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**Insufficient understanding of benthic impacts of trawling is due to methodological deficiencies – A reply to Gray et al. (2006)**

The impacts of towed fishing gears on benthic habitats and species have been investigated in a large number of studies. However, individual empirical studies that are designed to test the effects of trawling have yielded inconsistent findings (Kaiser et al., 2006). The ICES Advisory Committee on Ecosystems concludes that the scientific information presently available is not adequate to evaluate the impact of current fishing practices on sensitive habitats (ICES, 2002), and Kaiser et al. (2006) state that reviews of the available literature are open to interpretation and distortion by user groups. As a result, the conclusions drawn from these studies are highly contradictory. On the one hand, Kaiser et al. (2000a) stated that it would be difficult to date to attribute benthic community changes to fishing effort at a spatial scale that is representative of commercial fishing activities. On the other, Watling and Norse (1998) suggested that trawling disrupts the structure of benthic habitats from high latitudes to the tropics in ever-deeper waters and that it represents the greatest anthropogenic threats to the marine environment.

Thus it is not surprising that differences in views on the issue of trawl impacts exist between NGOs and fishermen, as this is often the case with extractive industries. However, disagreement is also found in the scientific peer-reviewed literature, as indicated by the quotations above. In a review of the effects of fishing on marine ecosystems, Jennings and Kaiser (1998) raise the concern that scientists lack a good framework for testing interactions in the marine environment and that they are now claiming that fishing has wider and deleterious impacts on ecosystem function because they intuitively believe this to be the case, rather than because they can convincingly demonstrate an effect. Jennings and Kaiser even suggest that ecologists probably receive more funding if they observe negative effects of fishing rather than obtaining "null" results.

Most reviews of trawl impact studies focus on the findings and interpret the results without taking into account the fact that there are important caveats in the methodologies employed in many of the experimental studies reported to date (Watling and Norse, 1998; Auster and Langton, 1999; Hall, 1999; Collie et al., 2000a). A review by Løkkeborg (2005) presents a critical evaluation of the methodologies applied in trawl impact studies. It concludes that important caveats and limitations are found in many experimental designs, and that the results obtained therefore ought to be interpreted with caution. However, in spite of these deficiencies, the review states that bottom trawling has a considerable effect on habitats dominated by large erect sessile fauna (e.g., corals and sponges) and that several studies provide clear evidence of short-term effects of beam trawling and scallop dredging.

In a viewpoint, Gray et al. (2006) examine Løkkeborg's review and claim that many of his conclusions and statements are wrong or at least arguable. In general, the viewpoints and assertions of Gray et al. are poorly supported and verified through references to the peer-reviewed literature. For example, in support of their general statement, "*comprehensive reviews…lead to the overwhelming conclusion that trawling has had negative effects on benthic habitats*", they refer to two websites and to Kaiser et al. (2006), who concluded that the effects of trawling are strongly habitat-specific and dependent on the type of fishing gear employed.

Gray et al. (2006) seem to ignore the caveats and difficulties associated with impact studies when they advocate that sampling and monitoring benthic assemblages are unproblematic processes. Without giving examples or citing relevant studies they state that benthic assemblages are the most widely and successfully systems used globally for monitoring the impacts of contaminants, eutrophication and other man-made disturbances. Whether or not this is the case, it does not mean that these systems are also appropriate indicators of the impact of trawling operations. It is like saying that because air pollution can be measured through the effects on terrestrial systems such as a forest, these systems can also be used to monitor impacts of road construction. There are several reasons why trawl impacts are more difficult to monitor than those of pollution and eutrophication, e.g., the "treatment" meted out by fishing is not applied uniformly in space and time (Rice, 2000).

Løkkeborg's conclusions are supported by several authors, who also state that evaluation of the ecosystem effects of fishing activities is associated with important methodological caveats such as quantitative sampling, which metric to use, statistical testing and determining causality (i.e., unambiguously linking changes in community metrics to fishing activities) (Holme and McIntyre,

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1984; Stewart-Oaten et al., 1986; Underwood, 1992; Bergman and van Santbrink, 1994; Jennings and Kaiser, 1998; Lindegarth et al., 2000a; Rice, 2000). The most serious shortcoming of impact studies may be the confounding of effects owing to lack of replicate control sites (Løkkeborg, 2005). Control sites unaffected by fishing are an essential prerequisite for understanding the effects of fishing on marine systems (Jennings and Kaiser, 1998). This problem is thoroughly discussed by Lindegarth et al. (2000a), who concluded that inadequate replication has potentially large consequences on the interpretations of impact studies. Gray et al. (2006) state that there is a vast literature (but once again, no references are given) across a wide range of sciences that demonstrates that the use of replicate control sites is not the only way to infer cause and effect. However, they do not discuss why these alternative methods have not been employed by impact studies that lack unfished control sites.

