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Report

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Task 3.3 Use of circular tanks for ongrowing of Dover sole

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Introduction

Circular tanks are widely used in aquaculture. They have the advantage of being self-cleaning, which is important for all forms of aquaculture. They also have a constant and non-ending flow throughout the tank, which is a particular advantage for active swimming fish species.
The use of circular tanks in sole production is not widely known. Sole is not an active swimming species; therefore a non-ending flow is probably not necessary. However, the self-cleaning aspect of circular tanks is still a great advantage. Therefore the objective of this study was to optimize the production of sole in circular tanks.
For that purpose four different aspects of circular tanks were studied. These were:

- Design of circular tanks
- Netting for additional surface area
- Sand as bottom coverage
- Feeding of circular tanks

1. Design of circular tanks

1.1 Introduction

Circular tanks have great self-cleaning capacity. At the same time they have continuous flow pattern throughout the whole tank. These two aspects make circular tank suitable for active swimming and fast eating fish.
Sole culture however requires different design criteria. Sole are not very active feeders; they eat during a longer period and also eat at night. With efficient self cleaning tanks the risk exists that feed is washed away before the fish had a chance of eating it.
The optimum feeding level can easily be determined through direct monitoring of the feeding behaviour of fast eating fish. Since sole are slow eating fish, observations of the feeding behaviour is not an appropriate measure to determine the optimum feeding level. Instead, checking the amounts of not eaten feed is an important tool to determine the optimum feeding level.
The criteria for an optimal circular tank for sole culture are therefore that feed has to be available over a large area of the tank, and has to remain available to the fish for some time. This requires that tanks are designed in a way that feed waste can be inspected, while the self-cleaning function of the tank remains intact. With these design criteria in mind, circular tanks with suitable ways of water management were developed.

1.2 Material and methods

Circular tanks of 10 m^2 were used to optimize the design of tanks for sole culture. These tanks were part of a recirculation system. Water treatment consisted of a drum filter (Hydrotech®) and biological oxidation of ammonia to nitrate in a trickling filter.
The tanks had a central drain and a double water inlet with optional addition of pure oxygen.

The four tanks were stocked with sole of different size and density. Observations were made on feeding level, feed waste, mortality and growth while rearing the fish. Modifications were made to the tanks and changes were monitored for a few weeks. No blanks or direct comparison between systems were used.

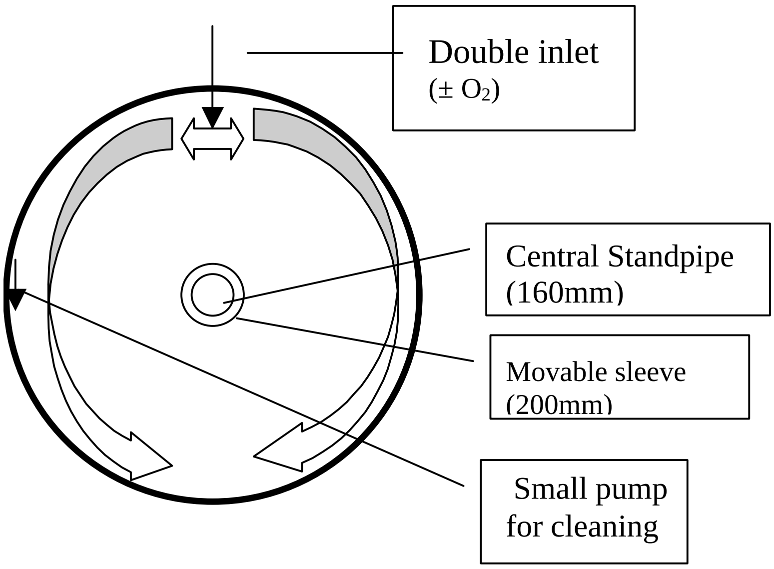
1.3 Results

We used four circular tanks with a surface area of 10 m^2 and a water depth of 40 cm. While rearing the fish, adaptations to the tanks were made and tested for a few weeks. Feeding level and feed waste is recorded daily per tank. Feed intake before and after changes were monitored and compared (no blanks). This led to stepwise improvement of the circular tank system.

<u>Design of water inlet and outlet system</u>
The following design parameters were set for the water inlet and outlet system.
Water inlet:
- Low energy inflow avoiding strong currents; with
- Temporary increased flow for self-cleaning.

Water outlet system:
- Central drain with overflow pipe
- Flexibility with regard to drainage bottom (cleaning) or surface (feeding) by movable sleeve;
- Retention and quantification of uneaten feed;

This resulted in the following design, which was constructed for all four tanks.



Water entered the tanks through the double inlet, creating a minimal flow of water in the tanks. Water left the tanks through the central standpipe. The fish were fed continuously. For a period of one hour in the morning a circular flow was created in the tanks by means of a small water pump. The water inlet was directed in the same direction as the water pump and by doing so a circular water current was created. This led to the concentration of waste and not eaten feed in the central part of the tanks. Observations could be made of the amount of not eaten feed, and by doing so the feeding level could be adjusted. After the observation the moveable sleeve was lowered over the central standpipe, thereby shifting from surface drainage to bottom drainage. As a result the concentrated wasted and uneaten feed was quickly and effectively removed from the tanks. In addition, this created an extra flow of water out of the tanks, which contributed to concentration and removal of waste and not eaten feed from the tanks.
This management of circular tanks for sole production proved to be ideal. Production results from the four tanks over two culture periods, and with different sizes of fish are given in table 1. Appendix A provides pictures of the moveable outer sleeve (picture 1) and the double inlet (picture 2).

Table 1 : Production results of sole in circular tanks

Tank number	**1**	**1**	**2**	**2**	**3**	**4**	**4**
Period	**1**	**2**	**1**	**2**	**1**	**1**	**2**
Starting date	29-05-02	28-05-03	29-05-02	29-01-03	29-05-02	12-09-02	5-08-03
Final date	27-05-03	30-10-03	28-01-03	29-10-03	28-01-03	4-08-03	28-10-03
Number of days	363	155	244	273	244	326	84
Initial individual weight (gr)	32	108	142	215	126	8	47
Final individual weight (gr)	100	152	225	297	197	51	59
Initial number	1869	1055	933	1298	503	1886	1845
Final number	1416	999	832	1245	466	1028	1811
Mortality number	453	56	101	53	37	858	34
Average daily mortality (%)	0,08	0,04	0,05	0,02	0,03	0,12	0,02
Initial biomass (gr)	59451	113421	132600	279029	63400	11206	86632
Final biomass (gr)	141934	151462	187097	369696	91650	66283	106084
Total mortality (gr)	18649	3577	14469	9432	5273	8483	1022,6
Weight increase (gr)	82483	38042	54497	90668	28250	55077	19452
SGR	0,32	0,22	0,19	0,12	0,18	0,57	0,26
Average daily feeding level (%)	0,63	0,45	0,43	0,27	0,54	1,10	0,51
Consumed feed (gr)	221844	92341	165263	240583	100705	120806	41575
Feed Conversion Rate	2,69	2,43	3,03	2,65	3,56	2,19	2,14
Minimum density (kg/m^2)	5,95	11,34	13,26	27,90	6,34	1,12	8,66
Maximum density (kg/m^2)	14,19	15,15	18,71	36,97	9,16	6,63	10,61
Average density (kg/m^2)	10,53	12,93	15,87	32,31	7,75	4,00	9,59
Average productivity (kg/m^2/yr)	8,24	9,04	8,10	12,10	4,22	5,80	8,49

2. Netting for additional surface area

Sole are bottom dwellers, and available surface area may be more important for these fish than water volume. Installing extra layers of resting material in tanks can create extra surface area. The question is whether the fish will use these layers, what material should be used and whether it is practical to use resting areas in the tanks.

2.1 Materials and methods

Between 22 October 2002 and 4 November 2002 three different types of netting were used to test the preference of the netting materials as lying area. The three materials were white plastic (meshsize 4 mm), Monodur 4000 netting (square nylon mesh of 4 mm), and plastified metal wire (square mesh of 10 mm). The netting materials were fixed to a frame, made of pvc piping of 32 mm diameter. The frame was 65 by 60 cm (surface area of the netting 0.39 m^2). The frames with the different netting were placed in a 10.2 m^2 tank with 840 fish. Average weight of the fish was 200 gr. Location of the nets were altered to compensate for possible preference for a certain location in the tank.
Numbers of fish lying on the nets were counted in the morning and late afternoon.
In Appendix A a picture (3) of the frames with the different netting materials is presented.

