RECOVERY OF POLLUTED ECOSYSTEMS: THE CASE FOR LONG-TERM STUDIES

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Recovery of marine ecosystems from known pollution has tended to receive less attention than the study of new or continuing impacts, but such studies are important in charting recovery from acute pollution incidents such as oil, chemical spills and pulses of mine-derived run-off. Following legislation to deal with chronic contamination of the environment, long-term studies can enhance our understanding of recovery patterns and help to provide guidelines for future remediation work after such incidents. Recovery is inevitably a long-term process, and where such studies have been made they are often too short-lived. Interest quickly wanes following an oil spill and governmental bodies rapidly switch to new legislative priorities for chronic inputs. In this short paper we review three case studies: recovery of dogwhelk populations after decimation by tributyl tin leachates from antifouling paints; recovery of rocky shore communities from oil spills; and recovery of estuarine ecosystems from industrial and urban development. We then make some generalisations about recovery processes before making a plea for long-term studies of polluted areas.

Recovery of populations from TBT

During the mid-1980's the toxic effects of TBT on a variety of organisms were demonstrated (see review by Bryan and Gibbs, 1991). Oysters and stenoglossan prosobranch molluscs (whelks) were shown to be particularly sensitive, exhibiting shell-thickening (Chagot *et al*., 1990) and imposex (Gibbs *et al*., 1988), respectively, in response to low environmental concentrations. In 1987 TBT was banned in the United Kingdom on vessels less than 25 m and similar legislation has followed elsewhere in the world (Abel 1996). In the UK, the dogwhelk *Nucella lapillus* was shown to be a sensitive indicator of impact (Bryan *et al*., 1986; Spence *et al.,* 1990) and has proved useful as a bioindicator of coastal ecosystem recovery (Evans *et al*., 1991). Figure 1 shows data on dogwhelk populations in the Plymouth area, encompassing sites with various degrees of TBT contamination, and a much cleaner site in North Cornwall. At the individual level the RPS (Relative Penis Size – a measure of TBT impact) shows a decrease from the enactment of the legislation onwards: all the contaminated sites show similar recovery rates with RPS in dogwhelks from St. Agnes (control) hovering near zero throughout. The proportion of badly affected sterile females (imposex stage V and VI, another measure of TBT impact, Gibbs & Bryan 1996) has also shown a decrease since 1987, at all affected sites. This recovery was initially more rapid at the worst affected sites, presumably due to female mortalities. Neither the RPS index, nor the percentage of sterile females has stabilised, showing that either there is still some contamination from large ships or that TBT is being remobilised from sediments. The longevity of *Nucella* and the irreversible nature of imposex, once initiated during early growth, also contribute to the slow reduction in this index. Population density has recovered, even at the worst affected sites, but note a longer trend of decline in populations at many sites including the control. In hindsight multiple controls would have been desirable during these studies, but remarkably the St Agnes region was one of the few places in South West England showing virtually zero response to TBT pollution (Bryan *et al.,* 1986; Spence *et al.,* 1990).

From the data presented here and elsewhere (Evans *et al*., 1991) recovery was initially rapid but has levelled out in recent years showing that further action, such as a complete ban on TBT, is probably necessary to achieve "no observable effects”. Up to 15 years or so is required for recovery at the sub-lethal level. At the population level, recovery occurs in 5-10 years (Evans *et al*., 1991).

Recovery of communities from oil spills

Oil spills are the most publicly visible pollution incidents and attract much media interest. This is usually accompanied by an urgent flurry of scientific activity to assess immediate impact, with only a few studies going on beyond a few years. We focus on the Torrey Canyon oil spill because not only was it studied intensively at the time by the Marine Biological Association (Smith 1968), but also long-term studies of recovery have been made at one of the worst affected sites (Southward & Southward 1978; Southward 1979; Hawkins *et al.,* 1983; Hawkins & Southward 1992). At

