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The Suitability of Electrode Measurements for Assessment of Benthic Organic Impact and Their use in a Management System for Marine Fish Farms

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Abstract A management system for marine fish farms in Norway has recommended the use of simple electrode measurements of redox potentials (E_h) and pH in sediments for monitoring of environmental effects at net cage locations. In the present paper we present results of such measurements performed over 15 years at farm locations in coastal Norway. Together with other chemical analyses of sediment and pore water, the electrode measurements provided a suite of biogeochemical variables used for environmental state assessment. The impact of external control factors such as biomass, local bathymetry and current velocities on the benthic effect parameters was investigated and comparisons

were made with alternative effect variables such as macrofaunal community structure. It was found that simple two-dimensional plots of pH vs. either E_h or pS ($= -\log[\Sigma H_2S]$) maintained a high degree of discrimination between stations located at different distances from farm locations and provided a state assessment with high relevance to farm management. Compared to other methods, electrode measurements are cost-effective, applicable on a wide variety of benthic substrates and provide superior resolution in the high end of the organic enrichment gradient.

Keywords Electrode measurements · Fish farm · Marine sediment · Monitoring methods · Organic enrichment

1 Introduction

Fish production in net cages in the coastal environment has the potential to affect natural environments primarily through spreading of organic matter and nutrients from fish excretions and excess feed [1–3]. The area affected will depend on several factors related to farm management and site characteristics such as water depth, current speeds and bottom topography. Severe accumulation of organic matter is frequently confined to the area below the cages or a few meters beyond the vertical projection of the cage perimeter [2, 4–6]. More wide spread effects have been observed around farms located in recipients with restricted deep water renewal due to seasonal proliferation of oxygen-deficient water masses [7] and also in exposed environments in which stronger currents and storm-generated resuspension increase the horizontal transport of discharged particles [8–10]. Field experiments and several investigations of seabed recovery after production has been terminated have shown a large degree of normalization of effect variables within weeks to months [8, 11–13] although more than 2 years may be required for complete recovery [14, 15].

The changes occurring in sediments heavily loaded with farm debris generally follow the classical description of the organic enrichment gradient [16] and involve changes in bacterial communities and degradation pathways [17, 18]. Biodegradation of labile organic fractions has resulted in up to a fifty-fold increase in the rate of sediment oxygen consumption and release of nitrogen and phosphorous nutrients relative to the surrounding seabed [5, 19, 20]. Oxygen penetration is generally poor in marine sediments [21] and the combination of a favourable substrate for heterotrophic bacteria and insufficient oxygen supply leads to extensive sulphate reduction [7, 8, 22], increased concentration of hydrogen sulphide in the pore water and a rapid decline in redox potential in the top layer of the sediments [23–25]. Simultaneously the composition of the higher biological communities will be altered [4, 26–29]. High densities of opportunistic species have frequently been observed in the vicinity of fish farms [9, 12, 15, 30]. This