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Demand Food Intake and Growth Performance of Wild Whiting in Captivity

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Abstract: This study elucidates the food intake and growth performance of wild whiting in captivity for 78 days using automatic demand feeding system. Whiting adapted well to using demand feeders. They fed approximately every 29-30 h at 19 °C during August-September and every 23 h at 15 °C in October. In the latter period, peak-feeding activities occurred between "dawn" and "noon" despite continuous 24 h lighting. During this period they ate similar daily amounts of dry weight to that predicted by the voluntarily feeding experiments using natural prey (0.78 %body wet weight (bw) day^{-1}). However growth performance was poor (FCR~4.2), suggesting that digestibility was poor or that holding conditions/stress was diverting energy from the growth processes. Hierarchical dominance among the individual fish might exist among the experimental fish.

Key words: Automatic demand feeder, food intake, growth performance, periodogram analysis

Introduction

There have been studies on longer-term fish feeding patterns- both in the laboratory and later in aquaculture systems- since the early development of demand-feeders for experimental use in fish (Rozin and Mayer, 1961, 1964; Adron, 1972; Adron *et al.*, 1973; Landless, 1976; Grove *et al.*, 1978; Majid, 1982). The basic principle that is widely adopted in laboratory studies is to train fish to obtain food by pressing a lever, biting a coloured tip rod or entering a selected area of the tank to break a light beam or touch a sensor plate. The "touch and reward" technique proved successful in many species of fish and usually requires 3-4 weeks of intensive training for naïve individuals. Trigger devices coupled to computers have been used to record trout demand-feeding activity (Boujard and Leatherland, 1992b; Cuenca and De La Higuera, 1994), including a combination with PIT-tags to record individual feeding behaviour within a group (Brännäs and Alanärä, 1993,1994). Demand-feeding has also been investigated in large groups of trout and Atlantic salmon kept in full-scale farming conditions, in net cages (Alanärä, 1992a), ponds and tanks (Statler, 1982; Tipping *et al.*, 1986) or in marine net pens (Fernoe *et al.*, 1995).

For aquaculture, the deployment of automatic demand feeders has reduced both labour and feed costs, whilst allowing fish to feed *ad-libitum* with reduced feed wastage. Potential disadvantages of this method include the variation in ability of individual fish to adapt the equipment as well as the establishment of hierarchies and territorial behaviour around the feeding points. Not all individuals may be able to feed to satiation (McCarthy *et al.*, 1992). Well documented studies for commercially-important fish species exist for rainbow trout *Oncorhynchus mykiss* (Walbaum) (Grove *et al.*, 1978; Alanärä, 1992a; Boujard and Leatherland, 1992a; Alanärä and Brännäs, 1993; Alanärä, 1994), Arctic charr *Salvelinus alpinus* (Christiansen *et al.*, 1992; Brännäs and Alanärä, 1994), sea bass *Dicentrarchus labrax* (Sanchez-Vazquez *et al.*, 1995; Begout Anras, 1995; Madrid *et al.*, 1997; Sanchez-Vazquez *et al.*, 1997; Azzaydi *et al.*, 1998; Aranda *et al.*, 1999) and Atlantic salmon (Juell, 1991; Juell *et al.*, 1993; Juell and Westerberg, 1993; Juell *et al.*, 1994a,b; Juell, 1995a,b). Investigations have included the influence of time-restriction on demand feeder activation on fish growth (Alanärä, 1992b). There is very little information on longer-term feeding patterns in the whiting. A report by Seyhan *et al.* (1998) compared the dry weight intake of a more natural food (frozen sprat *ca* 75% water, offered continuously) with that for whiting trained to demand pelleted food (5% water) from a newly-designed feeder whose trigger was a narrow beam of infra-red light. The groups of demand-fed fish maintained their daily dry weight intake of pellets (0.8% body wet weight (bw)) when compared with the equivalent intake for fish offered frozen sprat manually (0.85%bw). The former group, when held under a 12L:12D regimen at *ca* 11°C, fed rhythmically every 20-22 h suggesting that appetite returned when average stomach contents had reduced by 60% from a previous meal. These authors did not however report any results for growth of the demand-fed fish.

In this study, further trials were conducted to monitor voluntary food intake and also growth of wild whiting in captivity using an improved demand feeder design, again incorporating an infrared beam as trigger. The objective of this experiment was to study the food intake and growth performance of whiting adapted to feed on artificial diets (dry pelleted food) in captivity over a longer period of time.

