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Short communication

The cleaning efficacy of lumpfish (*Cyclopterus lumpus* L.) in Faroese salmon (*Salmo salar* L.) farming pens in relation to lumpfish size and seasonality

Kirstin Eliasen[a,*], Eirikur Danielsen[a], Ása Johannesen[a], Lisbeth L. Joensen[b], Esbern J. Patursson[c]

[a] Fiskaaling, Við Áir 11, 430 Hvalvík, Faroe Islands
[b] Bakkafost, Bakkavegur 8, 625 Glyvrar, Faroe Islands
[c] Hiddenfjord, Við Ánna 1, 512 Norðragøta, Faroe Islands

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ABSTRACT

Sea lice infestations causes major economic losses in the Atlantic salmon aquaculture industry, and cleaner fish, e.g. the lumpfish, *Cyclopterus lumpus* L., are therefore increasingly deployed as a biological control method. However, large variations in the cleaning efficacy have been observed, and in the Faroe Islands, the most prominent variation is seasonal. Over a period of approximately two years 5511 lumpfish stomachs were analysed. The stomach contents, where present, were identified and grouped as, a) sea lice, b) lumpfish feed, c) salmon feed, d) organisms associated with biofouling, e) zooplankton organisms and/or f) other. The presence of zooplankton organisms had a significant, and negative, influence on the cleaning efficacy, while the presence of organisms associated with biofouling had a more moderate, but positive, influence on the prevalence of sea lice in the lumpfish diet. Our findings indicate that biofouling, and the subsequent availability of alternative prey organisms, does not reduce the cleaning efficacy of lumpfish, while zooplankton does, i.e. reducing it by a factor of approximately five. The lumpfish size only seemed to play a minor role in the variation observed in the cleaning efficacy, while it had a significant influence on the proportion of empty stomachs, i.e. the smaller lumpfish (< 50 g) had the highest occurrence of empty stomachs.

This is convenient knowledge for implementation in the sea lice strategies of farming sites using lumpfish as cleaner fish in general, but especially in farming areas with large seasonal variations in the zooplankton abundance such as in the Faroes. The high occurrence of empty stomachs in small lumpfish highlights the necessity to adapt husbandry in the first period post lumpfish deployment, especially when the opportunity for naturally occurring food is sparse. Furthermore, our findings of biofouling having a positive influence on the grazing efficacy of lumpfish indicate that net cleaning might have a negative influence on lumpfish grazing efficacy.

1. Introduction

Sea lice have been a serious problem for the Atlantic salmon farming industry since the 1970s (Brandal and Egidius, 1977), and its economic impact is greater than that of any other parasite (Costello, 2009). The increased occurrence of resistance against medical treatments for sea lice has called for alternative and non-pharmaceutical methods (Browman et al., 2004; Dempster et al., 2011; Flamarique et al., 2009; Treasurer et al., 2002), and consequently the use of cleaner fish has emerged to be a robust method for controlling sea lice (Torrissen et al., 2013).

Several fish species have been identified as cleaners, particularly among the wrasses (Feder, 1966; Skiftesvik et al., 2013). However, the wrasse species currently in use for biological delousing are temperature sensitive, making them unfit for use at low temperatures (Sayer and Reader, 1996). As a cold-water alternative, the common lumpfish (*Cyclopterus lumpus*) can be used (Imsland et al., 2014a).

As of today, lumpfish mainly dominate the production of cleaner fish. The vastly expanding lumpfish production in Norway has increased from around 3.5 million individuals in 2014 to around 15 million in 2016. In 2016, lumpfish represented approximately 45% of the deployed cleaner fish in Norway (Norwegian Directorate of Fisheries, 2017). Due to relatively low temperatures, and the wrasse not being native, lumpfish is the only cleaner fish used in the Faroe Islands.

Despite its relatively small size (~10,000 km^2) the Faroe shelf (62°00′N 06°47′W) contains a distinct neritic ecosystem surrounded by an oceanic environment. The shelf water is relatively well separated from the open ocean by a persistent front that surrounds the shelf

* Corresponding author.
E-mail address: kirstin@fiskaaling.fo (K. Eliasen).

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usually at between 100 and 130 m bottom depth (Gaard et al., 1998; Larsen et al., 2009). Due to strong tidal currents, the water column in the shallow parts of the shelf is mixed from surface to bottom throughout the year and no summer stratification occurs (Gaard, 1996; Gaard et al., 1998). The timing and intensity of the spring bloom on the Faroe shelf can vary considerably from one year to the next, but mainly occurs in the period from April to September (Gaard et al., 2002; Debes et al., 2008).

Lumpfish was for the first time introduced as a cleaner fish in the Faroese salmon farming industry in late 2014. Since then the numbers of farming sites using lumpfish has increased continuously, and of today, approximately half of the Faroese salmon farming sites are using lumpfish as cleaner fish. However, variations in the cleaning efficacy are frequently observed, especially seasonally, and the main aim of current paper is to clarify the influence of zooplankton and biofouling on the cleaning efficacy of lumpfish in the Faroe Islands.

