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Effects of aquaculture fallowing on the recovery of macrofauna communities

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ABSTRACT

The fallowing period is a management measure in aquaculture where the production is paused for a few months to reduce the impact on the benthic environment. We studied the effects of different fallowing periods on the recovery of macrofauna at two salmon farms in Norway. The macrofauna at the farm stations were characterised by high abundances of opportunistic taxa (e.g. *Capitella* spp.), low diversity and significantly different community structure compared to reference sites. The fallowing initiated macrofauna recovery at both farm stations, indicated by a decline of dominant opportunistic taxa after 2 months. Significant changes in taxa composition occurred only after 6 months, although indications of disturbance were still evident. Surprisingly, no corresponding spatial or temporal differences were found in the sediment parameters such as redox, TOC and pH. The results suggest that macrofauna is a more sensitive indicator and that the seasonal timing of fallowing may affect recovery dynamics.

1. Introduction

Atlantic salmon (*Salmo salar* L.) is the predominant culture species in temperate marine waters and its use in aquaculture has expanded significantly over the last few decades especially in northern Europe (Black et al., 2008; FAO, 2014). In Norway, salmon production is the most important aquaculture sector, accounting for more than 80% of the total aquaculture production (FAO, 2014). The on-growing phase of salmon takes place almost exclusively in open sea cages, releasing large amounts of organic matter into the surrounding environment in form of nutrients, faeces and waste feed (Pereira et al., 2004; Lee et al., 2006; Kutti et al., 2007; Huang et al., 2012). This organic enrichment can result in changes of the benthic sediment chemistry and macrofauna communities, primarily in the direct vicinity of the farms (Pereira et al., 2004; Obee, 2009; Boyra et al., 2004; Pohle et al., 2001), which has been studied on different spatial and temporal scales (e.g. Karakassis et al., 1999; Kraufvelin et al., 2001; Lee et al., 2006; Brooks et al., 2003; Pohle et al., 2001). Measurements of physicochemical parameters of sediments, such as redox potential (Eh), pH and total organic carbon (TOC), are often applied as a main tool to monitor sediment degradation (Macleod et al., 2006; Black et al., 2008). However, macrofauna community structure is considered as one of the most powerful indicators of organic pollution (Carroll et al., 2003; Pereira et al., 2004; Lee et al., 2006).

Periodic abatement of sites between farming cycles (fallowing) is frequently used in order to reduce the effects of fish farming on the benthic environment and to avoid adverse effects on farmed stocks (Black et al., 2008; Carroll et al., 2003). In Norway, salmon farms are usually operated on a 2-year production with a 6–8 week fallowing period (Black et al., 2008). The fallowing period can be sufficient to prevent progressive deterioration of the sediments and, thereby, supporting long-term farming operation (Macleod et al., 2006; Black et al., 2008; Aguado-Giménez et al., 2012). However, the usual fallowing periods may not be sufficient for a complete recovery of the benthic system. Recovery is here defined as the return to conditions similar to that in adjacent undisturbed sediments or the return to the stage as it was before farming operation (Aguado-Giménez et al., 2012; Keeley et al., 2014). The rate and degree of recovery depend on the extent of the impact (the amount of organic matter released and the time-scale over which the release took place), hydrological characteristics of the area, the sediment type and, in case of fallowing, on the duration of fallowing (Macleod et al., 2006; Brooks et al., 2004; Norkko et al., 2006). The recovery of macrofauna, especially in response to organic enrichment, often follows the empirical succession model of Pearson and Rosenberg (1978), where the macrofauna progresses from a low-diversity community dominated by opportunistic species to a more diverse community with stable abundances of deep burrowing species. Additionally, macrofauna composition and seasonal population dynamics (e.g. dispersal rate,

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reproduction mode, recruitment) may also further influence the physicochemical recovery processes (Macleod et al., 2006; Aguado-Giménez et al., 2012).

Although numerous studies have described the general changes in benthic community structure in response to organic enrichment and sea-cage farming, the response of macrofauna to a pause in fish production is not well known (Macleod et al., 2006; Aguado-Giménez et al., 2012). Only few studies have assessed recovery of benthos after fish farm fallowing, of which most were based on comparisons of a single farm with a single reference site (e.g. Karakassis et al., 1999; Macleod et al., 2006; Aguado-Giménez et al., 2012; Brooks et al., 2004, 2003). The majority of studies showed that full recovery of benthic communities may take up to several years (e.g. Karakassis et al., 1999; Pereira et al., 2004; Macleod et al., 2006; Aguado-Giménez et al., 2012; Keeley et al., 2014; Brooks et al., 2004), whereas comparatively short recovery times of macrofauna were reported by Ritz et al. (1989) (7 weeks) and Brooks et al. (2003) (6 months). In order to use fallowing practice as an effective management measure, not only to allow recovery of the physicochemical parameters of the environment, but also to reduce the impact on the benthic fauna, the effects of fallowing on the macrofaunal communities need to be better understood. Therefore, we studied the changes of macrofauna communities in response to different fallowing start times and periods at sea-cage fish farms in Northern Norway. Environmental and biological characteristics were measured at two fish farms with different start times and fallowing durations. We addressed the following objectives: (1) assess the short-term recovery dynamics of macrofauna in response to different start times and fallowing durations and (2) compare the macrofaunal communities at the fish farms to the communities in intermediate and far distance to the farms.