2.2 Results

Results show that the fish did not have a preference for the location in the tank, but had a clear preference for the Monodur 4000 netting ($p<0.001$). The Monodur netting was also preferred as resting surface above the tank bottom (Table 2).

Table 2 . Results of Average number of Dover sole per m^2 on the resting nets and tank bottom.

Treatment	White plastic	Monodur Nylon	Plastified wire	Tank bottom	lsd
Number of fish per m^2	64.3^a	85.6^b	66.9^{ac}	74.1^c	9.31

Different a, b, or c indicates significant difference between treatments ($p<0.05$)

We also tested the effect of the depth of the location of the Monodur nylon netting. Nets were placed either 20 of 30 cm below the surface area. Water depth in the tank was 40 cm. Nets located at a depth of 30 cm were preferred over net located at a depth of 20 cm ($p<0.05$, averages 64.1 and 49.2 fish per m^2 respectively, lsd 11.3).

Although the fish effectively used the nets, for practical application we did not consider them useful. The main reasons were that the nets became very dirty and the areas under the nets were difficult to control. Besides, it was much more difficult to maintain an appropriate water flow and self cleaning capacity in the tanks, with the netting as undesired obstacles.

3. The effect of sand as a bottom cover in Dover sole (*Solea solea*) ongrowing on tail erosion, growth and mortality

3.1 Introduction

General
Tail erosion is a common problem for Dover sole kept in captivity. In this experiment it was tested whether a sand bottom, a natural substrate for Dover sole, has a beneficial effect on the tails. At the same time the effect of sand on growth and mortality was evaluated and experience with management of sand in tanks was gained.

Background
The cause for tail erosion has so far not been established. At the Netherlands Institute of Fisheries Research it has been observed that tail erosion arises as early as just after settlement to the bottom of metamorphosed larvae. It has also been observed that tails hardly recover from damage at this early age. On the other hand, tails that are not damaged at an early age tend to remain intact throughout the ongrowing period. These observations suggest that during the period right after settlement tails are sensitive to the causative agent of tail erosion, whereas once the fish have grown bigger this sensitivity has reduced. Based on this it is possible to speculate on the nature of the causing agent. Possibly the tails of just settled juveniles are delicate enough to be damaged by microorganisms that live in the biofilm on tank bottoms, while the tails of larger fish are resistant to such colonization.
The scraping effect of sand possibly results in the constant removal of microorganisms colonizing the tail, providing the tail the opportunity to recover from chronic erosion caused by microorganisms.
In 2002 formalin treatments were applied at RIVO to reduce the load of microorganisms present in the tanks and on the fish in order to protect the tails from erosion. Several batches of just metamorphosed juveniles were given a formalin treatment (100 ppm for 12 hours) every two weeks over a period of 6 weeks. Although the effects were not studied systematically it was clear that the treatment did not have its expected beneficial effect as a large proportion of the juveniles were observed to still have an eroded tail. Apparently microorganisms sensitive to such a formalin treatment do not cause tail erosion.

3.2 Materials and Methods

Set up
Two treatments, a bare bottom versus a sand bottom were compared without replications. The two square polyester tanks (1x1m, water depth 30 cm) used were hooked up to the large recirculation system in which water quality is maintained by drum and trickling filtration as described in Chapter 1. One tank bottom was covered with a 2.5 cm layer of fine river sand, the other tank bottom was untreated. Both tanks were stocked with 100 Dover sole with an average weight of 25.8±12.5g. The fish originated from the 2002 off spring of wild breeders kept in captivity at our institute. The fish were randomly selected from a group of in total 2500 fish.

Feeding
The fish were fed by belt feeder at an initial level of 1%BW/d. Feeding levels were adjusted independently based on the amount of left over feed in the tanks in the morning. The aim was to feed the fish just over satiation to ensure that feed load never limited growth. Daily observation of left over feed was used as a tool to ensure feeding over satiation. Originally the tank with no sand was fed during 20 hours per day starting from approximately 10.00 o'clock, while the tank

with a sand bottom was only fed at night by supplying only feed to the second half of the belt. The background for this feeding strategy was that sole in the tank with a sandy bottom were expected to display their natural behaviour that includes burying in the sand during daytime and coming out of the sand for feeding after dark. In that case feed administered during the day would remain uneaten and wasted. This feeding strategy was adjusted after the first sampling as the sole in the tank with sand were observed to be also active during daytime. From then onwards both tanks were fed for 20 hours per day.

Sand tank management

The presence of sand in a tank based fish culture system in general and in a recirculation system in particular, challenges system management. First of all sand conflicts with the desired self-cleaning capacity of fish tanks: faeces and uneaten feed need to be removed from the tank but sand should remain inside. Secondly, sand can be harmful to equipment within the fish culture system and should therefore remain inside the tank. Two potential problems arise: sand is washed out of the tank or removal of uneaten feed and faeces is hampered by the presence of sand. Sand washed out of the tank is likely to damage the pumps in a recirculation system. Sand may also settle and accumulate in pipes, reducing their capacity and eventually blocking them. In case sand hampers the removal of uneaten feed and faeces these substances accumulate in the tank or in the sand causing deterioration of water quality. Breakdown of organic matter in the sand bottom can result in anaerobic pockets. Under these conditions harmful substances like hydrogensulfide will be formed.
The current experiment was the first time sand was applied in ongrowing tanks at our facilities. Experience gained during the course of the experiment with management of a tank with a sand bottom will be reported in Results.

Measurements and sampling

Tails

The primary goal of this trial was to investigate a possible beneficial effect of sand on tail erosion. In order to quantify the state of the tails, a tail scoring system was developed. The tail score was based on the relative proportion of tail surface present, as described in Table 3.

Table 3: Tail scoring system

Score	Description
1	Complete tail
2	75% of the tail present
3	50% of the tail present
4	25% of the tail present
5	Tail completely gone

Appendix A contains photographs that illustrate the tail scoring system (pictures 4-8).
At day 1, 49, 103 and 166 of the experimental period the tails of all individual fish were scored simultaneously by two persons.

Growth

In order to measure growth all fish in the experiment were weighed at day 1, 49, 103 and 166 of the experimental period. For the initial and final weights (day 1 and 166) all fish were weighed individually. At the two intermediate sampling days (day 49 and 103) all fish were weighed in bulk per tank.

Daily recordings

Mortality and feeding level were recorded daily.

Data analyses, calculations and statistics

General
For all statistic procedures SPSS 10.1 for windows and a significance level of 0.05 were used.

Tails
For both treatments the relative frequency of tail scores were established and displayed in graphs.
In order to investigate a possible relationship between poor tail condition and growth, the tail scores were related to weight. It is not unthinkable that poor tails depress growth. For instance because swimming efficiency is reduced, resulting in a higher energy expenditure. In this experiment paired samples of individual weight and tail quality were available both at the start as well as the end of the experiment. Tail quality at the start and the end of the experiment were pooled and linear regression was used to describe the correlation between tail quality and weight.

Growth and feed conversion rate
Growth was expressed as the specific growth rate (SGR), which was calculated as follows:

Specific Growth Rate (%/day) $SGR = (\ln(W_t) - \ln(W_0))* \quad T$

Where: W_0 = average weight on day 1
W_t = average weight on day 166
T = number of feeding days

As we were first of all interested in the effect of sand on growth rate and not the gain of biomass during the experiment, growth was calculated based on average weight gain, disregarding differences in mortality. However, to illustrate the effect of mortality on biomass increase total, the SGR was also calculated based on the total final and initial biomass, thereby taking into account mortality.

The difference in initial average weight was tested using One-Way ANOVA. In the procedure the individual initial weights were used as variables.

