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Feeding sounds of turbot (*Scophthalmus maximus*) and their potential use in the control of food supply in aquaculture
I. Spectrum analysis of the feeding sounds

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Abstract

Turbot generate feeding sounds which vary with food intake intensity. The feeding sound activates a broad frequency band (0–20 kHz). Nevertheless, in frequency range 7–10 kHz, the feeding sounds are little modified by the different noises generated by farming environment (pumps, compressors, . . .) and by farming activities (pellet spreading giving two emission peaks: 0.5–1 and 6 kHz). Within the 7–10 kHz frequency range, the amplitude of the variations in sound pressure level during feeding is 15 to 20 dB. This variation appears sufficient to faithfully reproduce the variation in intensity of fish feeding and to ensure the development of a fish-feeding acoustic detector.

Keywords: Feeding sounds; *Scophthalmus maximus*; fish-feeding acoustic detector

1. Introduction

The variability of food intake by intensively farmed fish (Mallekh et al., 1998) poses problems in adjusting supply to meet food demand without creating excessive waste (Burel et al., 1997). This has created an interest in the study of signals that are directly related to feeding.

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Fish produce sounds in a variety of contexts (Myrberg, 1981), and the emission of sounds during capture and mastication, or the ingestion of prey, appears to occur in several teleostean species. These sounds may arise due to a sudden acceleration of the fish when they seize their prey (40–160 Hz) (Kaparang et al., 1998), may be associated in the splashing at the surface (20–380 Hz) (Phillips, 1989), may result from rapid variations in pressure in the oral cavity when the prey is being sucked in (Muller and Osse, 1984; Lauder, 1985), or may be stridulation sounds (2–20 kHz) caused by the friction between bones or teeth (Bordeau, 1982; Colson et al., 1998).

The feeding sounds of turbot are clearly audible and the aims of this study were to define the acoustic characteristics of these sounds (frequency band excited, signal intensity, . . .), and assess their potential use for the monitoring of feeding intensity of farmed fish.

2. Materials and methods

The feeding sounds of turbot were measured between May and July 1997 at the France–Turbot sea farm, situated on the island of Noirmoutier (France). The recordings were made in 37 m^3 tanks containing small (mean weight < 300 g, $n = 3500$), medium-sized (500–800 g, $n = 2500$) and large (> 1300 g, $n = 1500$) turbot (*Scophthalmus maximus*); recordings were made from three different tanks for each size category of fish. The fish were held under normal farming conditions and were fed by hand with pellets being thrown onto the surface of the water.

The recording system consisted of a hydrophone (Brüel and Kjaer, type 8101) and measuring amplifier (Brüel and Kjaer, type 2610), connected to a Nagra IV-SJ tape recorder (sampling speed: 9.5 cm s^{-1}, ± 1.5 dB; frequency response of the whole recording system: 25–10 000 Hz). The system was calibrated using a Brüel and Kjaer calibrator (type 4223). The sound pressure level produced in the 8101-coupler volume is 157 dB ref 1 μPa at a frequency of 250 Hz.

Sound measurements were made in two phases. Firstly, a 2-min recording of background noise in the tank was made just prior to the start of feeding. This provided a reference for the sound level generated routinely in the farm (pumps, compressors, water overflow, etc. . . .). A second recording was then made during feed provision (< 5 min). In addition to the background noise recorded in phase 1, there was also the sound of the pellets hitting the surface of the water, of the fish swimming to the surface, and of the ingestion of pellets.

The recordings were stored on magnetic tapes, and then processed on an fast Fourier transform (FFT) analyser (Tektronix 2622) using IP software for an analysis of the time signal and a narrow-band spectrum analysis. Narrow-band frequency spectra were obtained by a 2048-point FFT analysis and the average calculated from 70 samples.

The sound caused by the pellets hitting the water was recorded for the two sizes of pellet that were used for feeding small and large turbot to include all the activated frequencies. These measurements concern the 4-s period from when the pellets were first thrown onto the water until the moment when the fish began to feed.

3. Results

3.1. Description of the feeding sounds

The feeding sounds are transitory signals formed by a series of impulses of variable length no longer than a few milliseconds in duration (Fig. 1). These very short impulses are of much greater amplitude than the background noise. They were perfectly audible as a high-pitched crackling, which was clearly different from the background noise and from the sound of the pellets hitting the water.

The number of these impulses per time interval depends mainly on the rate at which the pellets are thrown and the appetite of the fish.

Figs. 2–4 show the narrow-band spectra during feeding in the three size (large, medium, small) groups of turbot at different times after the start of feeding. The sound level of the background noise was high in the low frequency range then quickly fell from approximately 90–100 dB ref 1 μPa at ca. 1 kHz to 70–75 dB ref 1 μPa at 3–4 kHz. Above 7 kHz, the sound level of the signal was generally no higher than 65 dB ref 1 μPa.

