical agents, can have serious long-term effects. As one example, chemical or abrasive treatment can remove the biological / biochemical cues needed for larvae to recognize an appropriate habitat (Crisp, 1974). Oil may kill many animals and plants, but it usually leaves remnants of them to act as "signals" for new arrivals.

In soft-sediments, the trampling around and use of pumps and machinery can be a serious disruption of ecological processes and may make a habitat uninhabitable for long periods after the chemical contamination has gone.

As an example, after the "Exxon Valdez" spill in Alaska, it has been estimated that many oiled, but not cleaned, areas of rocky coast were essentially "recovered (i.e. within reference values) within 18 months to 2 years. In contrast, cleaned areas did not recover in less than 3 – 5 years (Wells et al., 1995; Gilfillan., 1995). Notably, the oil and all traces of its residues were absent from many areas within 3 years of the spill (Bence and Burns, 1995).

There are, of course, exceptions: where oil continued to leach from sediments (in some cases for up to 8 years), there were long-term impacts (Peterson, 2001). In some areas, residues of hydrocarbons from the "Exxon Valdez" oil were still present in bivalves 6 years after the spill (Carls et al., 2001).

Sampling and experimental work needed to make better decisions

The variable and complex nature of coastal ecological assemblages (as briefly identified above) requires considerable skill in the design, analysis and interpretation of sampling (see particularly Schmitt and Osenberg, 1996; Downes et al., 2002).

For univariate data (measurements of single variables, such as the numbers or sizes of a particular species), the principles are well-known (Green, 1979) and robust methods have been developed (Underwood, 1992, 1993, 1994). For multivariate measures (e.g. changes in sets of species), considerable progress has been made (Clarke, 1993), but there is still a long way to go.

It is worth noting that the research to develop robust methods to detect impacts in variable and complex ecological systems is well-supported by the oil industry in Europe. Despite the intensity of effort in south-east Australian universities, which is widely recognized internationally, I am unable to find any sustained support from the oil-exploration, transport, processing, distribution or retail components of the oil industry in Australia!!

The general methods that have been developed to assess ecological impacts can rarely be used for oil-spills because they are much more reliable where there are data from before the disturbance. It is quite unusual to have such data in areas where unpredictable accidents, such as oil-spills, occur. So, methods using data only from after the disturbance (Glasby, 2000) must be used. A much better approach would have two strategies:

(i) commissioned ecological sampling of species most likely to be affected by oil-spills in areas where spills may occur. For example, near refineries and bunkerage wharves;
(ii) opportunistic experimental studies to test hypotheses about the3 actual effects of spills and of clean-up (e.g. the local studies done after the "Laura d'Amato" spill in Sydney; Chapman and Blockley (1999), Lindegarth et al. (1999).

Both need careful and expert planning and getting the designs wrong will make results useless (Underwood 1997, 2000). In fact, there has been considerable debate in the relevant professional literature about the methods used to examine oil-spills and, although there is wide agreement, there are quite marked areas of technical concern (Gilfillan et al., 2002; Peterson et al., 2001, 2002).

In addition, there are occasional planned disturbances to habitats. For example, several hectares of seagrass were destroyed to build the third runway in Botany Bay. This sort of planned disturbance should be used to do experiments about effects of oil and responses to a spill. In that case, there was enough room and time to do a properly controlled and replicated study to determine both (impacts and effects of clean-up) in the seagrasses of a major estuary. Specifically, replicated experimental plots of a realistic size (100 m x 100 m) could have been used as controls, subject to experimental oiling, oiled and cleaned and cleaned in the same way (but without oiling). Data, from before and after, about the densities and types of animals and plans would have identified any problems due to, or merits in, clean-up in addition to identifying the actual impacts. Without such experiments, little scientific realism will be brought to bear on the problems of what to do and how and when to do it.