The feed conversion rate (FCR) was calculated as follows:

Feed Conversion Rate (kg/kg) = FL/(Wt-Wo)

Where: W_0 = total biomass at day 1 (kg)
W_t = total biomass at day t (kg)
FL = Total feed load (kg)

Biomass loss due to mortality was found to heavily affect the FCR. In order to eliminate the effect of mortality on the FCR and to base the FCR more on the actual feed utilization by the fish for the two treatments, the FCR was also calculated without considering mortality not into account. This was done by subtracting the biomass lost to mortality from the total initial biomass. This method results in a certain underestimation of the FCR.

3.3 Results and discussion

Fish behaviour

Fish behaviour has not been studied systematically in this experiment. However, visual observations made during the experiment are relevant and interesting enough to be mentioned here.

The sole used in this experiment are the off spring of brood stock caught in the North Sea. This first generation in capitivity-raised fish has never been in touch with sand before. It was therefore quite remarkable to observe that numerous fish immediately buried in the sand at the time they were first introduced in the tank with the sand bottom. There were also fish that laid on top the sand and did not bury themselves for the first hours or even days. At day 3 of the experiment all fish were buried in the sand during the day. Although never observed, they were expected to come out of the sand after dark to browse for feed, hence the night feeding schedule. After 4 to 5 weeks fish were observed to come out of the sand during the daytime. For this reason the feeding schedule was adjusted as described in Materials and methods.

Tails

Tail scores

The relative frequencies for the tail scores are presented in Figures 1a till 1d. For each sampling day one figure is presented. Appendix B provides an overview of all data. As treatments were not replicated in this experiment, differences in tail scores could not be tested for significance.

The results show that for both the sand as the bare tank the quality of the tails improved during the course of the trial. However, comparison of the results of the sand and bare tank shows no difference in tail quality. Apparently the presence of a sandy bottom had no beneficial effect on the quality of the tails in this trial.

This overall improvement of tail quality during the trial can be explained by the experimental conditions in both the sand and the bare tank being better than the conditions the fish were subject to prior to the trail. This may have shaded the effect of sand on tails. The most outstanding difference between the experimental conditions and the tank conditions prior to the trial is stocking density. Additional research is needed to establish the potential relation between tail erosion and stocking density.

Figure 1a: Relative frequencies at sampling Day 1of the tail scores of Dover sole kept on a sand and bare tank bottom. Scores 1, 2, 3, 4 and 5 indicate a presence of the tail based on surface area of 100, 75, 50, 25 and 0%, respectively.

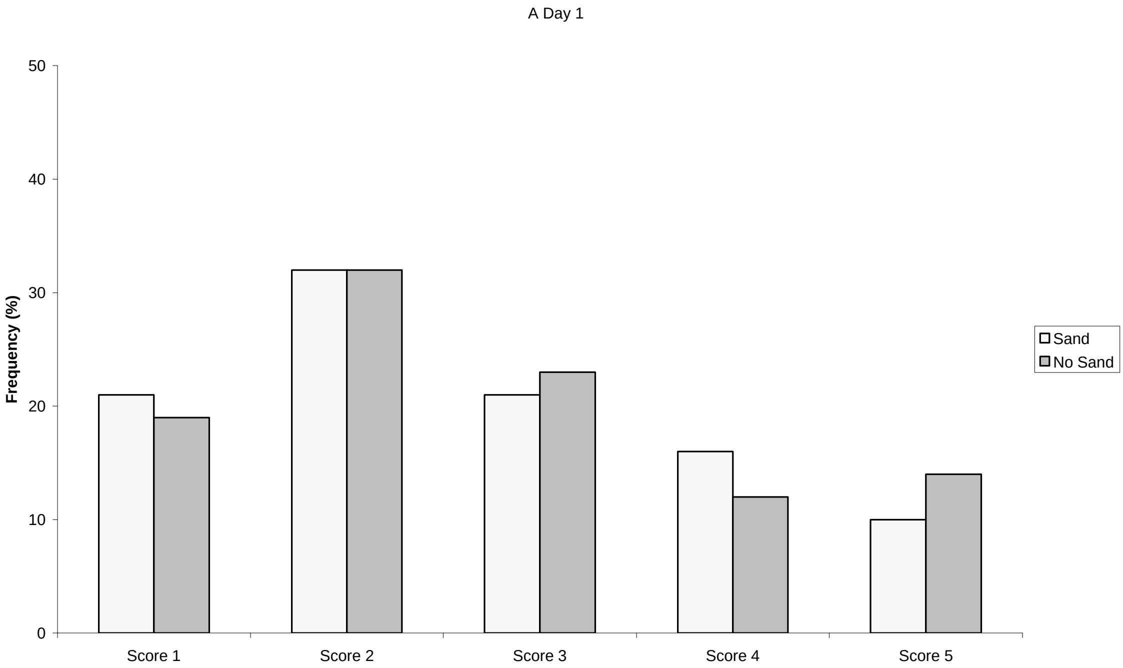


Figure 1b: Relative frequencies at sampling Day 49 of the tail scores of Dover sole kept on a sand and bare tank bottom. Scores 1, 2, 3, 4 and 5 indicate a presence of the tail based on surface area of 100, 75, 50, 25 and 0%, respectively.

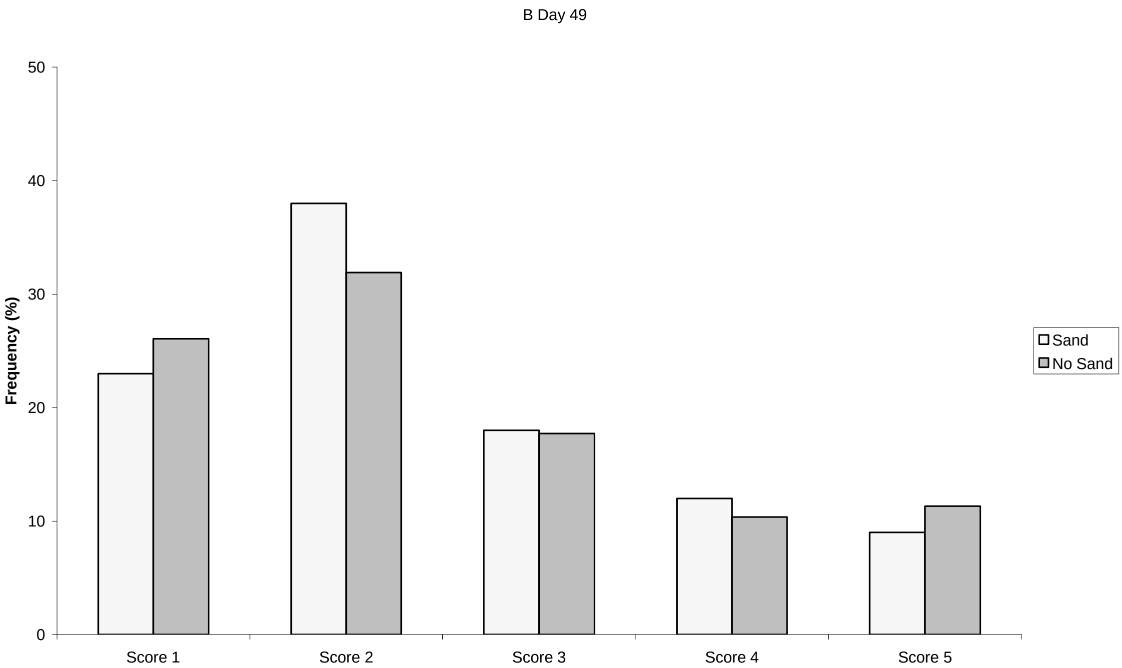


Figure 1c: Relative frequencies at sampling Day 103 of the tail scores of Dover sole kept on a sand and bare tank bottom. Scores 1, 2, 3, 4 and 5 indicate a presence of the tail based on surface area of 100, 75, 50, 25 and 0%, respectively.