Material and Methods

Experimental procedure: An isolated 4000L experimental tank located in a closed, quiet room was used throughout the experiment. Twenty wild whiting were transferred into this tank from a laboratory stock, which were caught locally in the coastal waters around Anglesey in the previous six months. Prior to the start, the fish were trained to demand feed for 3-4 weeks based on the "response and reward" technique using a red-tipped glass rod (Seyhan *et al.*, 1998). The fish were initially deprived of food for 72 h to maximize hunger, the rod was put into the tank and when a fish touched the red tip, a few pellets were offered to the fish. The fish training was continued twice daily until 50-60% of the whiting stocks were judged to be used to the demand feeding. The diet used throughout the experiment was high performance trout diet # 50 (Trouw Aquaculture (UK); 5 mm pellets) (Table 1). The new automated infrared demand-feeding unit was set up, a shorter red-tipped rod was placed into the water between the transmitter and the receiver to attract the fish (Fig. 1). After the training period all fish were anaesthetized in fully aerated seawater containing 0.11-0.3 ml L^{-1} of 2 Phenoxy-ethanol for 5-10 min, removed from the experimental tanks and individually weighed.

Subsequent demand feeding experiments were carried out under continuous (24h) lighting; ambient temperature decreased from 21-13.5 °C over the 78 days of the subsequent experiment (mid-July 1999 to the first week of November 1999). Although the average delivery of pellets for each actuation of the food hopper

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was known, unlike the method of Seyhan *et al.* (1998) the amount of food delivered was checked independently. The initial and final weights of pellets stored in the hopper system were recorded at suitable intervals, usually every two days. The weight differences measured the amount of Subsequent demand feeding experiments were carried out under continuous (24h) lighting; ambient temperature decreased from 21-13.5 °C over the 78 days of the subsequent experiment (mid-July 1999 to the first week of November 1999). Although the average delivery of pellets for each actuation of the food hopper was known, unlike the method of Seyhan *et al.* (1998) the amount of food delivered was checked independently. The initial and final weights of pellets stored in the hopper system were recorded at suitable intervals, usually every two days. The weight differences measured the amount of pellets demanded.

Results for growth of whiting in relation to the amount of food eaten were based on the following formulae recently reviewed by Lazo and Davis, 2000):

- Instantaneous growth rate (G, day^{-1}),

$$G = \frac{Ln\ (w_i/w_o)}{t_i - t_o}$$

where W_i = final weight at time t_i and
W_o = initial weight at time t_o.

- Specific growth rate (SGR, %bw day^{-1})

$$SGR = 100^{*}\ (e^{G}-1)$$

(Houde and Schekter, 1981), where G is growth rate.

- Estimated gross growth efficiency (GGE, %):

$$GGE = 100^{*}\left(\frac{\text{Weight gained}}{\text{Weight of food eaten}}\right)$$

- Food conversion ratio (FCR):

$$FCR = \frac{\text{Food eaten}}{\text{Weight gained}}$$

Table 1: Proximate contents of high performance trout pellets #50 (Trouw Aquaculture U.K)

Diet Ingredient	Percentage of diet (by weight)
Protein	45
Water	8
Oil	21
Carbohydrate and fibre	16
Ash	10
Phosphate	1.1
Digestible energy	18.88KJ/gram of diet

Statistical analysis: Results are reported as mean ± standard error (SE). The individual specific growth rates were found to be normally distributed (Anderson-Darling test; Minitab Inc., 1999). The results from the experimental fish were divided into three groups based on body size, so that the means of specific growth rates and their coefficient of variation (CV) could be calculated and compared. The coefficient of variation (Zar, 1984) was used to examine the variability in specific growth rate for individual fish:

$$CV\ (\%) = \frac{\text{(St. deviation (SGR) x100)}}{\text{Mean (SGR)}}$$

A high coefficient of variation for the SGRs among individuals of a group or between groups may mean that factors, such as hierarchical dominance, affect the process of demanding food. Dominant fish could actuate the trigger more frequently compared to others and/or claim the food. Statistical comparisons of mean specific growth rate were made using Scheffe's multiple comparison test (SPSS Inc., 1999).