Porthleven as elsewhere in Cornwall, excessive use of dispersants led to massive kills of grazers, particularly limpets (*Patella* sp) - probably the key-stone species on rocky shores in north west Europe (Hawkins & Hartnoll 1983; Hawkins *et al*., 1992). This led to a massive proliferation of algae - ephemerals followed by *Fucus* spp. - that had dominated the previously barnacle-covered shore for several years. Underneath the canopy however, there was a major recruitment of limpets. These prevented further algal proliferation and even attacked the adult plants, eventually rendering the shore very bare. With no food available, large numbers of limpets abandoned their usual homing habits and moved across the shore eating everything in their way, before the population collapsed. This led to a second, but smaller, increase in fucoids and thus the shore recovered - via damped oscillations (Southward & Southward 1978; Hawkins *et al.,* 1983; Hawkins *et al.,* 1992) - to the normal levels of small-scale patchiness and fluctuation typical of such shores in Cornwall. Recovery took at least 10 years, and up to 15 years on shores badly affected by dispersants, although in areas where no dispersants had been applied (e.g. Godrevy Island which has a seal colony) recovery took no longer than 2-3 years (Southward & Southward, 1978).

Following other spills there have been further long-term studies, the most comprehensive of which were those that followed the Exxon Valdez spill in Alaska (reviewed by Paine *et al.,*1996; Peterson 2001). Peterson *et al* (2001) have commented on how different experimental designs have led to varying interpretations of the time-scale of recovery. Our work on the Torrey Canyon incident was not set up for formal statistical testing, but benefited from extensive prior knowledge of the affected shores stretching back many years (e.g. Southward 1967).

Recovery of polluted estuaries: the Mersey

Many of the world's industrial and urban complexes are situated on estuaries, leading in the past to gross pollution of these ecosystems. In Europe, the Mersey has the reputation of being one of the worst polluted (Clarke, 1989). In recent years there have been major catchment scale clean-up initiatives (Alexander & Harper 1989; Wade 1987). These, coupled with de-industrialisation and tighter controls of point sources, have led to better water quality (oxygen levels), reduction in levels of persistent pollutants such as heavy metals, and the return of benthic animals and fish to the Estuary.

There have been some relapses on the route to recovery, the most spectacular of which were the Mersey bird kills between 1979 and 1981 (Bull *et al.,* 1983). Recovery of the Mersey had led to a rich invertebrate fauna in the middle estuary, on which over-wintering waterfowl were feeding. However, following the decline of the Port of Manchester, the Manchester Ship Canal was less frequently locked and industrial effluent was released to the estuary in concentrated pulses. Alkyl lead compounds from a petrol additive plant became concentrated along the food chain, and poisoned thousands of wading birds. The Mersey oil spill in 1989 was a further set-back but with relatively short lived consequences (Davies & Wolff 1990).

In addition to broad-scale improvements in the Mersey Estuary, active restoration has been used in former commercial docks that are now the focus of urban redevelopment schemes. In these, water quality has been improved by mixing (Russell *et al.,* 1983) and by biofiltration with both introduced, and naturally settling populations of mussels (Allen *et al.,* 1992; Hawkins *et al.,* 1992; 1999). The docks now have clear water, and a diverse flora and fauna have become re-established now that periodic anoxic events and dense (often toxic) algal blooms have ceased.

Once water quality had improved - especially bottom oxygen levels - natural recolonisation of both the Mersey Estuary and the restored docks followed, presumably as a result of recruitment from healthy populations in the rest of the Liverpool Bay Estuary system (e.g. the Dee, the Ribble). Recovery has been slow, taking over 40 years from the worst affected period in the 1950s and 1960s. There are still problems: re-established animals such as fish can survive long enough to accumulate heavy metals and persistent organics (Leah *et al.,* 1997; Collings *et al*., 1996) which are a potential health problem for people eating them. The success of the Mersey clean-up campaign, however, is reflected by its status as an important winter feeding ground for shorebirds and waterfowl and the estuary now has many national and international conservation designations.

Pathways of recovery

As pollution load increases, responses are first seen at the subtle molecular and cellular level before having effects at the individual and population level. With increasing severity (if chronic) or frequency (if acute), community-level effects are seen before ecosystem dysfunction happens. Recovery at this higher level of biological organisation follows a more rapid backward trajectory (summarised in Fig.

2). Quite small improvements in water quality can allow an impoverished biota to occur and community level processes resume quickly. Most recovery occurs by recruitment from remote populations, via larval dispersal. There is also some recovery *in situ* by animals with direct development, such as dogwelks, although even with their limited dispersal, some recruitment from uncontaminated populations occurs. However, despite 'recovery' at the community and population level, apparently thriving breeding populations can still exhibit sub-lethal effects, detectable perhaps by a powerful battery of sensitive biomarkers at the cellular and molecular level (Depledge 1999).

