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Test on fish survivability of Bedford Pumps model SAF 90.05.12

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Content

Appendices

Summary

For the past few decades the welfare of fish in their natural habitat has become a serious issue. For this reason, fish must be able to pass pumping station pumps ("pumps" in short), relatively unharmed.
On June 12th and 13th 2012 Bedford Pumps model SAF.90.05.12 was tested for its ability to let fish pass the motor without being injured. Bedford Pumps pump has been specially developed to be fish survivable. The test known as "the fish survivability test", was performed in a dry dock in the Netherlands. For the tests, three representative fish groups in two different size classes were forced to flow through the pump. The groups are:

- *Percidae (perch-like species, mainly perch and ruff),*
- *Cyprinidae (carp-like species, mainly roach and bream) and*
- *Anguillidae (European eel).*

The score is based on the amount of fish that pass the pump and survive without lethal injuries. The final rating of the pump is related to the score of other pumps of the same type.

In total 823 fish were exposed to the pump by force (water elevating height of 2.9 m) during three different rotation speeds: 373 fish in scenario 1 (330 rpm, 1.3 m^3/s); 363 fish in scenario 2 (425 rpm, 1.8 m^3/s) and 87 fish in scenario 3 (518 rpm, 2.3 m^3/s). In scenario 3 only eel were exposed.

1. *Except for a few large cyprinids (bream), all fish survived the test at 330 rpm and no lethal injuries were observed. Therefore Bedford Pumps SAF pump can be rated as "<u>Excellent</u>" for its fish survivability for this rotation speed and discharge.*
2. *All small percids and 99% and 98% of small cyprinids and small eel survived the test at 425 rpm (all delayed mortalities). Of the big percids 94% survived, 96% of the big cyprinids, and 98 % of the big eel (2% was considered lost for a spinal injury) survived the test. Bedford Pumps SAF pump can be rated as "<u>Good</u>" for this rotation speed and discharge.*
3. *In the test at 518 rpm 92 % of both small and big eel survived (8% was considered dead after 48 hours due to internal injuries).*

The end score fish survivability for Bedford Pumps model SAF.90.05.12 is a weighed average of the first two tests (330 and 425 rpm, water elevating height: 2.9 m) and is rated "<u>Excellent</u>".

1 Introduction

1.1 General

Pumping station pumps (pumps: in short) play a central role in water management and flood control. Common types of such pumps are screw pumps (also called axial pumps) and centrifugal pumps. Besides water, debris and fish are carried along through the pump. Fish passage can partly be avoided by means of a debris grill, so damage and mortality can be reduced. But at the same time, it prevents fish from reaching their spawning grounds. Especially for eel it is an absolute necessity to reach the sea on their way to the spawning grounds in the Sargasso Sea. Moreover, it is a species which is protected by EU regulations and has therefore special priorities. In recent years fish survival, fish damage and delayed mortality was tested for several types of pumps. The survival, damage and delayed mortality rates due to pump passages vary widely. The fish survival rate can be as low as 0%. In the context of fish welfare, manufacturers like Bedford Pumps Ltd., focus on the development of fish survivable pumps. At the request of Bedford Pumps Ltd, VisAdvies BV performed three tests on the fish friendly Axial Flow pump SAF.90.05.12 at rotation speeds of 330 rpm (approx. 1.3 m^3/s), 425 rpm (approx. 1.8 m^3/s), and 518 rpm (approx. 2.3 m^3/s). With these tests the fish survivability of the pump was evaluated. The tests were carried out to the protocol and classifying method, developed by VisAdvies BV.

1.2 Aim of the study

The aim of the study is to rate Bedford Pumps SAF.90.05.12 pump in the sense of fish survivability. The rating is based on:

1. The percentage of fish that survive the passage through the pump.
2. The type of injuries.
3. The percentage of (non lethal) injuries.
4. The reference to other pumps that are tested on fish survivability.

1.3 Pump description

The pump that was tested was Bedford Pumps SAF.90.05.12 (specifications: see table 1.1 and figure 1.2). A complete overview of the pump specifications is shown in appendix I. The pump with its impellor is shown in figure 1.1.

table 1.1 Specifications of Bedford Pumps SAF.90.05.12.