Analysis of demand feeding data: Description of method for periodogram analysis was given by Seyhan *et al.* (1998): Analysis of the actuations recorded by the recorder to determine feeding rhythms was carried out by the periodogram analysis method using PERIO software (ver. 1.0) (Institute of Biology, University of Odense, Denmark, 1993). This method is an extension of the earlier method developed by Enright (1965) and later by Williams and Naylor (1978). In this method the number of actuations in each succeeding hour (X_1, X_2, X_3, ...) is scanned for possible rhythms. To test for feeding every f h, the data are arrayed as:

$$X_1\ X_2,\ \ldots\ldots\ldots X_f$$
$$X_{f+1}\ X_{f+2}\ \ldots\ldots\ldots\ldots X_{2f}\ \text{----------------} \qquad (a)$$

From this array (form estimate) the mean (X):

$$\frac{\Sigma X_1 + \Sigma X_2 + \Sigma X_f}{f}\ \text{----------------} \qquad (b)$$

was calculated. Although many statistical techniques can be employed in the analysis of data collected in a time series, the periodogram is particularly well suited to biological data (Williams and Naylor, 1978). Essentially calculations are made of the variance of ΣX_i around X for a stated length of time or period. A function of this variance in the form of standard deviation is then plotted against period length to produce a graphical periodogram. High values of the periodogram statistics occur when the period under test approximates to the periodicity inherent in the raw data.

The original data set is then randomized and a new periodogram statistic calculated for each period tested. The periodogram of the randomized data approximates a straight line and upper and lower 95% confidence limits are produced. Significant periodicity is assumed when the true periodogram statistic for a given period is greater than the upper 95% confidence limit to the randomized data regression line at that point. The periodogram analysis is regarded as a descriptive statistic rather than one giving a very critical significance value.

Results

Estimation of the growth performance of whiting fed on high Performance trout diet # 50 (5 mm pellets): The total amount of pellets consumed by the group of whiting (mean initial wet weight = 155 ± 28g) during the course of the experiment (78 days) was 908g (Table 2, 3), although one of the 10 fish died after 58 days. The amount of diet released from the hopper at each actuation was 2.223 ± 0.072 (SE) g dry wt. (n = 30). Since the total amount of diet consumed was on average 11.641g day^{-1} (Table 2), the mean daily food intake for each fish was found to be 1.20g, corresponding to 0.774% body weight.

During the first 46 days of the experiment, temperature fell slowly from 21 to 18.5 °C and decreased abruptly to *ca* 15.5 °C at the start of October. Total daily intake for the group in this first period averaged only 9.3g day^{-1}. After the sudden temperature decrease and a few days delay (until October 6^{th}) appetite increased dramatically to average 17g day^{-1} despite the loss of one fish on October 18^{th} and a continued decrease of temperature to 14 °C. Table 3 shows the growth performance of individual whiting in the group (n was initially 10) voluntarily demand-feeding on Trouw High Performance trout diet # 50. The observed instantaneous

Table 2: Amount of diet consumed by whiting during the demand-feeding experiment. From 21/08/99-30/09/99 temperature average 19 °C; from 01/10/99-3/11/99 it was 14.8 °C (Average diet consumption/day=11.641g).

Loading Date	Initial Wt. (g)	Retrieval Date	#days Interval	Remaining Weight (dry:-g)	Amount Eaten (dry:-g)
21/08	304.5	27/08	6	230.1	74.4
27/08	206.1	06/09	10	87.5	118.6
6/09	132.2	22/09	16	29.6	102.6
22/09	102.5	30/09	8	31.5	71.0
30/09	88.6	06/10	6	26.3	62.3
6/10	80.1	11/10	5	24.0	56.1
11/10	58.6	14/10	3	2.3	56.3
14/10	70.2	16/10	2	18.0	52.2
16/10	80	18/10	2	26.8	53.2
18/10	76.6	21/10	3	11.6	65.0
21/10	110	25/10	4	55.1	54.9
25/10	149.2	28/10	3	72.0	77.2
28/10	148.6	30/10	2	81.3	67.3
30/10	129.2	03/11	4	78.7	50.5
03/11	108.2	07/11	4	87.2	21.0
Totals			78		908.0

Table 3: Growth performance in a group of 10 whiting during the demand-feeding experiment; ambient temperature ranged between 13.5-21°C.