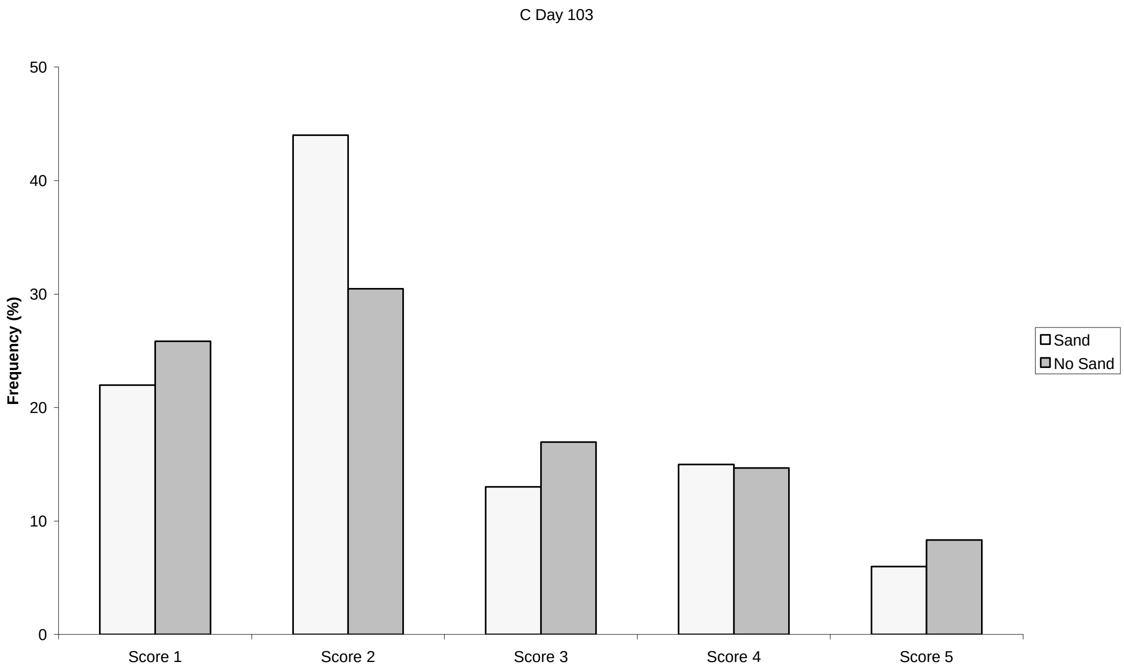
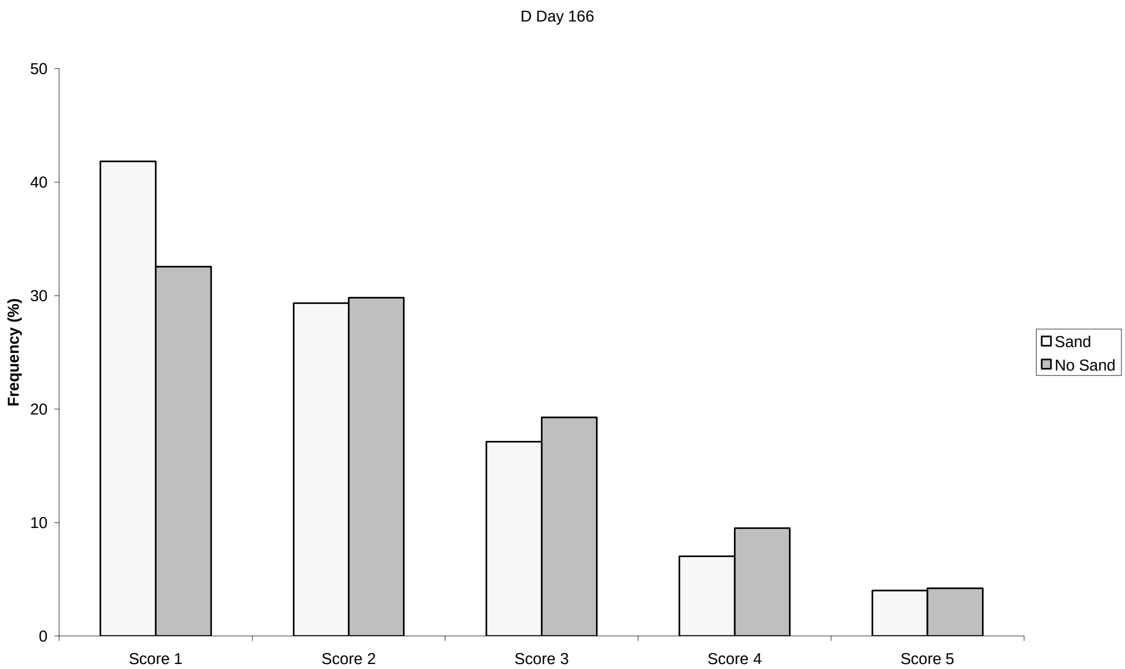
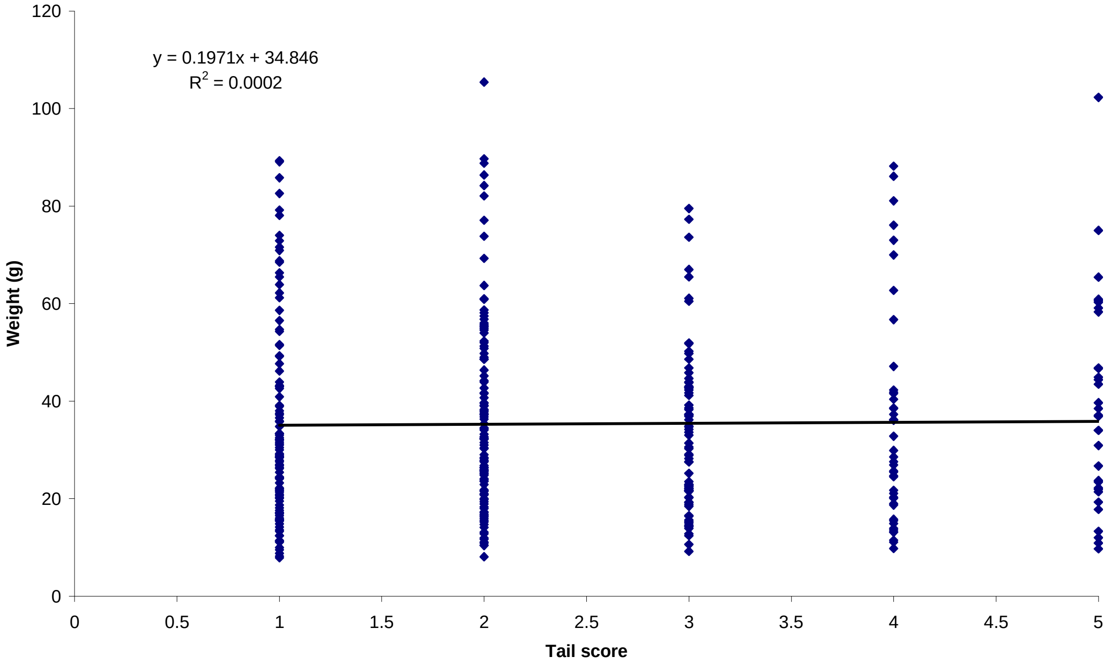


Figure 1d: Relative frequencies at sampling Day 166 of the tail scores of Dover sole kept on a sand and bare tank bottom. Scores 1, 2, 3, 4 and 5 indicate a presence of the tail based on surface area of 100, 75, 50, 25 and 0%, respectively..



Tails in relation to weight
As mentioned in Materials and methods it is not unlikely that individual weight is affected by the condition of the tail. In order to establish this possible relation linear regression was performed. The result is shown in Figure 2. It is clear from this Figure that there is no relation between tail score and weight. Apparently a damaged tail has no negative impact on growth.