Weight	3856 kg
Electrical supply	50 Hz / 400 V / 3 pH
Nominal running speed	585 rpm
Motor rating required (max)	166 kW
Full l load current (166 kW)	307 A
Pump set inertia (166 kW)	13.09 kg/m^2

figure 1.1 *Impeller of Bedford pumps SAF.90.05.12.*

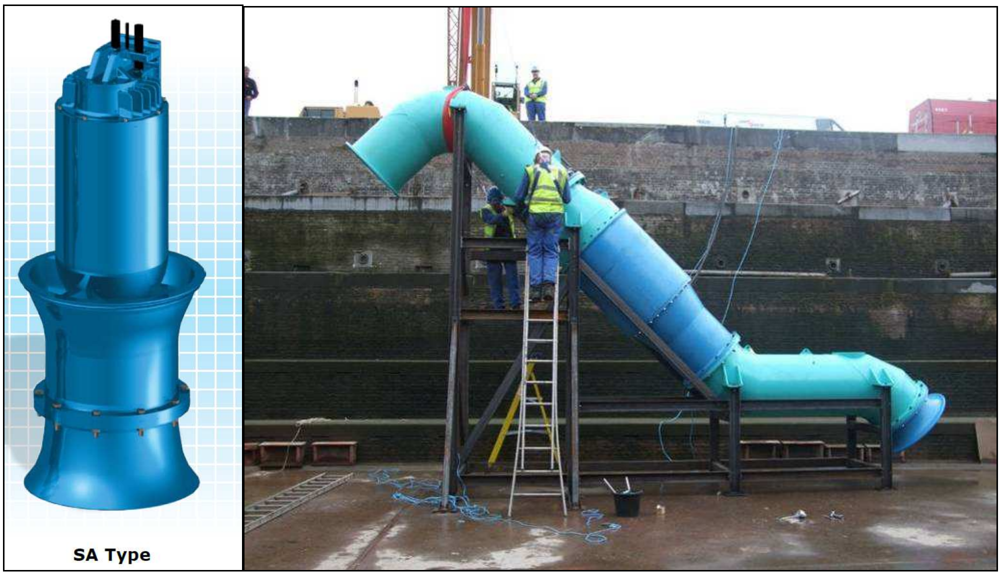


figure 1.2 *Drawing (left) and picture (right) of Bedford Pumps submersible axial pump SAF.90.05.12. Right: the pump with in- and outlet pipes, mounted on the rig.*

2 Field test approach

2.1 Experimental animals

In order to test new ‘fish friendly’ pumps on their fish survivability, before the pump is actually released onto the market, a unique test on its fish survivability is required by a so called forced exposure of fish to the running pump (in a controlled environment).

The experimental animals used in this study belong to three families of fish that are very common in European waters. Within each family target species are chosen who can be considered as representative for the European fish fauna:

- *Anguillidae* (eel-like): **eel** (*Anguilla anguilla*);
- *Cyprinidae* (carp-like): **bream and roach** (*Abramis brama, Rutilus rutilus*);
- *Percidae* (perch-like): **perch and ruff** (*Perca fluviatilis, Gymnocephalus cernua*).

Two representative length classes for each group were used for each of the tests:

Eel:	size group 1: ≤ 45 cm; size group 2 > 45 cm.
Cyprinids:	size group 1: ≤ 15 cm; size group 2 > 15 cm
Percids:	size group 1: ≤ 15 cm; size group 2 > 15 cm

For each group and length class of fish, preferably fifty individuals were exposed to the running pump. (table 4.1).

The reasons for the selection of the groups are:

- They are representative for the most common fish.
- They are representative for the <u>more</u> vulnerable (cyprinids) and <u>less</u> (percids) vulnerable fish groups, due to fish passage through pumps.
- Eel is of special interest because of its cathadromous[1] migration pattern, which makes it a necessity to pass all pumping stations and hydro power plants on their way, to reach its spawning ground.

The percids and cyprinids were wild caught specimens, provided by a commercial fisherman (Bram van Wijk, Visserij Service Nederland). The eel are obtained from a commercial eel farm in the Netherlands (Nijvis BV, Nijmegen).
For each fish group and length class an amount of fish will be exposed, such that the desired confidence interval is accomplished (see also § 2.3).

