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ScienceDirect
Marine Pollution Bulletin 52 (2006) 840–843
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Viewpoint

On effects of trawling, benthos and sampling design

John S. Gray [a,*], Paul Dayton [b], Simon Thrush [c], Michel J. Kaiser [d]

[a] *Marine Biodiversity Research Program, Department of Biology, University of Oslo, P.O. Box 1066 Blindern, 0316 Oslo, Norway*
[b] *Scripps Institution of Oceanography, UCSD, 9500, Gilman Drive, La Jolla, CA 92093-0227, USA*
[c] *National Institute for Water and Atmospheric Research, P.O. Box 11-115 Hamilton, New Zealand*
[d] *School of Ocean Sciences, University of Wales-Bangor, Menai Bridge LL59 5AB, UK*

Abstract

The evidence for the wider effects of fishing on the marine ecosystem demands that we incorporate these considerations into our management of human activities. The consequences of the direct physical disturbance of the seabed caused by towed bottom-fishing gear have been studied extensively with over 100 manipulations reported in the peer-reviewed literature. The outcome of these studies varies according to the gear used and the habitat in which it was deployed. This variability in the response of different benthic systems concurs with established theoretical models of the response of community metrics to disturbance. Despite this powerful evidence, a recent FAO report wrongly concludes that the variability in the reported responses to fishing disturbance mean that no firm conclusion as to the effects of fishing disturbance can be made. This thesis is further supported (incorrectly) by the supposition that current benthic sampling methodologies are inadequate to demonstrate the effects of fishing disturbance on benthic systems. The present article addresses these two erroneous conclusions which may confuse non-experts and in particular policy-makers.
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Keywords: Benthic trawling; Dredging; Fisheries impacts; Benthic disturbance; BACI design; Statistical errors; Benthic disturbance

A few years ago Watling and Norse produced their famous paper where they likened effects of trawling to clear-cutting of virgin forest (Watling and Norse, 1998). This was followed in 2003 by a large ICES Symposium focussed on the topic of "Marine Benthos Dynamics: Environmental and Fisheries Impacts", Eleftheriou, 2000). Comprehensive reviews (Thrush and Dayton, 2002; Kaiser et al., 2006) and many other papers lead to the overwhelming conclusion that trawling has had negative effects on benthic habitats and species. In commenting on the degradation of coastal areas and their resources the United Nations Environment Programme, GEO2000 global environmental outlook, notes that resource exploitation, changes to habitats and disruption of ecosystem functions probably pose more serious threats to many marine and coastal areas than pollution (http://www.unep.org/geo2000/english/0223.htm). Furthermore, the recent Millennium Assessment (http://www.millenniumassessment.org/en/index.aspx) also highlights the role of fishing in degradation of the marine environment. Yet now the backlash appears! The United Nation's Food and Agriculture Organisation commissioned and published a review of the impacts of trawling and scallop dredging on benthic habitats and communities (Løkkeberg, 2005). The main conclusion of this report (p. 47) is that, "It is difficult to conduct impact studies leading to clear and unambiguous conclusions because knowledge of the complexity and natural variability of benthic communities is rudimentary". The review speculates further on the utility of grabs and box-corers as sampling tools (p. 9) stating that "these methods are not suitable for sampling benthic fauna with patchy distribution and low abundance." These worrying assertions reflect a profound ignorance of an abundant literature and could lead to inappropriate conclusions by a non-expert reader.

The author of the FAO report does not seem to know that benthic assemblages globally are the most widely used

* Corresponding author. Fax: +47 228 54438.
E-mail address: j.s.gray@bio.uio.no (J.S. Gray).