Benthic habitats provide refuge and food sources for associated populations of fish and crustaceans, and the main concern regarding the impacts of towed fishing gears involves how changes to benthic community structure may affect exploited marine resources. Accordingly, many impact studies have sampled and investigated potential effects on megafauna and large macrofauna, e.g., the studies carried out on the Grand Banks of Newfoundland (Prena et al., 1999; Kenchington et al., 2001) and in the Swedish Gullmarsfjord (Hansson et al., 2000; Lindegarth et al., 2000b), which are two of the most comprehensive and well-designed impact studies that have been carried out to date. Gray et al. (2006) criticize the latter study because only the large macrofauna was sampled, and state, "*Thus these papers from which Løkkeborg draws his conclusions missed most of the benthic community!*" Large animals and sessile epibenthic species are the groups most likely to be vulnerable to trawling (Jennings and Kaiser, 1998; Hansson et al., 2000), and many impact studies use sampling tools (e.g., camera, dredge, beam trawl) that sample only the larger animals (Collie et al., 1997, 2000b; Freese et al., 1999; Hall-Spencer et al., 1999; Kaiser et al., 2000a,b; McConnaughey et al., 2000; Moran and Stephenson, 2000; Jennings et al., 2001). Here, Gray et al. (2006) also wrongly state that Løkkeborg (2005) "*so strongly relied on*" the Gullmarsfjord experiment. The conclusions drawn by Løkkeborg rely on a thorough review of numerous studies.

Løkkeborg (2005) and Gray et al. (2006) agree that the most serious and clear effects of trawling are seen in habitats dominated by corals and sponges. To support their statement, Gray et al. refer to a survey carried out on the Tromsøflaket (off northern Norway) by the Institute of Marine Research (Bergen) in 2006. They wrongly claim, without citing their source, that by the use of multibeam this survey "*shows that almost all of the rich sponge communities have been destroyed by trawling*". Trawl tracks were often observed along the video-transects of the area surveyed (multibeam was not used). However, possible effects on the fauna have not yet been analysed and no results regarding damage to sponges have been reported from this survey (P.B. Mortensen and L. Buhl-Mortensen, personal communication). Citing findings without reference to their sources, not to mention misquoting the results are not consistent with academic principles and scientific ethics.

Gray et al. (2006) discuss Type I and II errors and use the wording, "*a fundamental problem with this FAO report*" in referring to the way that Løkkeborg (2005) handles this statistical issue. However, the examples given do not support their criticism of the report. Here Gray et al. are simply confusing the terms "Type I statistical error" and "cause-and-effect fallacy", as their examples are related to confusing cause and effect, which correctly is a common problem associated with several impact studies owing to lack of true replicate control sites. Furthermore, Løkkeborg does not imply that there are no disturbances if an effect of trawling is not demonstrated, as Gray et al. also wrongly claim. The report repeatedly emphasizes (in the Abstract, Introduction and Discussion) that disturbances caused by trawling may be difficult to demonstrate due to the masking of more dominant natural factors, and thus does pay attention to Type II errors.

The last sentence in Gray et al. (2006) states that "*there have never been comparisons made with controlled areas that were not fished!*" This of course is wrong. Several studies have compared controlled and fished areas (e.g., Tuck et al., 1998; Prena et al., 1999; Hansson et al., 2000; Kutti et al., 2005), and Fig. 8 in Løkkeborg (2005) shows that more than 50% of the impact studies reviewed used unfished areas as controls.

In conclusion, Gray et al. (2006) misinterpret the review by Løkkeborg (2005) and put forward several selective quotations and statements that are not in the report. In their abstract they state that the report concludes "*that no firm conclusion as to the effects of fishing disturbance can be made*", whereas the review actually concludes that bottom trawling has a considerable effect on habitats dominated by large erect sessile fauna. Furthermore, Gray et al. state that "*subtle treatment effects can be discerned*" by studying benthic assemblages, and indicate that evidence demonstrating negative effects of trawling is overwhelming. However, because empirical studies designed to test impacts of trawling have yielded inconsistent findings, and reviews of this literature are open to interpretation and distortion, their utility for marine environmental policy makers at present is limited (Kaiser et al., 2006). More seriously, if claims about the impacts of fishing are subsequently shown to be in error, then there is a danger that the role of scientists in offering management advice will be further discredited (Jennings and Kaiser, 1998).

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