Overview

All the examples given have involved long-term studies. Work on the Mersey would have benefited from a planned programme of study, rather than the somewhat piecemeal monitoring undertaken to date. Recovery of shores after the Torrey Canyon oil spill could not have been interpreted without broader scale contextual information. Studies of dogwhelks have not been continuous but at least extend over 15 years encompassing three sequential PhD studentships. Such work tends to be labelled as "merely monitoring", however without observational programmes of this type we cannot hope to establish the efficacy of legislation, nor measure the true impact of a major acute incident.

In recent years Underwood (1992) has urgently argued the case for a rigorous 'hypothesis-taking' approach in impact assessment. He has advocated experimental designs classed as "beyond BACI" (BACI = Before/After and Control/Impact, after Green 1979, Stewart-Oaten *et al*., 1986) and these are beginning to be adopted. Although the examples here did not conform to the rigours of the beyond BACI approach they do emphasise the need for long-term and broadscale contextual research to understand recovery of impacted ecosystems. Perhaps what is needed is a "far away and long beyond" BACI approach to study recovery of polluted ecosystems.

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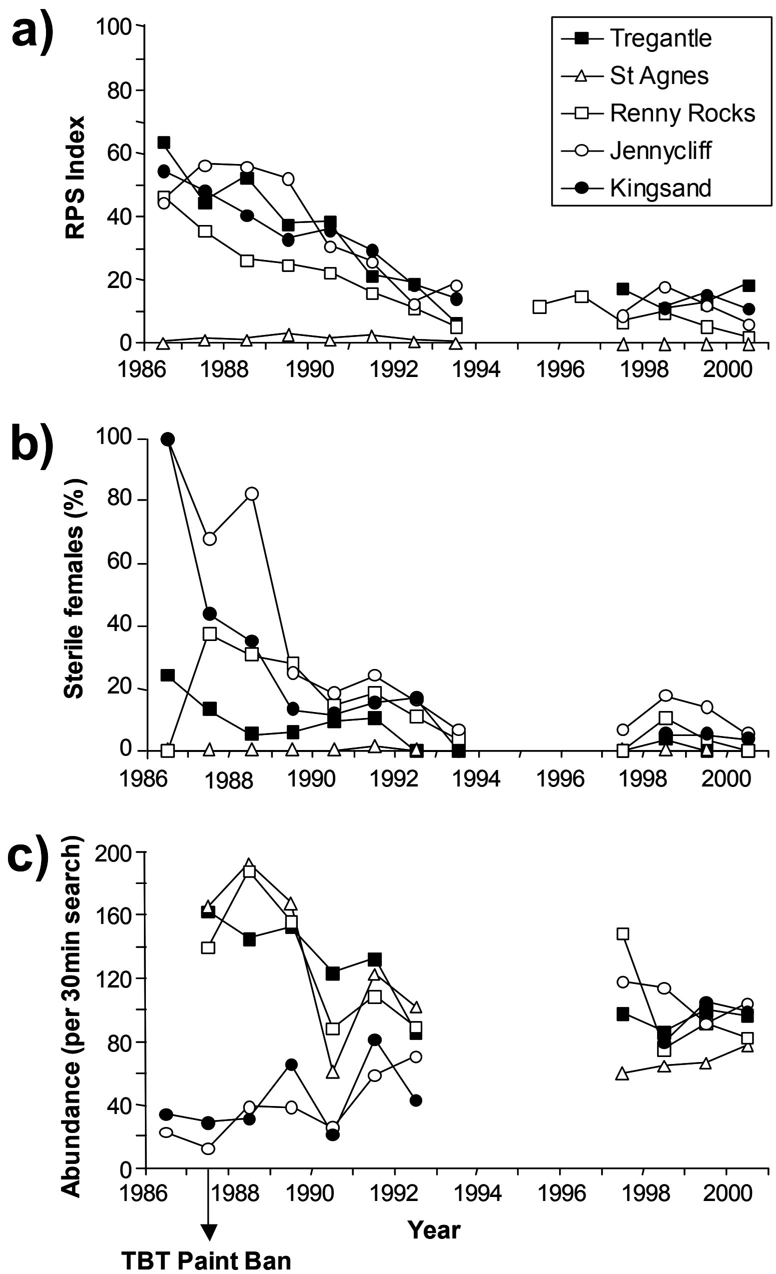