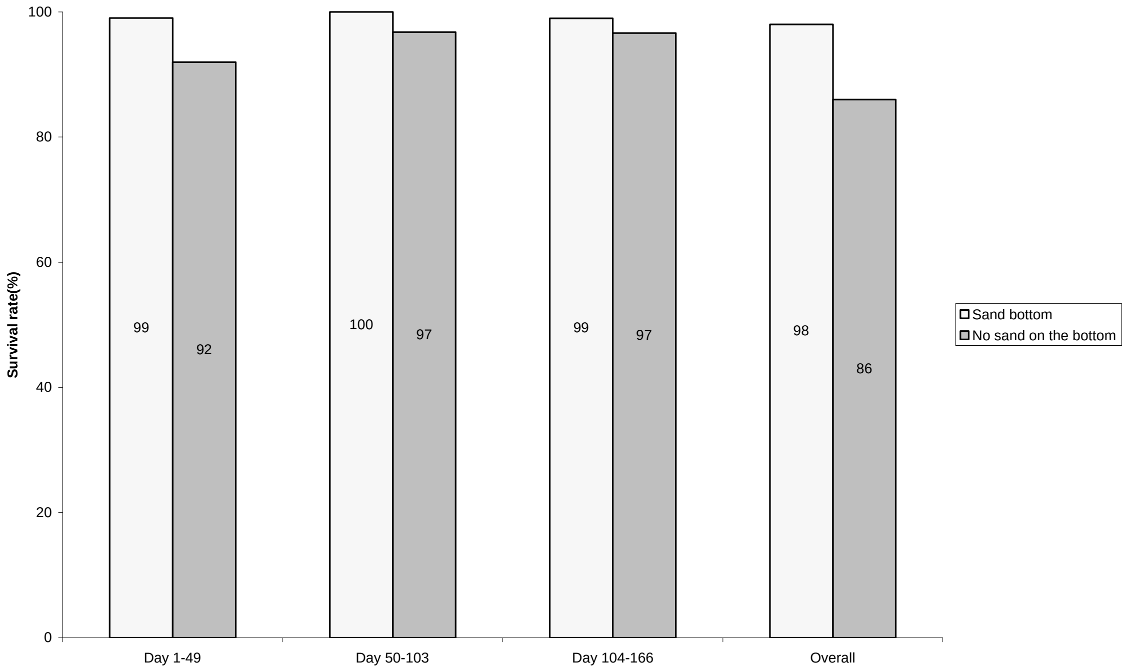
Figure 2: Linear regression of tail score to weight



Mortality, Growth and feed conversion

Mortality
Mortality was recorded daily. Based on the mortality the survival rates were calculated for the three periods between the sampling points and the overall survival. The results are presented in Figure 3. In total 2 fish died in the tank with a sand bottom. It should be mentioned that one of the mortalities in the sand tank resulted from jumping out of the tank. In total 14 fish died in the tank with no sand on the bottom.

Figure 3: Survival rate of Dover sole stocked in a bare and a sand bottom tank for the periods between sampling points and the overall survival rate. Data are displayed in the bars.



Growth

Growth was expressed as Specific Growth Rate (SGR). Figure 4 presents the SGR for the three periods between the sampling days (Day 1-49, Day 50-103, Day 104-166) and the overall SGR for both treatments.

In the first period, between the start of the experiment and first sampling at day 49, the fish in the tank with a sand bottom grew much faster than the fish in the bare tank. In second period, growth was reduced for both treatments. The fish in the sand tank still were faster growing but the differences in SGR with the bare tank were reduced. In the third and last period, both treatments displayed almost equal growth at a rate similar to the sand tank in the first period. Overall the fish in the sand tank displayed a higher SGR than the fish in the tank with no sand, 0.38%BW/d compared to 0.30%BW/d. Due to lack of replications SGR data could not be statistically analysed.

As explained in Materials and methods, the SGR as presented in Figure 4 are based on average weights. This method describes the differences in individual growth rates between the two treatments. However, it disregards mortality and therefore does not describe biomass production. To demonstrate the effect of mortality on biomass production, the SGRs were also calculated based on the total initial and final biomass. This considers biomass loss to mortality. The results are presented in Figure 5. It is clear from Figure 5 that mortality impacts heavily on the growth results in the tank with no sand on the bottom. The differences in SGR between the two treatments increased when mortality is taken into account.

Figure 4: Specific Growth Rate based on initial and final average weights of Dover sole stocked in a bare and sand bottom tank for the periods between sampling and overall over the experimental periods. Values are presented in the bars. Data are displayed in the bars. Wo =25.8±12.5g

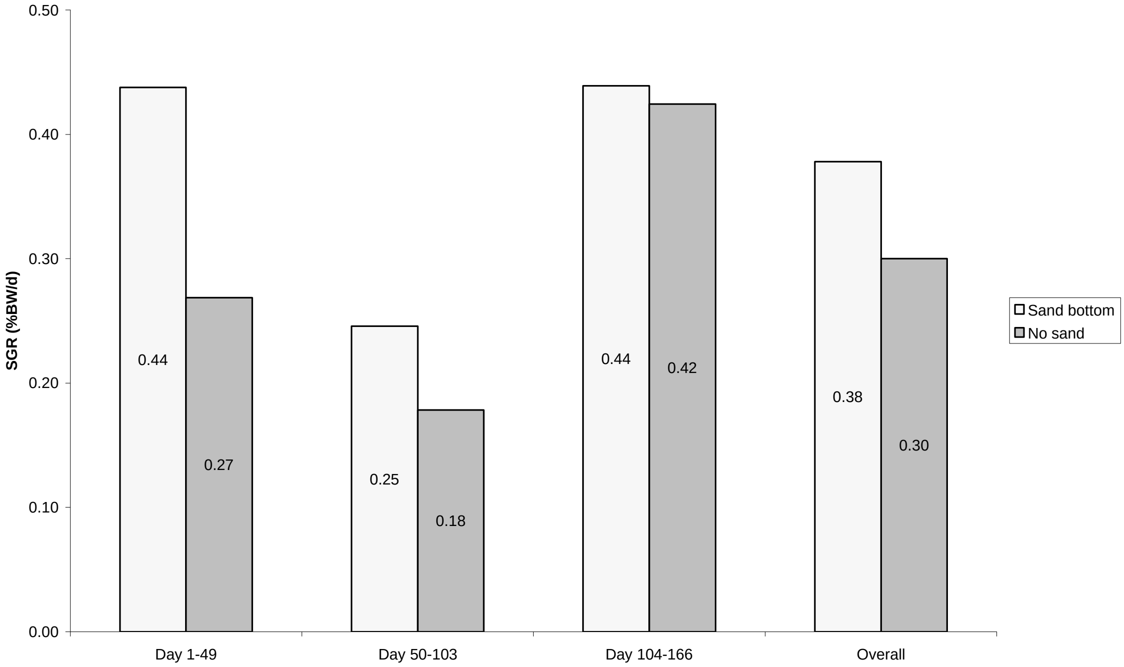
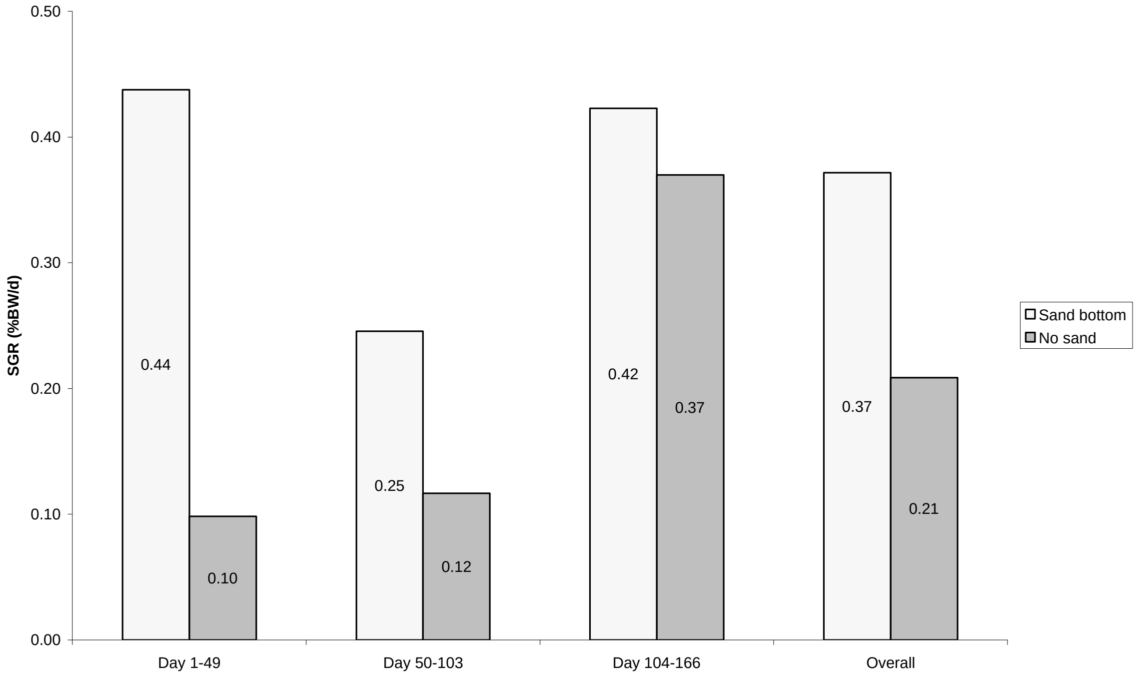