The use of experimental animals is authorized by the Animal Experimental committee Dier Experimenten Commissie, DEC) of the Central Veterinary Institute of Wageningen University and Research Centre (see appendix II). All personnel involved in the experiments were authorized by the Animal Experimental committee (cf. Article 9 authorized officer WOD (J.H. Kemper and I.L.Y. Spierts) and cf. Article 12 authorized

[1] Fishes that spend most of their lives in fresh water and migrate to the sea to breed.

officer WOD (H. Vis)) under the guidance of Drs P.S. Kroon of the Central Veterinary Institute (cf. authorized officer with Article 14 WOD).

2.2 Field setup and fish handling

The experiments were carried out on the 12th and 13th of June 2012 in the dry dock 'Jan Blanken' in Hellevoetsluis, the Netherlands (figure 2.1).

figure 2.1 *Dry dock 'Jan Blanken' (left) and pump in dock (right).*

The essence of the set-up is that the fish are inserted in the pump in such a way, that escapement from the device is impossible. In figure 2.2 the forced exposure of the fish is shown. A net was positioned over the inlet pipe, through which fish entered the pump. After passing the pump, fish were caught in a knot less Norwegian life net (4x4x3,5 m), as shown in figure 2.2 and subsequently 'forced' to swim in the direction of a fyke, positioned directly behind the life net. Immediately after each test run was finished, fish were taken out of the fyke and checked for survival and damages. In this check four classes were distinguished:

- no damage;
- scale damage;
- cuts;
- immediate death.

figure 2.2 *Forced exposure of fish to the running pump.*

The SAF.90.05.12 was tested at three rotation speeds, and one water elevating level (table 2.1).

Fish that pass the pump alive and without any noticeable damage, can still have invisible damages or even die after some time as a result from internal damages. In order to determine if this was the case, all fish that passed the pump and had no damages were stored for the duration of 48 h in four large fish tanks (1000-1500 l each (see figure 2.3).

table 2.1 *Experimental conditions.*

Test	Rotation speed (rpm)	Flow (m^3/s)	Water elevating level (m)
1	330	1.3	2.9
2	425	1.8	2.9
3	518	2.3	2.9

figure 2.3 *Fish storage tanks for delayed mortality study.*

After storage, fish were checked again. All surviving fish were released, and dead fish were discharged. Special attention was paid to eel that showed haemorrhages and irregularities (figure 2.4 & figure 2.5). Eel that showed these signs, but did survive the 48 h storage period, were killed and internally examined. These eels were classified as lost ("delayed mortality") in the analysis. Eel with haemorrhages as a result of muscle bruises were considered as survivable. Although eel with fracture (s) in their spinal column, can survive for quite some time, it is assumed that these fish are not able to reach their spawning grounds in the Sargasso Sea, eventually.

figure 2.4 *Eel with blood stained ventral fin (under). Eel with no haemorrhage (top).*

figure 2.5 *Dissected eel with internal haemorrhage.*

2.3 Statistical evaluation

From the results not only an estimate of the chance of survival of fish is being determined, also the borders between which this chance of survival exactly lies is given, the so-called confidence interval. The estimated chance of survival is equal to the number of fish that survived divided by the total number of fish that passed the pump. The variance in the number of fish that survived is then estimated by:

$$s^2(n) = N\hat{p}(1-\hat{p})$$

Where s2 (n) the estimated variance in the number of survived fish, n and $N\hat{p}$ the number of survived fish, N is the total number of fish and $\hat{p}$ the estimated probability of survival. A rough estimate of the 95% confidence interval of the number of survived fish is given by n ± 2s (n). By dividing these values by the number of observations we obtain the confidence interval of the chance. The confidence interval can be determined more precisely, where the most conservative results are obtained with the so-called exact method, which directly uses the properties of the binomial distribution (Wikipedia). The reliability are calculated using a confidence interval calculator on the Internet.
(http://statpages.org/confint.html#Binomial

3 Fish survivability score

3.1 Computation

Fish survivability of a pump is determined on the basis of the number of fish that passed the pump and survived, by group and by length class. The determination of fish survivability of a pump is based on fish which, after passage through a pump, are classified in the category 'survive', in which:

Percentage survival = total amount of fish that survived / total amount of fish passed,
Total amount of fish that survived = sum all fish that survived the pump passage.