2. Materials and methods

2.1. Study area

The studied salmon farms were established in 1993 at Nord Arnøy, Northern Norway (Fig. 1). Both fish farms were located relatively close to each other (approximately 900 m) in an environment with moderate bottom currents (3–4 cm/s) that provide good recipient capacity and spreading power (Table 1). Both farms were at the end of their production cycle. The fish farm Hestholmen (station HE) was located on a slope with increasing depths from 55 to 165 m. The production cycle at Hestholmen started in July 2010 and finished in March 2012 (5 weeks prior to the first sampling survey). The fish farm Arnøysundet (station AR) was located above a sloping terrain with a depth range from 47 to 86 m and close to a deep-water channel. The production cycle at Arnøysundet started in October 2010 and finished in July 2012 (5 days before the second sampling survey). Both farms were not re-stocked until the end of the sampling campaign in September 2012.

Each farm comprised eight cages (25 × 28 m at Arnøysundet; 90 m diameter at Hestholmen). The production of fish was approximately 1655 t at Arnøysundet and 1656 t at Hestholmen sites. Fish were fed using identical diet with an average nutrient content of 34–38% protein, 32–34% fat, 4% carbohydrate, 6% ash and 0.9% phosphorus.

2.2. Sampling and sample processing

The sampling surveys were conducted at four stations (Fig. 1): close (approximately 20 m distance) to the fish farms Hestholmen (station HE) and Arnøysundet (station AR), in intermediate distance (400–500 m) to both farms (station IM), and in distance of 1.5 km (HE) and 2.1 km (AR) (station CO). See Table 2 for exact locations and sampling depths. All stations were sampled in April, July and September 2012 with three replicates at each station. The sampling design could not exactly be aligned with the production cycle of the farms, thus station HE was first sampled after the following period had begun.

Macrofauna samples were taken with a 0.1 m^2 Van Veen grab. Samples were sieved through a 1 mm screen and preserved in 4% formaldehyde buffered with Borax. In the laboratory, the macrofauna samples were stained with Rose Bengal, sorted and transferred to 70% ethanol. All macrofauna organisms were counted after determination of family or higher taxonomical level, while polychaetes were identified to species level if possible. We focused species determination on polychaetes because they were the most abundant and diverse group and are regularly used as indicator species in aquaculture monitoring. Taxa belonging to meiofauna were excluded from further analyses.

Physicochemical parameters of the sediment (pH, Eh) were measured by opening the hatch in the Van Veen grab and by placing electrodes in the upper 1–2 cm of the sediment. pH was measured with a WTW pH-electrode Sen Tix 41 and redox potential (Eh) was measured with a Schott Platinum Electrode BlueLine 31 RX. For determining the total organic carbon (TOC) and grain size composition, subsamples of the upper 2 cm of the sediment were taken from the grab samples and frozen at −20 °C. For determination of the TOC content, the sediment samples were homogenised and inorganic carbon was removed by the addition of a mineral acid. Samples were dried at 105 °C and organic carbon was measured by colorimetry based on ISO 10694 and modified following EN 13137/A. The sediment grain size composition was determined using sieve analysis and laser diffraction (for the grain size classes 0.002–0.063 mm) based on ISO 10694. TOC and grain size distribution analyses were done by the ALS Laboratory Group (Norway AS, Oslo). TOC, pH and Eh were measured each sampling date at each station, while the grain size composition was only determined for the samples of April at all stations.

2.3. Statistical analyses

Total macrofauna abundance, number of taxa, Shannon diversity index (H'), and Pielou's evenness index (J') were used as univariate attributes of the macrofauna communities. Abundances and the taxa numbers refer to the sample size of 0.1 m^2. All univariate analyses were conducted using R version 2.15.3 (R Development Core Team, 2013).

Factorial analyses of variance (ANOVAs) were conducted to test the effect of station (four levels: CO, IM, HE, AR) and month (three levels: April, July, September) on the total abundance and number of taxa. Both station and month represented fixed factors. Month was included as a fixed factor because sampling months were not random but chosen to capture the effects of seasonality. Prior to analyses, the assumptions for ANOVA were tested with the Shapiro–Wilk test (for normality) and the Fligner-Killeen test (for homogeneity of variances). Tukey's HSD (honestly significant difference) test was used to identify means that significantly differed from each other, where ANOVA results were significant (Crawley, 2007).

Both Shannon diversity index (H') and Pielou's evenness index (J') distributions displayed highly heterogeneous variances and were therefore analysed using Generalised Least Squares models (GLS) (Zuur, 2009). GLS models were performed using the function 'gls' from the nlme-package (Pinheiro et al., 2013) following the guidelines given by Zuur (2009). First, the full model including both fixed factors and their interaction was formulated. Then, a specific 'weights' argument was added to correct for heterogeneity

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