Figure 4: Specific Growth Rate based on initial and final total biomass of Dover sole stocked in a bare and sand bottom tank for the periods between sampling and overall over the experimental periods. Values are presented in the bars. Data are displayed in the bars. Wo =25.8±12.5g



Feed conversion rate

The amount of feed administered to the tank was recorded daily. Based on the feed loads and the total biomass increase, the feed conversion rates were calculated for the three periods between the sampling days (Day 1-49, Day 50-103 and Day 104-166) and for the total experimental period. The results are presented in Figure 6. It is clear from Figure 6 that the feed conversion efficiency is better in the sand treatment. However, it should be mentioned that the FCR of the no sand treatment is heavily affected by mortality. To demonstrate this effect the FCRs were also calculated disregarding mortality. The results are displayed in Figure 7. Comparing Figure 6 to Figure 7 demonstrates that mortality had indeed a severe impact on FCR, but it also shows that even when mortality is not taken into account the FCR of the no sand treatment is still poor compared to the treatment with the sand bottom.

Figure 6: Feed conversion rate based on total initial and final biomass for Dover sole stocked in a bare and a sand bottom tank for the periods between sampling and overall over the experimental periods. Values are presented in the bars.

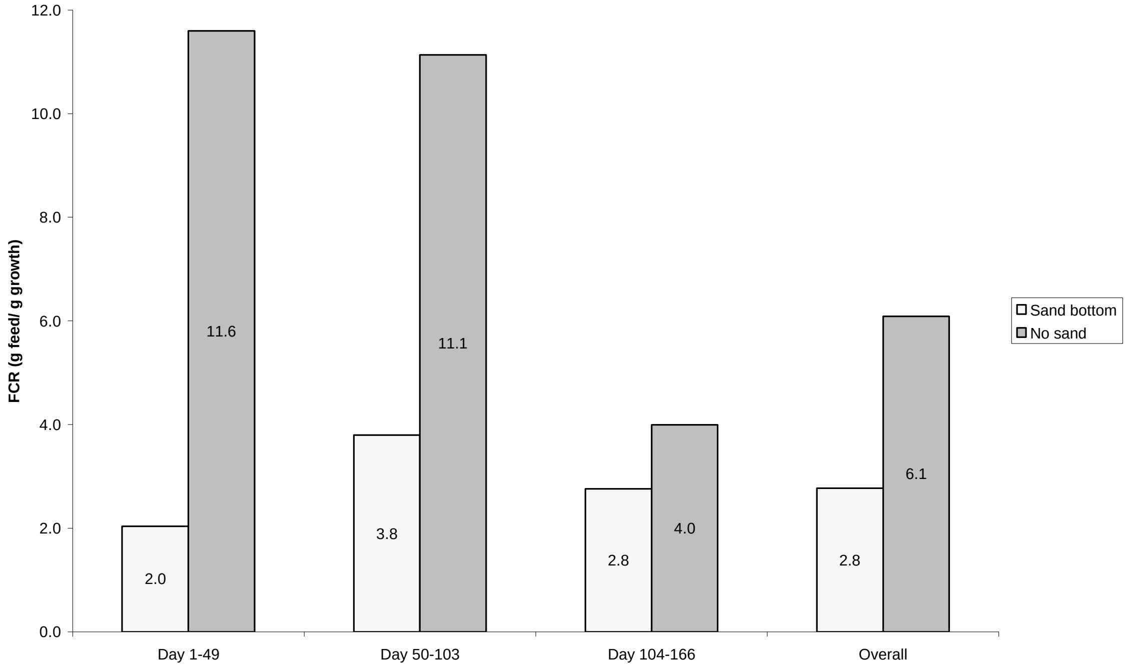
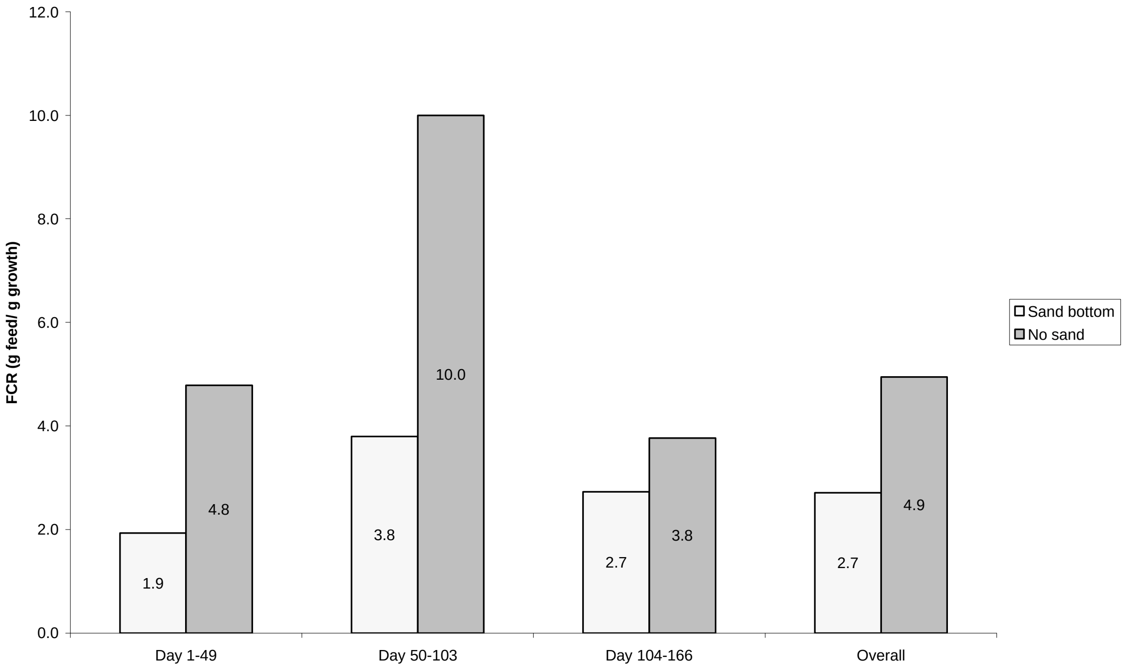


Figure 7: Feed conversion rate based on total initial and final biomass corrected for mortality for Dover sole stocked in a bare and an sand bottom tank for the periods between sampling and overall over the experimental periods. Values are presented in the bars.



Overall Discussion

Overall and during all three periods between the sampling points, the fish in the tank with sand on the bottom displayed faster growth. In addition, the final weight in the sand tank was significantly higher than in the bare tank, while initials weights were equal.
Compared to earlier results, growth was in fact quite poor for both treatments. In previous experimental work at our institute SGR's of 0.60%BW/d were measured for Dover sole at comparable stocking density and weight (Schram, 2000).
The difference in mortality found for the two treatments is remarkable. The mortality in the sand tank was in fact low compared to both the other experimental treatment and routine ongrowing. Mortality in the bare tank on the other hand was high compared to both the other experimental treatment but comparable to routine ongrowing. Dead fish did not display any abnormal external features therefore the cause of death remains unclear at this point. At our institute peaks in mortality of ongrowing sole can sometimes be related to outbreaks of external parasites like costia and trichodina. In this experiment the fish were unfortunately not examined for the presence of such parasites. However mortality did not display peaks characteristic to parasite outbreaks and such a cause of death is therefore unlikely. It is however not unthinkable that the scraping sand effect of sand reduces colonisation of the skin by parasites. Infestation with parasites is known to reduce both growth and survival. Reduction of the number of parasites could therefore play a role in the beneficial effect of sand on growth and survival as found in this experiment. It is therefore recommended that in future experimental work involving sand bottoms the fish are checked for external parasites on a regular basis.
Although the reasons remain unclear at this point, it seems clear that sand had a beneficial effect on survival.