Fish #	init. wt. (g)	Final wt (g)	Duration (Days)	Av. Daily growth (g)	G day^{-1}x10^{-3}	SGR (%bw day^{-1})
1	92.3	108.3	78	0.22	2.04950	0.20578
2	107.7	117.6	58	0.17	1.51620	0.15279
3	122.0	137.4	78	0.19	1.52404	0.14878
4	123.4	147.8	78	0.32	2.31319	0.23750
5	123.1	151.0	78	0.36	2.61901	0.26329
6	135.8	157.1	78	0.27	1.86794	0.18426
7	151.9	173.9	78	0.28	1.73408	0.17345
8	154.0	183.4	78	0.37	2.23996	0.22144
9	155.2	184.0	78	0.37	2.18232	0.22013
10	168.6	187.8	78	0.24	1.38267	0.13669
Total	1334	1548				
Avg	155				1.94289	0.19449
SE	9				0.13228	0.01325
Wt. Gained (g)	214					
Food eaten(g)	908					
Estimated Gross Growth Efficiency (%)					23.568	
Food Conversion Ratio					4.243	

Table 4: Variation in specific growth rate (SGR) between three size groups (final weight) of whiting.

Size Groups	Wt (g)	SGR (%bw/day)	Mean*	Stdev.	CV(%)
1	108	0.20516			
	118	0.15173	0.1745	0.0375	20.897
2	137	0.15252			
	148	0.23159			
	151	0.26224			
	157	0.18697	0.2083	0.0516	24.768
3	174	0.17356			
	183	0.22425			
	184	0.21847			
	188	0.13836	0.1887	0.0408	21.713

growth rates ranged between 1.366-2.629 x 10^{-3}, with a mean value 1.942±0.418 x 10^{-3} day^{-1} and specific growth rates ranged between 0.137-0.263, with a mean value of 0.194±0.042% wet body weight day^{-1}. The accumulated weight gained among the 10 whiting was 214g.

Based on the amount of weight gained for the total amount of food eaten, the estimated gross growth efficiency was 23.6%. The overall food conversion ratio was 4.243, which implied that the whiting, when fed with high performance trout diets, might not be suitable for aquaculture. However, since food intake increased dramatically after temperature fell below 16 °C, it is probable that whiting FCR values under optimum conditions may be lower than this. The FCR value recommended suitable for aquaculture should be lower, between 1-1.5.

There were no significant differences in specific growth rates among the three size groups ($P > 0.05$, Table 4). A higher relative coefficient of variation for specific growth rate was found in whiting within size group 2 in comparison to the other two size groups although the differences were small.

Periodogram analysis of demand feeding data: It took 4 - 5 weeks for the whiting to learn how to break the infrared beam to demand food. During the early stages of learning, development of hierarchical dominance was observed among the fish. However, at times when one fish broke the infrared beam, other fish took advantage by competing for the available food. The pattern of actuations and the corresponding estimated amount of diet released from the hopper system over the observation period (1700h) is shown in Fig. 2. The numbers of actuations were relatively low in August and September, mainly between 3-5 actuations/day (6-12g dry wt. diet day^{-1}), when temperatures were high. Demand feeding increased as the ambient temperature decreased at the start of October. From the middle and toward the end of October, where the ambient temperature ranged between 13.8-15 °C (13.98±0.026 °C), the number of actuations