Final thoughts

The undoubted successes of ecological experiments (Connell, 1983; Paine, 1994) in numerous areas of study have been matched in recent times with explicit experimental and comparative studies on various types of impacts and methods to detect them (e.g. MEPS, 1988). Experimental ecologists long ago abandoned description and guess-work in favour of the more robust and much more logical frameworks that characterize other progressive areas of science (Connell, 1972; Underwood, 1985). It is a pity that so much regulatory effort has gone into requiring environmental impact statements that are, almost without exception, of little to no value for understanding systems and processes (no value), predicting impacts (very limited to no value) or providing coherent views about how to manage or restore a disturbed system (no value).

The resources committed to these old-fashioned requirements of an ill-informed legal and bureaucratic machinery could be much better spent.

It is even more tragic that oil-spills cause expenditure of large sums of money that would be of very much greater (infinitely greater if current efforts produce no valuable information) value if spent on the necessary long-term ecological studies needed around urban coast-lines. Experimental analyses of consequences to biodiversity of loss and deterioration of habitat, rises in sea-level due to global warming, long-term chronic contamination, built structures in harbours, etc., would be a much better investment. Much of the money spent on such spills as that from the “Laura d’Amato” was not obviously usefully employed in terms of scientific understanding. It could, however, have underpinned a considerable advance in real understanding.

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Literature cited

Bence, A.E., Burns, W.A., 1995. Fingerprinting hydrocarbons in the biological resources of the Exxon Valdez spill area. In, *Exxon Valdez oil-spill: fate and effects in Alaskan waters*, edited by P.G. Wells, J.N. Butler & J.S. Hughes, ASTM, Philadelphia, 84-140.

Bender, E.A., Case, T.J., Gilpin, M.E. 1984. Perturbation experiments in community ecology: theory and practice. **Ecology 65**, 1-13.

Boehm, P.D., Page, D.S., Gilfillan, E.S., Stubblefield, W.A., Harner, E.J. 1995. Shoreline ecology program for Prince William Sound, Alaska, following the Exxon Valdexz oil-spill. Part 2, Chemistry and toxicology. In, *Exxon Valdez oil-spill: fate and effects in Alaskan waters*, edited by P.G. Wells, J.N. Butler & J.S. Hughes, ASTM, Philadelphia, 347-397.

Botkin, D.B. 1990 Discordant harmonies. Oxford University Press, Oxford.

Burns, K.A., Garritty, S.D., Levings, S.C. 1993. how many years until mangrove ecosystems recover from catastrophic oil-spills. **Mar. Poll. Bull. 26**, 239-248.

Carls, M.G., Babcock, M.M., Harris, P.M., Irvine, G.E., Cusick, J.A., Rice, S.D., 2001. Persistence of oiling in mussel-beds after the Exxon Valdez oil-spill. **Mar. Environ. Res. 51**, 167-190.

Chapman, M.G., Blockley, D. 1999. Intertidal assemblages on seawalls at Berry Island and Blues Point before and after the oil spill, August 1999. Centre for Research on Ecological Impacts of Coastal Cities, University of Sydney, Sydney.

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. **Aust. J. Ecol. 18**, 117-143.

Connell, J.H. 1972. Community interactions on marine rocky intertidal shores. **Ann. Rev. Ecol. Syst. 3** , 169-192.

Connell, J.H. 1983. On the prevalence and relative importance of interspecific competition: evidence from field experiments. **Am. Nat. 122**, 661-696.

Crisp, D.J.1974. Factors influencing the settlement of marine invertebrate larvae. In: P.T. Grant, A.N. Mackie (Eds.), Chemoreception in Marine Organisms. Academic Press, London, pp. 177-215.

Downes, B.J., Barmuta, L.A., Fairweather, D.P., Keough, M.J., Lake, P.S., Mapstone, B.D., Quinn, G.P., 2002. Monitoring ecological impacts: concepts and practice in flowing waters. Cambridge University Press, Cambridge, U.K.

Gilfillan, E.S., Page, D.S., Harner, E.J., Boehm, P.D.., 1995. Shoreline ecology program for Prince William Sound, Alaska, following the Exxon Valdez oil-spill. Parrt 3. Biology. In, *Exxon Valdez oil-spill: fate and effects in Alaskan waters*, edited by P.G. Wells, J.N. Butler & J.S. Hughes, ASTM, Philadelphia, 398-443.