2. Material and methods

2.1. Lumpfish

The lumpfish studied (N_{Total} = 5511) were from nine Faroese Atlantic salmon farming sites using lumpfish as cleaner fish in the period from May 2016 to July 2017. Lumpfish were sampled on 93 different sampling days divided on the nine farming sites. The lumpfish were sampled from the edge of the pen using a dip net. On average ± SE 60 ± 29.2 lumpfish were studied on each sampling date. After sampling from the salmon pens, the lumpfish were euthanized with an overdose of Finquel (Tjaldurs Apotek, Tórshavn, Faroe Islands).

The sampled lumpfish were weighed to the nearest gram. The weight of the lumpfish ranged from nine to 883 g. Due to lumpfish mortalities on site, the smaller sized lumpfish were heavily over-represented (Fig. 1), and had an overall average weight ± SE of 97.9 ± 1.30 g.

2.2. Stomach content analysis

Where present, the stomach content, from oesophagus to pylorus, was identified and grouped as a) sea lice, b) lumpfish feed, c) salmon feed, d) organisms associated with biofouling, e) zooplankton organisms and/or f) other. Sea lice were *Lepeophtheirus salmonis*, *Caligus elongatus* and unspecified chalimus. The organisms associated with biofouling were mainly amphipods, *Caprella* spp., *Tubularia* spp. and seaweed, while the zooplankton organisms mainly were calanoid copepods, crustacean larvae, jellyfish, and fish larvae. “Other” was scale, insects, terrestrial plants, feathers, plastic, etc.

2.3. Statistical analysis

The effect of lumpfish size on likelihood of finding sea lice in the stomachs was analysed using a logistic regression with an untransformed “weight” predictor variable and a binary dependent variable (sea lice found or not). Due to the high variability in the number of sea lice found in the stomachs, and the many factors, which may affect the number of sea lice found, presence of sea lice was used instead of number. There was an outlier in a fish that weighed 545 g (the only fish larger than 361 g that had consumed sea lice), but leverage was negligible and did not affect the results. The analysis was carried out again excluding all fish larger than 200 g as the data is highly skewed with > 80% of all fish weighing < 200 g and the rest weighing between 200 g and 900 g. In this second analysis 680 fish were excluded resulting in 4831 fish. The results were not qualitatively different, so the final analysis includes all the data.

Stomach content was classified into five categories (see methods), and each stomach was coded as 0/1 for each food type and the data were tabulated for the purposes of analysis. A log-linear model was constructed by elimination of terms from a saturated model until no further terms could be eliminated without damaging the model fit. One three-way interaction was removed despite being borderline significant, because there were only two fish that had consumed all three food types, so any error in data collection would severely affect this

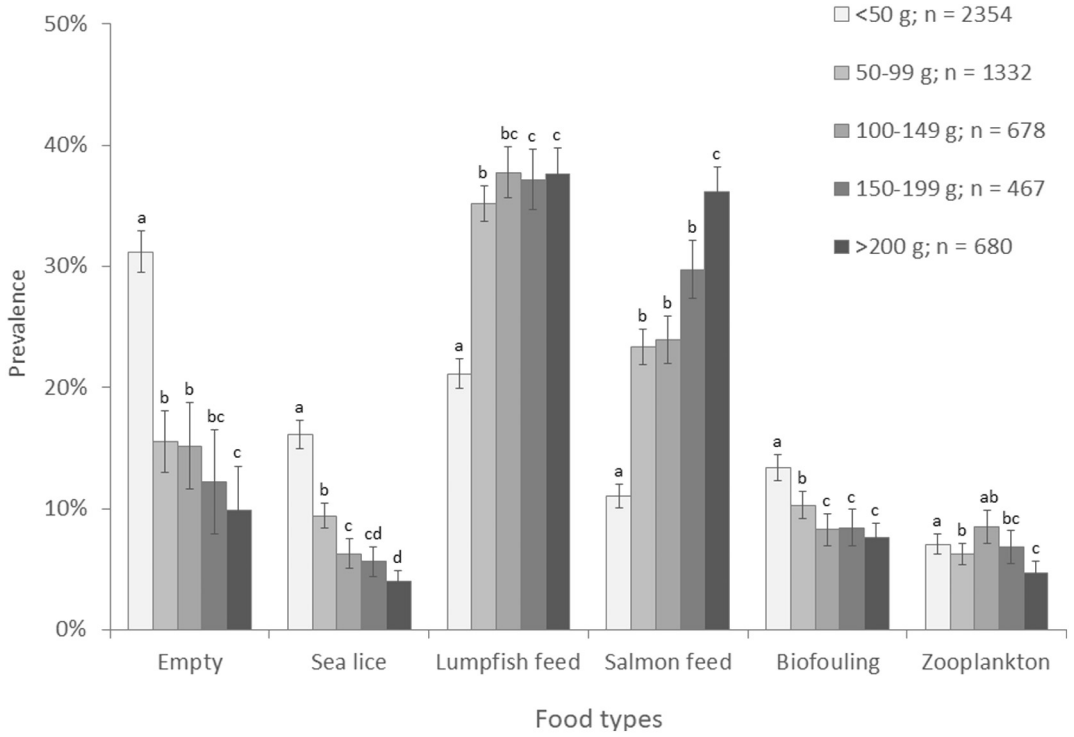

Fig. 1. Percentage values of empty stomachs and food choices for lumpfish at different sizes (g). Values are presented as means ± SE. Different letters indicate significant differences (Wald tests, $P < 0.05$) within the same food category at each size class.