The high FCR as found for the sand tank can be explained by the overfeeding of the fish. As explained above tanks were overfed on purpose in order to ensure feeding to satiation. This of course results in higher FCR values. This overfeeding cannot fully explain the extremely high FCR values as found for the bare tank. Apparently feed utilization was poor in this tank, resulting in poor growth and high FCR values.

Sand tank management
Both tanks were equipped with a central outflow. A standpipe placed in the central out flow controlled the water level. A second pipe was placed around the standpipe. This pipe could be lowered and lifted; thereby controlling the level of drainage. Lifted completely, water was drained from the surface, lowered completely; water was drained from the bottom. Normally the outside pipe was lifted, in order to keep feed pellets inside the tank. This prevented feed being removed from the tank before the fish had the chance to eat it and it provided the opportunity to monitor uneaten feed and thus proper adjustment of the feeding level. Every morning prior to filling the belt feeder, the out side pipe was lowered to remove uneaten feed. At the same time the water inflow was directed sideways to induce a circular flow, which enhanced the collection of uneaten feed in the center of the tank, followed by removal of it. Normally the inflow was directed to the tank wall to prevent a strong circular flow to keep feed inside the tank during feeding. To create a circular flow and to remove all uneaten feed, the inflow was directed side ways and the outside pipe lowered for approximately half an hour per day. This system was previously established for bare tanks.

Collection and removal of uneaten feed by the above described system proved to be successful. Feed pellets were observed to lie on top of the sand and the temporarily circular flow was found to be efficient in moving the pellets towards the central outflow. Once collected around the central outflow the pellets were efficiently removed via the lowered out side sleeve. At normal operation sand was found to remain inside the tank. The sand did not pile up around the central outflow but remained evenly distributed in the tank. However, during the daily operation of the out side sleeve and circular flow, removal of sand could not be prevented totally. The amount of sand washed from the tank was not quantified but based on visual observation it is estimated that approximately 20% of the total amount of sand present in the tank was washed out during the experiment that lasted   days. It is safe to conclude that such wash out of sand would be unacceptable during continuous and commercial operation of ongrowing tanks.
At each sampling day all the sand needed to be removed from the tank in order to allow the capture of all fish present in the tank. This was an excellent opportunity to monitor the quality of the sand. In contrast to what was expected, the sand was found to be clean at all sampling days. Faces and uneaten feed were not observed to accumulate in the sand and anaerobic pockets had not developed. Given the fact that the fish were overfed and excess feed was therefore present at most times, this is remarkable.

In general it can be concluded that the current tank configuration can be successfully applied to manage a sand bottom. The only part that needs improvement is keeping the sand inside the tank. A first attempt was made during the experiment. An attempt was made to prevent flow out of sand by keeping it away from the central standing pipe by installing coarse gravel around it. As this was unsuccessful, sand reached the center of the tank anyway while the gravel was distributed all over the tank bottom, the gravel was removed at the first sampling day.
Other possible solutions include the development and installation of a sand trap at the out flow of the tank in which washed out sand is collected by sedimentation and further distribution of sand through the fish culture system. Furthermore an effort should be made to select the most suitable sand for this purpose. Selection should be based on physical characteristics that affect the sedimentation properties, like specific weight and grain diameter, but also cost price.

3.4 Conclusions

Sand was not found to have a beneficial effect on the quality of the tails of Dover sole

Sand was found to promote faster growth, lower FCR and higher survival.

The tank configuration used can be applied to manage a tank with a sand bottom but maintaining the sand inside the tank requires improvement.

4. Feeding of circular tanks

4.1 Beltfeeder versus spinfeeder

Fish in circular tanks can be fed with a beltfeeder that drops the feed in one place, or with feeders that distribute the feed over the whole surface area of a tank. The results of Task 2.3 on the relation between stocking density and growth performance suggested that spreading the feed over large part of the tank area results in better growth compared tto feed administration at one single place in the tank. For this reason the performance of feeders that spread the feed over the tank was tested.

4.1.1 Material and methods

The SpinFeed™ Unit consisted of a feed container with the feeding unit mounted underneath. The SpinFeed™ Unit was build with a spreading disc mounted underneath. The spreading disc was mounted on a centrifugal plate. Each time a feeding took place a short electrical impulse was given to the motor. The centrifugal plate accelerated into very high speed of rotations in a short period of time, and distributed an amount of feed in an area with a radius up to 4 metres. The amount of distributed feed was proportional to the number of impulses. Calibration of the amount of feed per impulse was carried out by the fish farmer and entered in the control software. The computer then used this amount per impulse to calculate the required number of impulses to feed the fish tanks. Picture 9 in Appendix A presents the spinfeeder.

4.1.2 Results and conclusion

At our facilities we experienced the problem of moisture on the centrifugal plate. Fish were reared in a greenhouse building with plastic cover. During periods of the year the water in the tanks was much warmer than the air temperature in the building. This created a very humid environment above the fish tanks. Since the centrifugal plate was relatively cold it became moist. As a result feed would stick to the centrifugal plate and the amount of feed per impulse would no longer correspond with the calibrated amount. The spinfeeder therefore became unreliable under these circumstances. The fundamental disadvantage of this spinfeeder is that dosage and distribution of the feed are linked. Since the environment influenced the distribution of the feed, so was the dosage.

4.2 Feeding robot

Circular tanks can be fed automatically with a robot feeder. It is of course important to know how accurate a robot feeder distributes the required amount of feed.

4.2.1 Material and Methods

At Zeeland Fish Farm a TransFeed™ robot feeder feeds circular tanks with a diameter of 5 m. The robot is an automatic feeder that runs on a rail in the ceiling of the plant. The robot runs from tank to tank where it feeds a predetermined amount of feed. The robot spreads the feed evenly over the individual tank in a circular area.

The features of this feeding system are:
- Up till 6 different feed types
- Feed pellets between 3mm and 13mm
- Automatic filling from Filling Station
- Capacity from 300 - 1000 Litres of feed
- Individual feeding in each tank
- Mixing of two feed types
- Automatic capture of feeding data

In order to determine the accuracy of the feeding robot we measured 64 times the amount of feed the robot distributed and compared it with the planned amount of feed and the computer read out of the distributed feed. These measures were taken between June 9 and August 16 2004.
We used feed with diameters ranging from 3 -13 mm. 3, 5, 7, 9, 11, and 13 mm diameter. We also used mixed feeds of two different diameters, in a combination of 50-50 or 25-75%.

In the analysis of the results we used the following parameters:

- Planned amount: the amount of feed planned to distribute and entered into the feeding computer as the amount to distribute,
- Computer read-out: the amount of feed the feeding computer claims to have distributed, and
- Weighted amount: the actual amount distributed by the feeding computer and weighted.
- The accuracy of the feeder was defined as the weighted amount/planned amount * 100%.

4.2.2 Statistical procedure

For the comparison of the planned amount, computer read-out and the weighted amount of feed we used a t-test for two-way analysis
The effect of the feed diameter and the effect of one or a mixture of feeds on the percentage of the planned feed weighted was analyzed by Anova.

4.2.3 Results

The weighted amount significantly differed from the planned amount ($p< 0.001$), as well as from the computer read-out ($p<0.001$). The planned amount differed significantly from the computer read out ($p<0.001$).

The differences were consistent. The computer read out was 5% higher than the planned amount (figure 8) whilst the weighted amount was consistently 4% lower that the planned amount (figure 9). The computer read-out showed an 8% higher amount of feed than the weighted amount.

Figure 8: relation between the amount planned and the computer read-out.