Gilfillan, E.S., Harner, E.J., Page, D.S., 2002. Comnment on Peterson et al., 2001 ‘ Sampling design begets conclusions’. **Mar. Ecol. Progr. Ser. 231**, 303-308.

Glasby, T.M., 1997. Analysing data from post-impact studies using asymmetrical analyses of variance: a case-study of epibiota on marinas. **Aust. J. Ecol. 22**, 448-459.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, Chichester.

Lindegarth, M., Underwood, A.J., Small, K. 1999. Assemblages of animals in intertidal sediments before and after the oil spill, August 1999 in Gore Cove (Sydney Harbour) and nearby reference locations. Centre for Research on Ecological Impacts of Coastal Cities, University of Sydney, Sydney.

MEPS, 1988. Biological effects of pollutants: results of a practical workshop (edited by B.L. Bayne, K.R. Clarke & J.S. Gray). **Mar. Ecol. Progr. Ser. 46**, 1-278.

Paine, R.T. 1994. Marine rocky shores and community ecology: an experimentalist’s perspective. Ecology Institute, Oldendorf/Luhe, Germany.

Peterson, C.H., 2001. The "Exxon Valdez" oil-spill in Alaska: acute, indirect and chronic effects on the ecosystem. **Adv. Mar. Biol. 39**, 1-103.

Peterson, C.H., McDonald, L.L., Green, R.H., Erickson, W.P., 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the Exxon Valdez oil-spill. **Mar. Ecol. Progr. Ser. 210**, 255-283.

Peterson, C.H., McDonald, L.L., Green, R.H., Erickson, W.P., 2002. The joint consequences of multiple components of statistical sampling designs. **Mar. Ecol. Progr. Ser. 231**, 309-314.

Schmitt, R.J., Osenberg, C.W., 1996. Detecting ecological impacts: concepts and applications in coastal habitats. Academic Press, New York.

Shaw, D.G. 1992. The Exxon-Valdez oil-spill: ecological and social consequences. **Environ. Cons. 19**, 253-258.

Underwood, A.J. 1989. The analysis of stress in natural populations. **Biol. J. Linn. Soc. 37**, 51-78.

Underwood, A.J. 1992. Beyond BACI: the detection of environmental impact on populations in the real, but variable, world. **J. Exp. Mar. Biol. Ecol. 161**, 145-178.

Underwood, A.J. 1979. The ecology of intertidal gastropods. **Adv. Mar. Biol. 16**, 111-210.

Underwood, A.J. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge

Underwood, A.J. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. **Aust. J. Ecol. 18**, 99-116.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. **Ecol. Appl. 4**, 3-15.

Underwood, A.J.1985. Physical factors and biological interactions: the necessity and nature of ecological experiments. In: *The ecology of rocky coasts*, edited by P.G. Moore & R. Seed, Hodder & Stoughton, London, pp. 371-390.

Underwood, A.J., Fairweather, P.G. 1989. Supply-side ecology and benthic marine assemblages. **TREE 4**, 16-20.

Underwood, A.J., 1999. History and recruitment in the structure of intertidal assemblages on rocky shores: an introduction to problems for interpretation of natural change. In, *Aquatic life cycle strategies*, edited by M. Whitfield, Institute of Biology, London, pp. 79-96.

Underwood, A.J., 2000. Trying to detect impacts in marine habitats: comparisons with suitable reference areas. In, *Statistics in ecotoxicology*, edited by T. Sparks, Wiley and Sons, Chichester, pp. 279-308.

Underwood, A.J. & M.J. Keough, 2001. Supply side ecology: the nature and consequences of variations in recruitment of intertidal organisms. In, *Marine community ecology*, edited by M.D. Bertness, S.D. Gaines & M. Hay, Sinauer Associates, Sunderland, Massachusetts, 183-200.

Wells. P.G., Butler, J.N., Hughes, J.S., 1995. Introduction, overview, issues. In, *Exxon Valdez oil-spill: fate and effects in Alaskan waters*, edited by P.G. Wells, J.N. Butler & J.S. Hughes, ASTM, Philadelphia, 3-40