0025-326X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2006.07.003

systems to measure the impacts of contaminants, nutrients (e.g., eutrophication effects) and other man-made disturbances. Far from grabs and box-corers being "unsuitable" they are typically the tools of choice and give quantitative and replicable data from which assemblage structure can be assessed with a known degree of precision. With the application of multivariate statistical methods, subtle treatment effects can be discerned, even when using higher taxonomical levels such as families rather than at the species level. Use of benthic fauna for such purposes is supported by hundreds of papers and reports and is widely recognised by environmental agencies with responsibility for assessment of the quality of coastal waters (e.g., the USEPA, 2000). The scale of sampling is an important issue facing any impact assessment, which has also spawned a large literature. Statements in Løkkeberg (2005) do not reflect the state of the science, and certainly do not support wise resource management.

The review states (p. 1) that there are three main reasons why, in the author's opinion, no general conclusions can be drawn on the effects of trawling. These are: (1) benthic assemblages are complex and show large temporal (both seasonal and interannual) and spatial variation, (2) a great variety of fishing-gear, disturbance regime, bottom type, level of natural disturbance and variety of assemblages have been incorporated into individual studies, (3) large variations in methodology have been used and only when "proper" sampling designs are used can clear conclusions be made. It is true: nature is both complex and complicated, but is studied by a wide variety of scientists using all sorts of techniques. The implications of the report appears to be that benthic systems are too complex and too poorly understood to precisely determine the response of these systems to fishing activities (and that all studies undertaken to date have not been 'properly' designed).

So what do we who have studied benthic assemblages actually know about our systems? Firstly, assemblages vary with the sediment type and depth as was shown by Petersen and Thorson in the early decades of the 20th century. No-one would expect assemblages from different habitats to respond in similar ways, you study a system and show the effects on that specific system and there is no reason to assume that there are responses that can be generalised across all benthic assemblages. We expect results to be context dependent. Benthic assemblages are indeed complex and we can find 50 species of macrofauna retained on a 1 mm sieve from one single grab sample covering 0.1 m^2. Take five grabs within a 10×10 m area of seabed and pool them and often 100 species are found. Increase the area sampled by adding further 10×10 m areas within say a 1 km radius and over 3–400 species are found in temperate areas. Yet at all sampled scales most of the species (70%) will only be represented by one or two individuals (whatever the size of sampling unit), while only a few species will be abundant. The reason why benthic systems are used so successfully for monitoring anthropogenic effects is because of the many species found with a wide variety of feeding and developmental types present. Thus, subtle but ecologically important changes in species composition can be measured with the application of modern statistical methods. Indeed, with reference to life-history characteristics, it is feasible to predict which species will be more or less adversely affected by the additional stress of fishing disturbance. Thus temporal and spatial variations are not the confounding problem, implied by this report.

But how does disturbance affect an ecological assemblage? The "intermediate disturbance" hypothesis has been shown to be a useful ecological rule, although it is scale dependent. A moderate disturbance can lead to an increase in species richness as some dominant species are reduced in abundance, so there is opportunity for new species to colonise and for species richness to increase. Trawling may have such an effect in systems characterized by low habitat structure and relatively ephemeral species. However, this conceptual response does not provide evidence that trawling is somehow beneficial simply because it may increase species richness at low levels of disturbance. Damage caused by trawling on a 400 year old cold water coral will take hundreds of years to repair. Such communities dominated by large and long-lived organisms are being impacted by fishing and elegant experiments are not need to prove the obvious immediate effects. Nevertheless we do need to learn about the full consequences of such impacts on biodiversity and define rates of recovery so that the ecological risks can be fully assessed. The intermediate disturbance hypothesis also predicts that as the disturbance persists or increases in strength, or frequency, then richness will decrease. Thus, the response is not a simple one and neither is a simple response expected by experienced researchers.