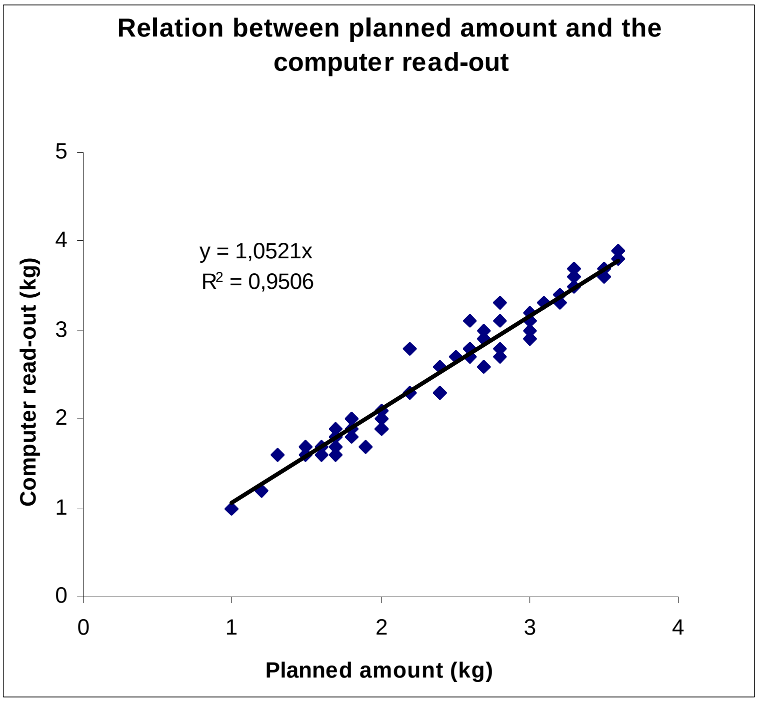
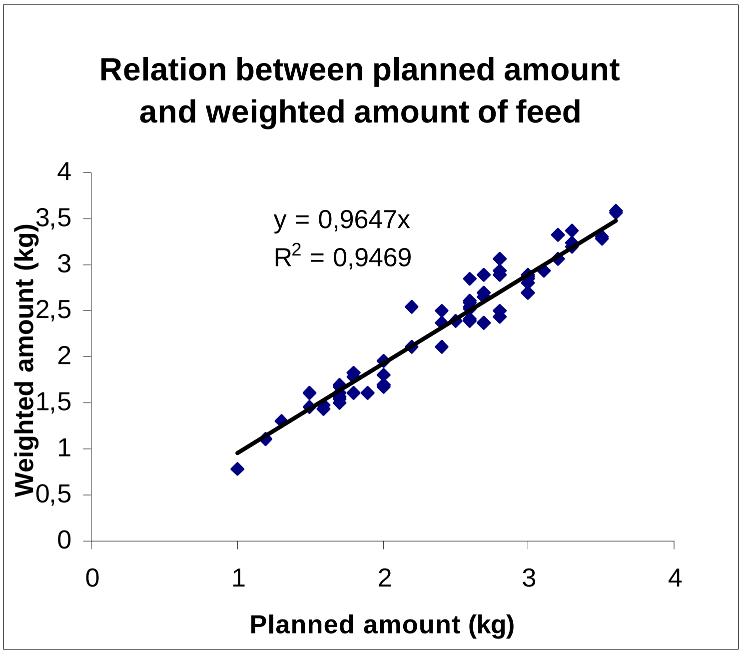


Figure 9: relation between the amount planned and the amount weighted.



We tested the accuracy of the feeding robot, by comparing the planned amount with the weighted amount of feed. We used the percentage weighted feed of the planned amount of feed as the measure of accuracy.
Feed pellets with a diameter of 3-13 mm were fed. Out of the 64 measures 19 times different feed sizes were mixed.

As a first step the effect of mixing different diameters on the accuracy was tested. Mixing diameters had no effect on the accuracy of the feeding robot. The average accuracy of mixed diameters was 97%, the accuracy of one diameter feeds was 95%, but the difference in average could not be contributed to the effect of mixing different diameters.

There was no effect of the actual amount fed and the accuracy of the feeding robot. It could be that the feeding robot would be less accurate for smaller quantities of feed, but in the range of dosage tested, from 1,0 to 3,5 kg, no such relation was found.

We did not find an effect of time. The accuracy was consisted during the whole testing period.

We did find an effect of feed diameter on the accuracy of the feeding robot ($p < 0.001$). The accuracy of all feeds was below 100%, except for the feeds that contained pellets of 7mm (table 4 and figure 10). The feeding robot delivered 103% of the planned feed when it contained pellets with a diameter of 7 mm, and 110% when it contained a mixture of 7 and 9 mm pellets in a combination of 25-75%.

Figure 10

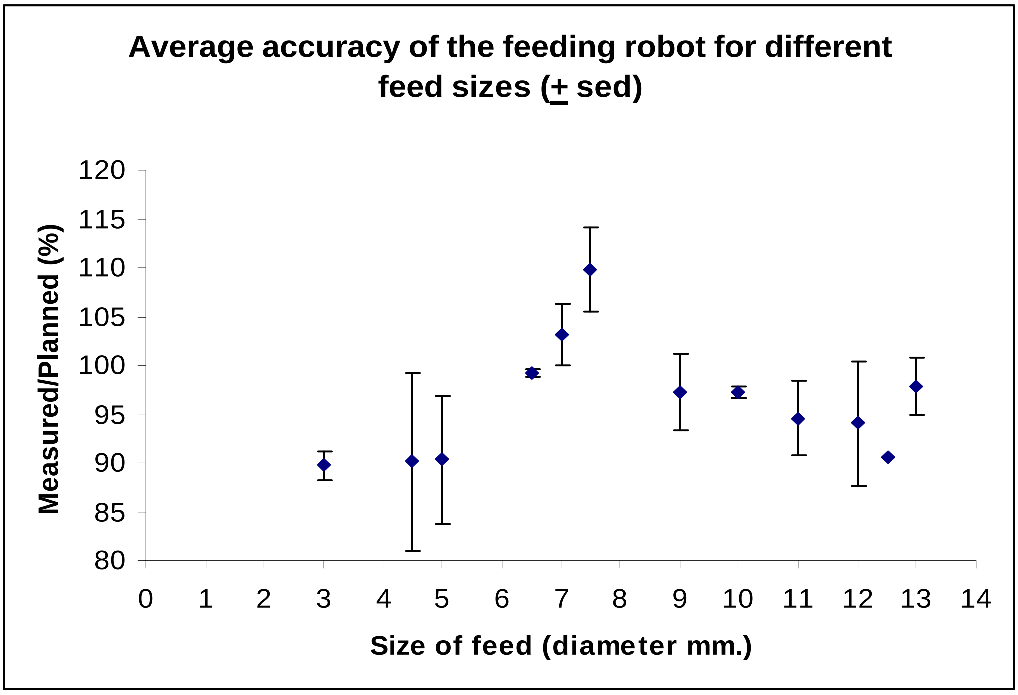


Table 4: average accuracy of the feeding robot by pellet size

Pellet diameter	n	Weighted/planned amount (%)	sed
3	4	89,72	1,54
4,5	4	90,13	9,13
5	12	90,34	6,52
6,5	2	99,17	0,39
7	6	103,09	3,18
7,5	4	109,74	4,30
9	11	97,27	3,90
10	2	97,31	0,54
11	6	94,59	3,79
12	6	94,06	6,36
12,5	1	90,59	
13	6	97,85	2,87
Overall total	64	95,84	0,07

4.2.4 Conclusion

The accuracy can be defined as a degree of matching with a real value. Precision is a measure of consistency of a reading with previous readings. From our study we can conclude that the feeder robot is not very accurate, but has a high degree of precision. This means that the actual amount of feed distributed does not correspond exactly with the amount the feeder claims to have distributed, neither with the amount the farmer planned to feed.

This should not be a problem since the precision of the robot is high. We did not find an effect of time, nor of the feed quantity. When a farmer programs the robot to feed 4% more than he actually intends to feed, the actual amount fed to the fish corresponds well with the intended amount. The robot states an 8% higher amount of feed fed.

The main problem with the robot is that its accuracy is influenced by the pellet size of the feed. The accuracy ranges from 90 to 110% for the different pellet sizes. At the same time no clear relation could be found between the accuracy and the pellet size, except that the middle range, from 6,5 to 10 mm, had a very high accuracy.

Depending on the accuracy a fish farmer intends to feed, he can make an overall adjustment of 4% for all his feed size. In that case he accepts that he will feed too much of the feeds with a diameter of 7 mm and not enough of the smaller pellets. Or he adjusts the robot depending on the feed size.

APPENDIX A: Pictures