Within the 0–3 kHz frequency range, the sound of fish feeding could not be separated from the background noise, but above 5 kHz, it could be clearly distinguished from the background noise with a signal-to-noise ratio (difference between the sound pressure level of the feeding sound and that of the background noise) greater than 10 dB within the 6–10 kHz frequency range. It was also observed that the spectrum of the feeding sound tended to become less distinct from the background noise as feeding progressed, and after 150 s, the feeding sound spectrum became indistinguishable from that of the background noise. A comparison of the spectra obtained for the different sizes of fish revealed some differences. The feeding spectrum observed between 10 and 16 s after the small turbot started feeding was distinct from those obtained later (Fig. 2). This might suggest that the first 30 s corresponded to a period when the presence of the pellets stimulated an intense feeding activity involving a large number of fish. This

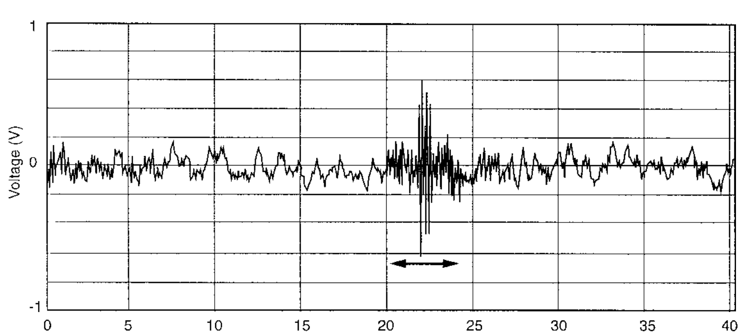

Fig. 1. Oscillogram of sound emission associated with turbot feeding. The sound is produced as a pellet is sucked into the fish's mouth. The arrows represent the duration of one feeding sound.

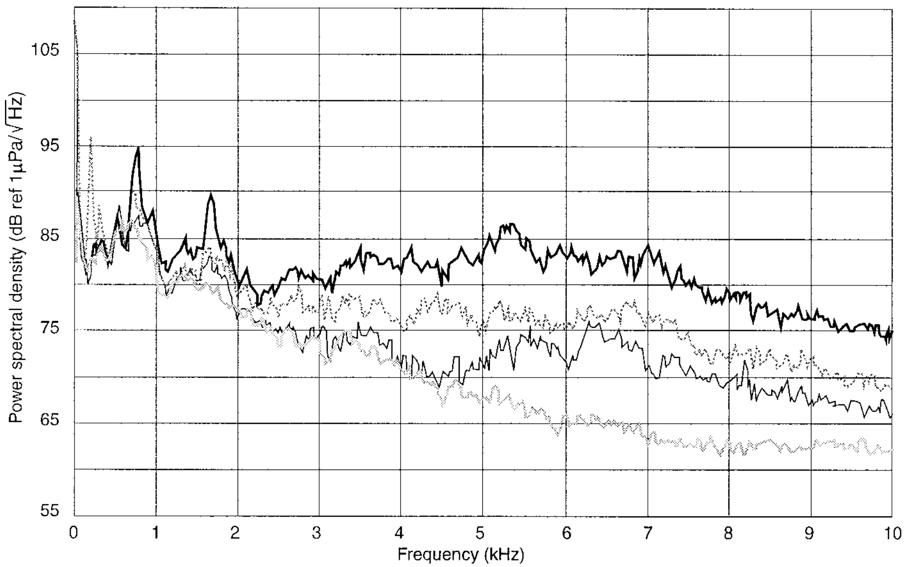

Fig. 2. Feeding sound spectra of small turbot individuals (average weight < 300 g) compared to the background noise in the farming tank environment (......). Averaged spectra for 10 s after the start of feeding (——), 30 s (∞∞∞) and 60 s (———).

period of strong feeding activity could last more than 1 min. The sound level reached 80–85 dB ref 1 μPa between 6 and 9 kHz, with a signal-to-noise ratio of 15–20 dB. The