The author believes that what we recognize to be natural variation is in fact a problem with sampling design. He has discovered the ANOVA-based before-after-control-impact (BACI) design (Green, 1979) and the Beyond-BACI designs of Underwood (1991). Several times he cites a study undertaken in the Gullmarfjord in Sweden (Lindegarth et al., 2000a,b) that did not report effects of trawling on the benthos using these analytical approaches. Rather than attempt to actually understand the biological basis of these findings, Løkkeberg comments, "*The results of this study differed from most other manipulative experiments in that fewer taxa were affected by trawling*" and that "*trawling affected small-scale temporal and spatial variability in the structure of assemblages" by counteracting the decreases in variability that occurred at untrawled sites*". What Løkkeberg fails to mention is that Lindegardh et al. only sampled the very large macrofauna (using 4 mm sieves rather than the usual 1 mm or 0.5 mm sieves used to extract the fauna from the sediment). Thus these papers from which Løkkeborg draws his conclusions missed most of the benthic community! Large animals are usually rare, especially in the fine muds typical of the floor of a fjord. This further exacerbates the low statistical power of the study to which he refers. The conclusions based on this paper that is so

strongly relied on by the FAO document are irrelevant to most benthic research, and we are not at all surprised that few taxa were affected since most species will have passed through the sieve! No amount of clever statistics can salvage a study that did not collect many of the species of interest. Likewise the high variability in the fauna found at control sites over time is just what would be expected of sampling a "random" selection of individuals captured by the unusual sieve size used. Also the effects of trawling on soft sediment habitats are to homogenise the sediment and reduce variability. Thus the effects are expected on the variance rather than the mean.

The second point raised from this report is that of the BACI design and that of the interpretation of spatial and temporal variability. One of the key aspects of the Beyond-BACI design is that there should be multiple controls and that sampling should be done randomly over time. Yet finding adequate control areas to assess effects of trawling is hugely difficult (as Løkkeberg correctly states) since there are so few areas in most coastal zones that are free from trawling, and those that are used almost always are in different areas and represent different ecological systems, that is, they are not really controls, (see Hewitt et al., 2001). This is a major problem challenging the assessment of all broad-scale environmental effects. What is needed is a vast increase in the number of trawl free areas on continental shelves. Such measures are being taken in New Zealand, Australia, the USA and Malaysia. Yet in the European Union there are no such plans. Few areas of the North Sea are free from trawling and thus it is simply not possible to assess the effects of trawling if you assume that the only way this can be done is via statistical contrasts between perfect control and impact sites. If we accept Løkkeberg's advocacy, that this is the only way to infer cause-and effect, we are faced with not being able to produce the proper sampling designs that are so sorely needed. A vast increase in the number of Marine Protected Areas and waiting an unknown time for recovery is then the only solution. Luckily, there is a vast literature across a wide range of sciences (ecology, physics, epidemiology) demonstrating that this is not the only way of inferring cause and effect.

The third point raised is of the need to measure the natural spatial and temporal variability before we can make statements about effects of trawling. This introduces the fundamental scale question: exactly what is the appropriate spatial scale to measure the effects of trawling? The Beyond-BACI design needs to be applied at the appropriate spatial scale for the question being posed. That is, if we are studying species richness of an area we know that a single 0.1 m^2 grab will not give a reliable estimate of the number of species. Take 10 grabs and the variance in the number of the species found is reduced and the number of species does not increase as fast as when two grabs are combined. In diversity studies the spatial scales are: *Point richness* is that of a single grab (in statistical terms a sampling unit); *Sample richness* is that of the 10 grabs taken within given area (e.g., 10×10 m); *Large area richness* that of a larger scale of say hundreds of km^2; and the final scale is that of *Biogeographical province richness*. So what is the appropriate scale to examine effects of trawling? If you use the single grabs as "replicates" in a categorical analysis then there will be high variability in numbers of species between grabs and the power to detect effects will be rather low. Determining appropriate scales for averaging is an important issue but the proponents of the ANOVA-based BACI design will argue that is essential to measure this small-scale variability both in space and time. In terms of interpreting the results, this is analogous to examining a random number of pixels on a DVD film and expecting to see the movie. Do we need to know the variance in groups of pixels to be able to see that they form a picture? The finding that the benthos shows high variance at small scales (in space and time) does not mean that there are not obvious effects of trawling, as indeed was demonstrated in the Gullmarsfjord using a sediment profiling image camera, (Rosenberg and Nilsson, 2005), which showed clear changes in sediment structure.