Fish that pass a pump alive and without any visible damage can still die after a while as a result of internal damage. To understand to what extent this is the case with the pump to be tested, also the delayed mortality is included in the total number of fish that did not pass the pump alive. For each fish group and length class the total amount of fish that survived will be expressed as a percentage of the total amount of fish in that particular class (length and specie) that were exposed to the pump by force. In the end this will result in six survival rates (three fish group and two length classes per specie).

3.2 Evaluation

For each tested pump the evaluation results in a score between 0 and 1, with which the fish survivability of a pump is determined. A final score of 0 means that a pump has minimal fish survivability, a final score of 1 means optimal survivability.

The determination of the degree of fish survivability of a certain pump, i.e. the final fish survivability score, is structured as follows. Each test group is classified into two length categories (table 3.1). For each length category a survival rate will be determined by the forced exposure test. The resulting survival rates are then divided into four possible classes of survivability (coloured columns in table 3.1).

table 3.1 *Structure final score fish survivability.*

	Group	Length class (cm)	Weighing factor	Survivability classes (%)			
				Excellent	**Good**	**Insuffici-ent**	**Bad**
1	**Eel**	0-45	0.15	99-100	95-98	90-94	0-89
2		>45	0.25	99-100	95-98	90-94	0-89
3	**Cypr.**	0-15	0.1	97.5-100	90-97.4	80-89	0-79
4		>15	0.2	95-100	90-94	75-89	0-74
5	**Perc.**	0-15	0.1	99-100	97.5-98	92.5-97.4	0-92.4
6		>15	0.2	99-100	95-98	90-94	0-89
Score % survival				**0.75-1**	**0.5-0.75**	**0.25-0.5**	**0.0-0.25**

The classification of these four classes is entirely based on the results of the survival rates (per group and length class) for pumps whose test results were available (see Appendix III, only in Dutch). The classification of the fish survivability is shown in table 3.1. The individual survival rates for each category (group and length class) of the pump to be tested will subsequently be compared with the average individual survival rates of the pumps already tested.
Each group has for each length class a separate weighing factor (fourth column table 3.1). The total weighting factor for eel is higher (0.4 out of 1) than for cyprinids (0.3 out of 1) and for percids (0.3 out of 1). This is due to the great need for migration of this species, and the (low) degree of occurrence. All groups have a higher weighting factor for larger fish than for smaller fish because: 1) the greater likelihood of being hit by the pump, and 2) the importance of larger specimens of each group for the conservation of the species. The sub score per group and length class (six in total) is calculated as follows:

<u>Sub score group 1, length class 1</u> = weighing factor X score % survival.

table 3.2 *Classification end score fish survivability.*

Score	Classification	Colour code
0.75-1	Excellent	
0.5-0.75	Good	
0.25 -0.5	Insufficiënt	
0.0-0.25	Bad	

Finally, the end score of the pump to be tested is the sum of all six sub scores. A pump with score 1 will have a score for fish survivability that is comparable with the best pumps tested until yet, and a pump with score 0 will have a score for fish survivability that is compared with the worst pumps tested until yet (table 3.2).
The individual sub scores per category are however also important to notice in the final evaluation of a pump.

4 Results

4.1 Fish data

table 4.1 *# Fish used for each pump scenario and fish category, with confidence interval.*

	Group	Length class (cm)	# Fish used for each test			Confidence interval for each test		
			330 rpm	**425 rpm**	**518 rpm**	**330 rpm**	**425 rpm**	**518 rpm**
1	**Eel**	0-45	52	50	49	0.069	0.005-0.14	0.073-0.3
2		>45	56	50	38	0.064	0.005-0.14	0.10-0.37
3	**Cypr.**	0-15	133	76	-	0.027	0.0003-0.071	-
4		>15	38	48	-	0.093	0.023-0.2	-
5	**Perc.**	0-15	68	104	-	0.053	0.035	-
6		>15	26	35	-	0.13	0.066-0.34	-
	Total		**373**	**363**	**87**			