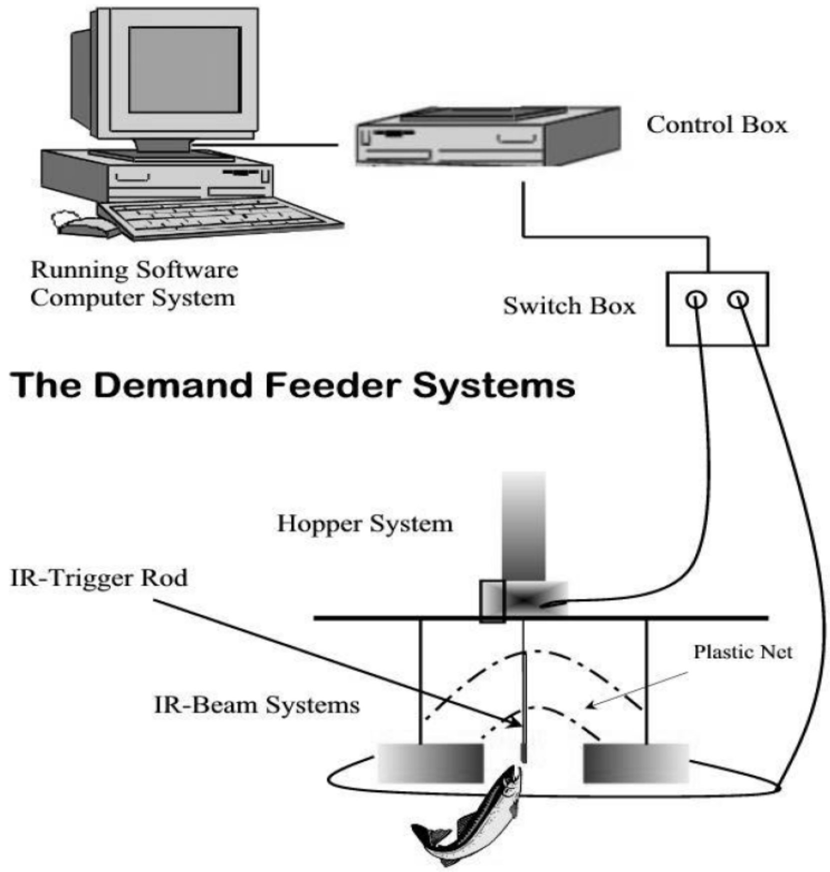

Fig.1: Infrared demand of feeder systems used in the experiment

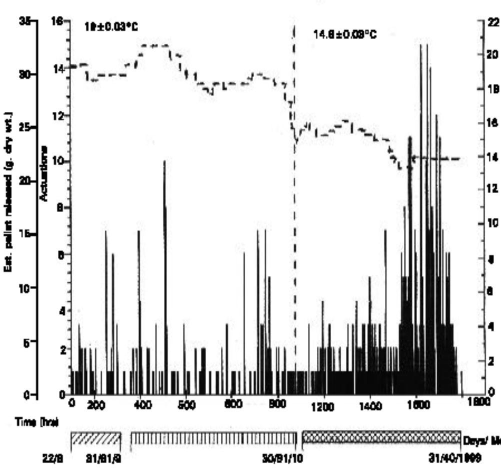

Fig. 2: The pattern of hourly actuations (aggregated actuation frequency) recorded during the demand-feeder experiment (Augest 22nd ᵗOctober 31st 1999)

increased on the average to 10 actuations day^{-1} (22g dry wt. diet) and occasionally as high as 15 actuations (33g dry wt. diet).

In the early part of the experiment (Fig. 3a) the whiting fed every 30 h. Once the temperature had decreased and the fish were feeding more intensively, a clear feeding rhythm every 23h was found (Fig 3b). It is difficult, (Fig. 2) to quantify daily intake during the period of heavy feeding in late October. To do this, during the last eleven days of October, when feeding activity was high, 669 actuations were made. The numbers of actuations on each day were expressed as a percentage of the total over this period (Fig. 4a) to see how variable daily intake was. The whiting daily demand for food varied almost ten-fold.

As a further study, feeding activity was examined over the 24-hour cycle (Fig. 4b). The fish preferred to feed during external daylight hours, despite the 24h continuous lighting. Whiting preferred to feed in the morning and in the afternoon followed by a marked decreased in feeding activity at dusk, night and at dawn.

Discussion

Optimization of growth rates and feed efficiency in fish are potentially influenced by the way in which food is made available, the type of diet, feeding method and frequency, the duration of each feeding period and the amount of food delivered at the suitable time. In this study, whiting were self-fed with high performance (Trouw) 5 mm dry trout diets using an infrared automatic demand feeder over 78 days without limits on available ration or access time. The 155g whiting responded poorly to this method of dispensing dry diets. Their low intake (0.78% bw day^{-1}) was close to that reported by Seyhan *et al.* (1998). The return of appetite curves for hand-fed whiting offered sprat (80% water) can be recalculated to show that the fish (151-465g bw) should be able to consume at least 0.6% bw dry matter every day values which agree with the demand feeder results (Mazlan *et al.*, 2002).