Figure 1 Changes in dogwhelk (*Nucella lapillus*) parameters at sites near Plymouth between 1986 and 2000. RPS = Relative Penis Size

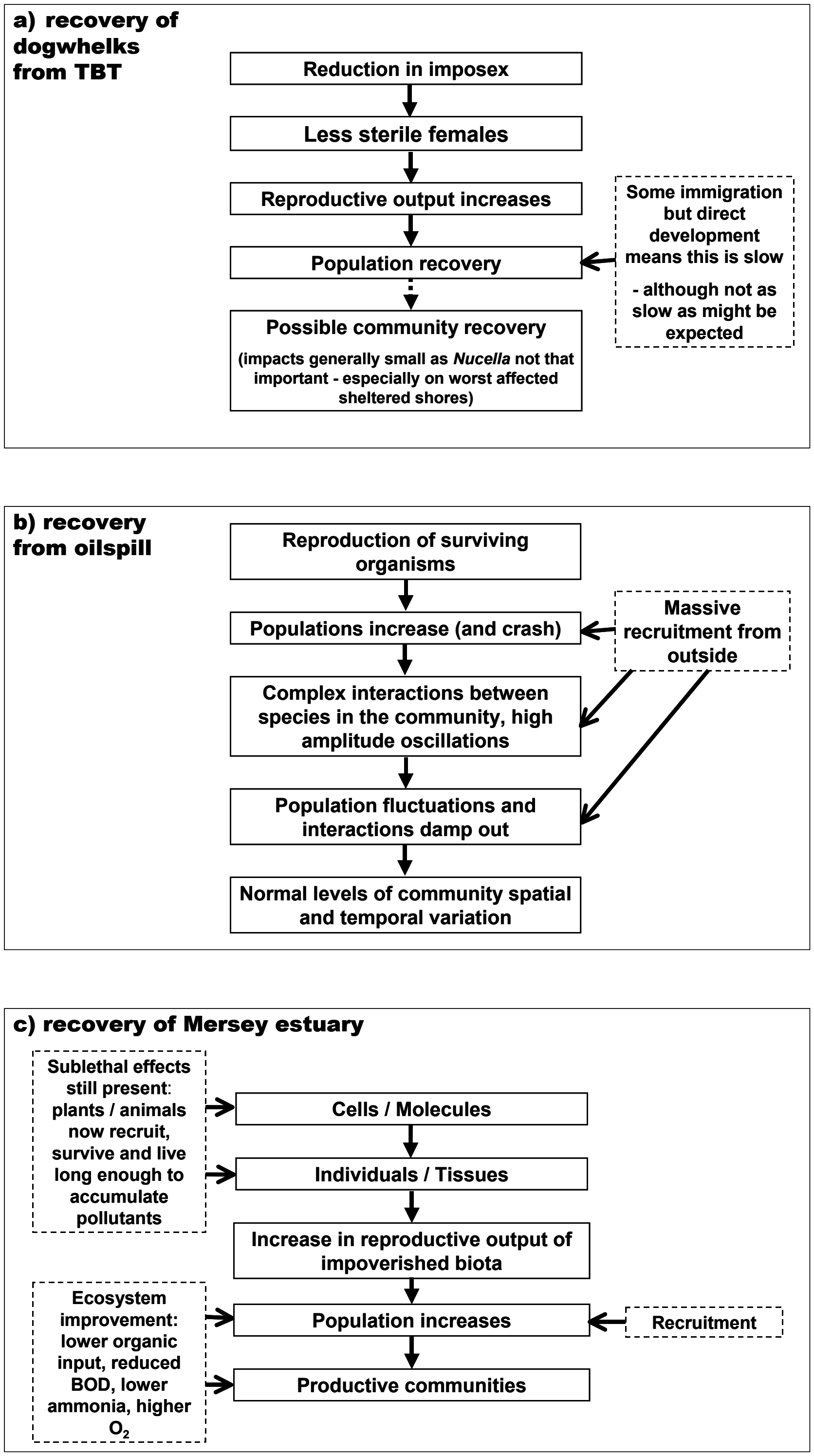

Figure 2 Examples of pathways to recovery after pollution