Almost certainly the most significant effect of trawling on benthic assemblages is that of habitat homogenisation and/or destruction (a very large literature reviewed in Thrush and Dayton, 2002). This can have important effects on sediment biogeochemical processes as well as modify structure above the sediment surface. Nowhere are these impact of fishing more immediate that in situations where cold water coral and deep sea sponge communities are impacted. Indeed a multibeam survey done in June 2006 of the Tromsøflaket in Norway conducted by the Institute of Marine Research, Bergen shows that almost all of the rich sponge communities have been destroyed by trawling.

Natural sedimentary environments are not vast homogeneous plains of sand or mud but contain a variety of three-dimensional structure. These may be caused by natural physical variations in substratum such as isolated stones and patches of different types of sediment. Biological alteration of the sediment is extremely important; shells, animal tubes of a variety of shapes, sizes and durability, faecal piles, holes and pits are all key elements of the structure and functioning of these habitats. Research has shown that such structures are important cues for settlement processes of many organisms, can act as refugia from predators and affect ecosystem processes. Yet trawling tends to homogenise the sediment and reduces three-dimensional structure above and below the sediment-water interface. Thus, in addition to quantitative grab or core sampling, video imaging and ROV surveys are key elements of work on effects of trawling. Fortunately, in the Oslofjord we still have areas with these 3D structures that abound and which themselves are indicative of an untrawled area.

A fundamental problem with this FAO report (Løkkeberg, 2005) is that it is based almost exclusively on assessment of Type-I statistical errors. That is if you do not find an effect of trawling on the benthos then you infer there

are no effects. This can be illustrated by the following statements:

"*Owing to a lack of true replicate control sites, the changes in benthic assemblages demonstrated in some impact studies may reflect natural variability (spatial and temporal) and not the effects of trawling disturbance.*" (p. 23)

"*Several studies have addressed the impacts of shrimp trawling on clayey-silt bottoms. No clear and consistent effects attributable to trawling were detected. Potential disturbance effects may be masked by the more pronounced temporal variability demonstrated in these studies.*" (p. 25)

"*The impacts of trawling have been indicated in some studies conducted in soft bottoms. However, evidence for clear and consistent changes attributable to trawling has not been provided from these experiments. The most prominent features of these studies are a lack of true and replicate control sites and pronounced temporal and spatial variability in community structures.*" (p. 30)

"*Intensive disturbance by beam trawling has been shown to cause short-term changes in community structure through considerable reductions in abundance of infauna. The long-term effects have not been studied.*" (p. 32)

What is far more important for environmental issues is avoiding the risk of accepting the hypothesis that there are no effects of trawling when there are in fact effects (i.e., making a Type-II error). So rather than considering Type-I errors as done by Løkkeberg one should pay far more attention to Type-II errors. Again a large literature in statistics and environmental science exist on these issues. In fact, globally new environmental legislation insists on the use of the Precautionary Principle toward environmental impacts (Gray, 1995). Løkkeberg does not seem to appreciate that, in Europe at least, we have gone beyond the Precautionary principle now and, in relation to discharges of chemicals, use the Reversal of the Burden of Proof for environmental legislation. By this the onus is on the disturber to prove that they will not affect the environment before a potential disturbance is allowed. Given that there are so few areas free from trawling to use as controls why is not trawling subject to the same legislation as the more spatially restricted effects such as mining and discharges of chemicals to the sea? Is it not time for commercial fishers and fisheries managers to demonstrate that trawling will not have negative effects on the environment prior to exploitation rather than expecting marine ecologists to prove damaging effects?

Finally, using the arguments advocated by Løkkeberg, fisheries have never been managed in a scientific fashion since there have never been comparisons made with controlled areas that were not fished!

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