This intake was reflected in the poor growth performance as indicated by low biomass increase (weight gained), individual growth and specific growth rates and high food conversion ratio

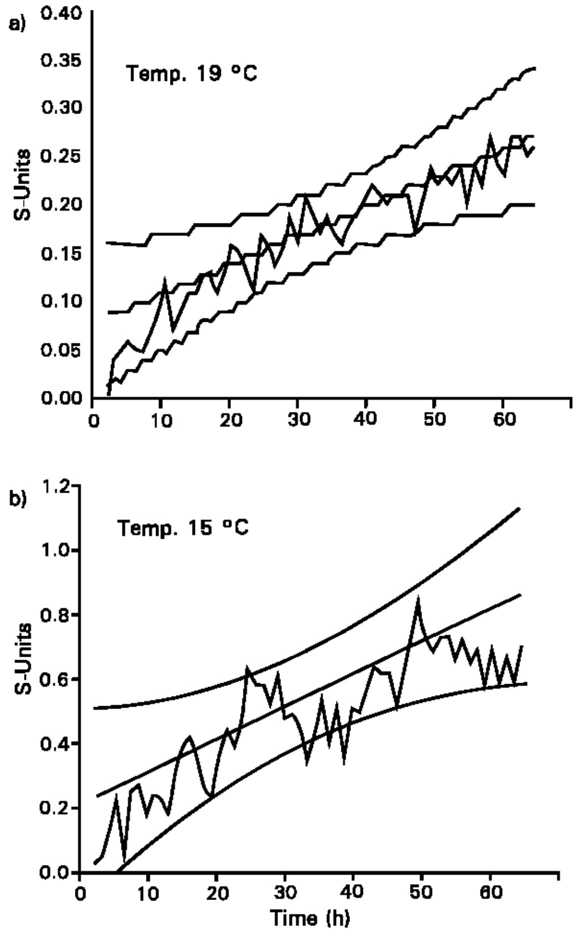

Fig. 3(a, b): Periodogram analysis for whiting fed on high performance trout 5 mm pellets at different temperature, (a) 19°C (b) 15°C

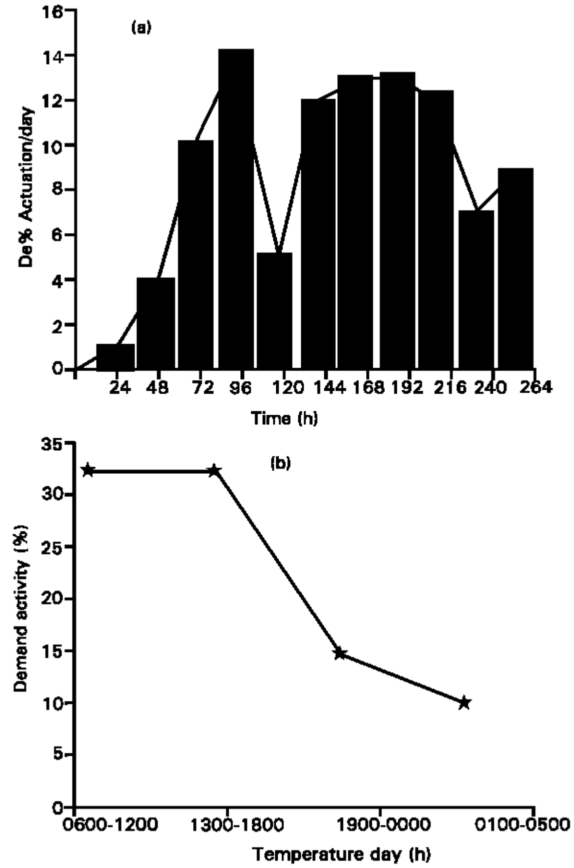

Fig. 4 (a,b): Trend of demand activity over (a) 264h period (20/10-1/11/99) and (b) during time of the day by a group of 10 whiting

(FCR). There were no detectable differences in specific growth rates among different size groups of whiting, but differences in coefficient of variation of the specific growth rates among the size groups might be explained by the hierarchical dominance that does exist among the individuals sharing the diets.

In this study, it is difficult to estimate the actual amount of diet consumed by each fish since individuals were not tagged and the test diets used were not reformulated with radio-opaque particles, which could be observed using X-radiography. Detailed findings on the variability of food intake and monitoring of individual response to demand feeding have been well documented. Brännäs and Alanärä (1993) used a PIT-tag (Passive Integrated Transponders) system with unique individual codes to monitor individual Arctic charr (*Salvelinus alpinus*) feeding activity with a demand feeding system. They stated that a pronounced shift in bite-number distribution among the individuals was due to the development of a dominance hierarchy, in which the dominant individuals monopolized the trigger. In related studies, artificial diets formulated with radio-opaque ballotini glass beads were used to estimate the amount consumed by the individual fish in different size groups using demand feeders (McCarthy *et al.*, 1992). They suggested that the strength of the feeding hierarchy and the variability in individual consumption decreased as the food availability increased.