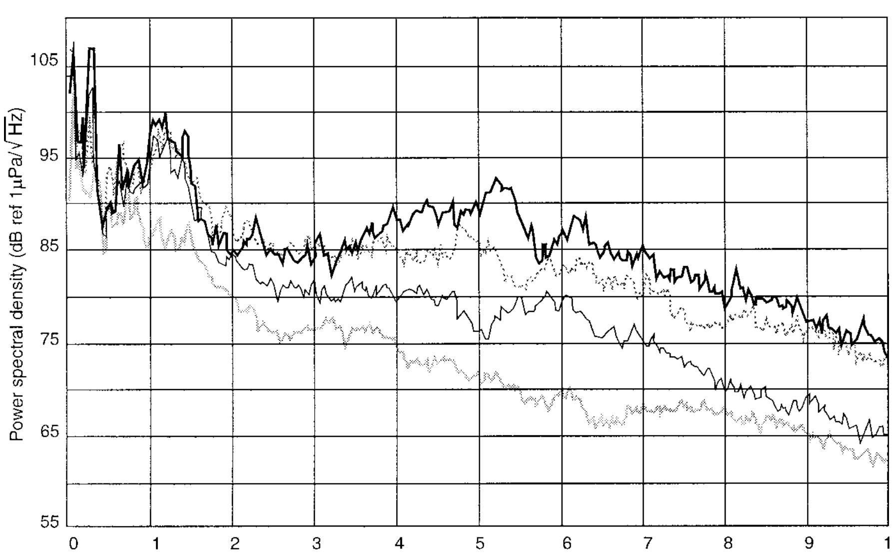

Fig. 3. Feeding sound spectra of medium-sized turbot individuals (500–800 g) compared to the background noise in the farming tank environment (......). Averaged spectra for 10 s after the start of feeding (——), 30 s (∞∞∞) and 60 s (———).

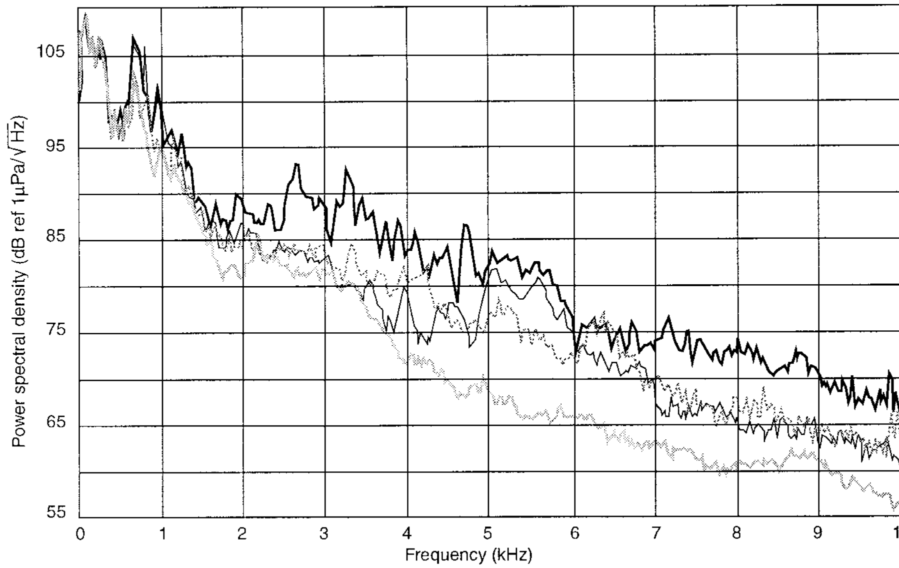

Fig. 4. Feeding sound spectra of large turbot individuals (> 1300 g) compared to the background noise in the farming tank environment (. . . . . .). Averaged spectra for 10 s after start of feeding (——), 30 s (∞∞∞) and 60 s (——).

feeding sounds recorded for the medium-sized fish were comparable to those of the small turbot. However, the excitation period from the start of feeding is shorter. The

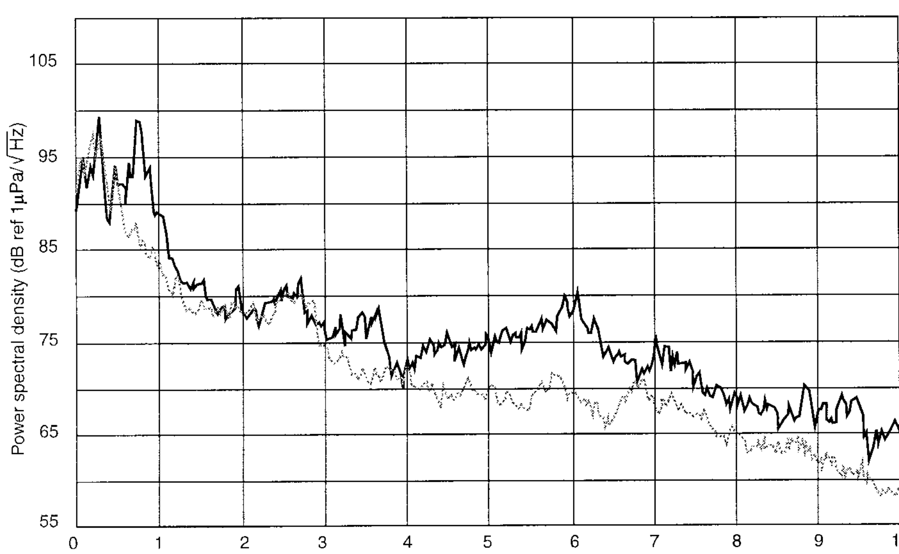

Fig. 5. Spectral analysis of the small food-pellet hitting the water (——), representing an average calculated over 4 s following the start of feeding. The dotted line spectrum (∞∞∞) represents the level of background noise before feeding.

sound level reached 80–85 dB ref 1 μPa in the 6–9 kHz frequency band, but the signal-to-noise ratio did not exceed 15 dB (Fig. 3). Feeding sound spectra of large turbot involved fewer fluctuations in the level of sound (Fig. 4). The sound level reached 75–80 dB ref 1 μPa above 5 kHz, and the signal-to-noise ratio never exceeded 15 dB.

3.2. Description of the pellet sounds

To cover all the noises radiated by the food-pellet impact on the water surface, we have chosen to use only the smallest (∅ 5 mm) and the largest (∅ 11 mm) pellets distributed by the fish farmer in accordance with the fish size.

The frequencies concerned when the food pellets were thrown at the start of feeding were revealed by superposing the average feeding spectrum of the first 4 s of feeding on the spectrum of the background noise for both sizes of pellets used (Fig. 5). The difference in pellet size does not significantly change the radiated-noise spectra over a wide frequency range. For both sizes, the spectra revealed a first peak of between 500 and 1000 Hz, and a second, smaller peak of around 6 kHz. Above 7 kHz, the contribution of the falling pellet noise on the background noise was of the order of a few decibels. Therefore, the frequency band in which feeding activity could be clearly heard with a minimum of interference of the other noises lay between 7 and 10 kHz.

4. Discussion

The sounds that accompany fish feeding are of diverse origin and, in the case of turbot, have an acoustic energy distribution over a wide frequency band. Apart from the sounds resulting from accelerated swimming, which always lie within a frequency band below 1 kHz (Moulton, 1960), these may have two possible origins. The first possibility is that they are produced by a stridulation resulting from the movements of the buccal bones. The second is that they are produced by the abrupt variations in pressure within the buccal cavity that accompany ingestion (Muller and Osse, 1984; Bergert and Wainwright, 1997).

Concerning stridulation, the main characteristic of this kind of sound is that it is made up of a series of harmonics around a fundamental frequency. A certain amount of acoustic energy is given off at high frequencies of 6–9 kHz (Fish and Mowbray, 1970).

The narrow band spectra of frequencies associated with turbot feeding sounds have neither a fundamental frequency nor harmonic structure and in fact involve a broad frequency range (0 → 10 kHz). The sound is similar to a white noise and has certain similarities to an abrupt change in pressure. When the mouth is opened to capture a food pellet, a strong current is created by the abrupt change in pressure in the buccal cavity. This current sucks the pellet in and also sets off vibrations of the branchial-arches and gill-covers. All these hydrodynamic or vibrating noises contribute to give the characteristics of turbot feeding sounds. The number of these sources of feeding sounds is all the greater when the fish are small, and thus, more numerous per tank. In addition, the smaller the pellet size, the more pellets there are in each handling distribution. As a result, the number of pellets sucked in per time interval is greater in small size turbot and, therefore, their feeding noise reaches a signal-to-noise ratio of 20 dB, compared with 15 dB for large turbot.

The feeding sounds of turbot involve a wide frequency band and, in this respect, are comparable to the feeding sounds produced by rainbow trout (0.02–25 kHz) (Bordeau, 1982; Phillips, 1989), Japanese minnow (1–10 kHz) (Yamaguchi et al., 1975) and many other species (Bordeau, 1982). However, the whole frequency range of feeding sounds cannot be used to detect feeding in industrial farming conditions. It has been established that the farming environment, both industrial and in the laboratory, increases the level of the background noise in the 20–1000 Hz frequency band (Lagardère and Spérandio, 1981; Regnault and Lagardère, 1983; Terhune et al., 1990) and masks all the swimming sounds that can be heard in the natural environment (Fujieda et al., 1993; Karapang et al., 1998). The sound of the pellets hitting the water gives a first emission peak of between 0.5 and 1 kHz, and a second, of around 6 kHz. Therefore, the noise of the equipment used to maintain the quality of the water (pumps, compressors, overflow noises and waterfalls, etc....) and the noise of the pellets hitting the water are major contributors to radiated noise and they are apt to mask a part of the spectrum of feeding sounds in the 0.02–6 kHz frequency range. Consequently, in the conditions of our study, only the frequency band between 7 and 10 kHz is modified very little by noises from the farm environment. During feeding and within this frequency range (7–10 kHz), the variation in the sound level has an amplitude of 15–20 dB, which would appear sufficient to faithfully reproduce the variation in intensity of fish feeding. This is the frequency band that could be used to develop an acoustic feeding detector capable of controlling food distribution in aquaculture.

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