A previous study by Seyhan *et al.* (1998) revealed that whiting consumed more control diet - which was closely similar to the diet used in the present study- in comparison to diluted diets (60% kaolin). The mean food intake of dry diets by individual whiting in this study was estimated at 1.20g day^{-1} (0.774% bw.) in comparison to 1.83 (0.82% bw.) reported by Seyhan on their control diets. The low consumption by mass of dry diet was not surprising, considering their low water content (5-7%) and higher amount of dry matter and energy (18.88KJ/g) in comparison to the high consumption (ad libitum) of the diet of sprats, which contained at least 75% water and approximately 21KJ/g energy content. Many workers postulate that the gross food intake of many fish decreases with decreasing level of moisture and increasing level of dietary energy (Grove *et al.*, 1978; Marais and Kissil, 1979; Kaushik and Olivia-Teles, 1986; Alanärä, 1994; Morales *et al.*, 1994, Ruohonen *et al.*, 1997). When fish are offered low energy diets, the rate of consumption increases- within limits - to maintain daily energy intake.

Since the diet used in this study was not developed for whiting, dietary moisture level and palatability may have influenced the food intake. Several studies reveal that fish offered wet diet consumed more and grew faster in comparison to dry diet in turbot (*Scophthalmus maximus*) (Grove, Per. Comm.). However, in Atlantic salmon, there were no significant effects of dietary moisture on the growth in comparison to the dry diet (Hughes, 1989). When dry diet enters the stomach, water is added to moisturize it, which causes the food to expand to fill the available stomach volume. The fish becomes satiated, lowering the appetite of the fish. The ability of fish species to moisturize the dry diet after ingestion varies among different species of fish; water content ranged between 63-75% in salmonid and 78% in largemouth bass (Hughes and Barrows, 1990).

The present study exposed the whiting to unlimited reward level and time access for feeding. Other studies report that there are significant effects of restricted reward level as well as time-restricted access on demand feeding activities in fish. For example, in rainbow trout (*Oncorhynchus mykiss*), voluntary feed intake and specific growth rates were significantly decreased as fish were exposed to reduced reward levels. Time-restricted access has led to a decrease in daily feed intake and, to some extent, low reward level was compensated by increasing the frequency of bite (actuation) activities (Alanärä, 1994; Gélineau *et al.*, 1998).

Ambient temperature, which was 13.8-21°C during this study, probably influenced the food consumption rate. Alanärä (1994) stated that demand feeding activity of rainbow trout was significantly lower at 5 °C in comparison to 15 °C; he also found no significant relationship between temperature and feed conversion. Similar findings were also reported in dab (*Limanda-limanda*) (Gwyther and Grove, 1981), where they found that *relative* daily food intake increased with temperature but decreased with body size. In sea bass (*Dicentrarchus labrax* L.) Azzaydi et *al.* (1998) and Aranda *et al.* (1999) found that daily feeding rhythm varies with temperature and photoperiod. Whiting was more readily available inshore during winter in local waters and observations throughout this study showed that it was susceptible to skin hemorrhagic ulceration when exposed to ambient temperature higher than 19 °C. Also in this study, the highest frequencies of actuations were obtained when the temperature ranged between 13.3-13.9°C (Fig. 2), which could be their optimal temperature range for feed intake.

Toward the end of the experiment (Figs. 4a,b), the whiting established a circadian feeding rhythm, even though they were held under constant 24h lighting. They preferred to feed between dawn and noon of each day. Circadian feeding and diel feeding rhythms were commonly found in many species as parts of their feeding ecology adaptation (Boujard and Leatherland, 1992b). Boujard et *al.* (1991) found marked circadian rhythms of food demand in *Hoplosterum littorale* (Hancock, 1828). Feeding activity was mainly nocturnal, with two peaks and was synchronized with the diel light cycle. In rainbow trout (*Oncorhynchus mykiss*) more than 98% of the feeding demand occurred during the photo phase with a main peak at dawn and an occasional peak at dusk (Boujard and Leatherland, 1992a).

In conclusion, the whiting held for longer-term demand feeding trials ate amounts of food (dry weight) at rates comparable to that from hand-fed whiting offered sprat, once water content was allowed for. Since digestion efficiency in whiting is comparable to other fish chosen for aquaculture, the poor growth performance may represent the need to formulate diets specifically for this species, to identify suitable holding temperatures and to minimize stress. These changes might allow more of the absorbed energy to be allocated to growth rather than be expended in respiration.

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