All fish that were used in the experiments were in perfect condition before the start of the experiment. In pump test scenario 1 in total 373 fish passed the pump: 108 eel; 171 cyprinids and 94 percids (table 4.1). The fish passed the pump well and were properly caught in the Norwegian life net. Also the second pump test scenario went well. In total 363 fish passed the pump: 100 eel; 124 cyprinids and 139 percids. During the start of the third scenario initially only the small eel (N=49) were exposed to the running pump. The force of the water that left the outlet pipe was however that strong, that there was a real chance that the Norwegian life net would be destroyed. In consultation with the project manager from Bedford Pumps Ltd it was therefore decided that in the last test only eel (49 small and 38 large) were going to be exposed, and no cyprinids or percids, in order to preserve the net. The mean TL ± stdev of all fish categories and test scenario' s are shown in table 4.2. As is shown in table 4.1 it is clear that the borders between which the chance of survival exactly lie for all groups (confidential intervals) are small.

In appendix IV all length frequency diagrams are shown for all fish categories and test scenario 's, separately.

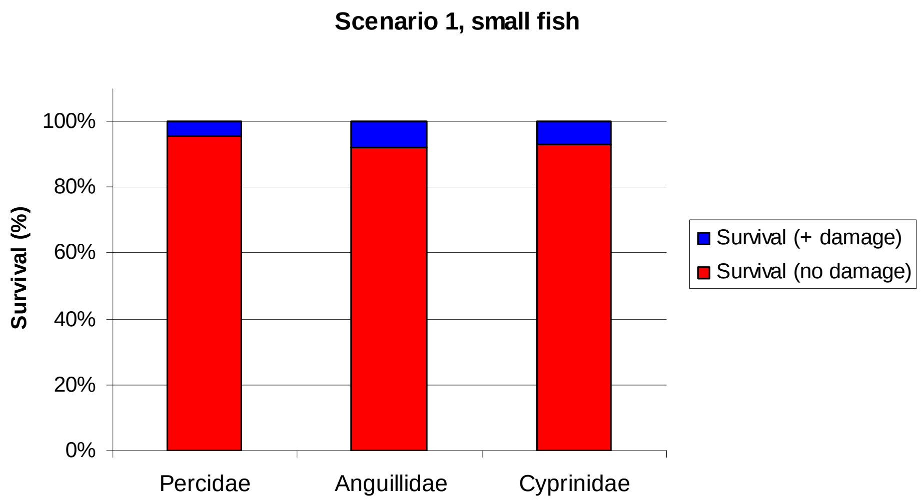
table 4.2 *Mean TL ± stdev of all used fish.*

	Group	Length class (cm)	Pump scenario: rotation speed		
			330 rpm	**425 rpm**	**518 rpm**
1	**Eel**	0-45	36±3.1	36±2.3	37±1.9
2		>45	54±4.4	54±5.8	55±5.9
3	**Cypri.**	0-15	11±1.8	14±4.4	-
4		>15	19±5.9	15±4.4	-
5	**Perc.**	0-15	10±1.6	13±4.4	-
6		>15	16±3.8	13±4.7	-

4.2 Survival rates

4.2.1 Test scenario 1 (330 rpm, 1.3 m^3/s)

All of the 253 small fish and 120 big fish that were exposed to the running pump survived their way through the pump (so 100% survival, figure 4.1). The most severe damage to the cyprinids and percids was scale loss, but no cuts (decapitation or dividing) were observed. This descaling however was not due to the forced exposure to the running pump and the impeller itself, but was caused by: 1) the heavy impact of the fish on the water when they left the outlet pipe of the pump (see also figure 2.2), and 2) the contact with the Norwegian life net in which the fish where captured after the exposure. It is clear that cyprinids and percids (in a lesser extend), are vulnerable to excessive skin contact. The fish that were used in these experiments were firstly cached, secondly brought into the inlet pipe of the pump, and thirdly caught in the Norwegian life net. This amount of contact is inevitable in these kind of experiments, but it does explain the occurring descaling of the skin.



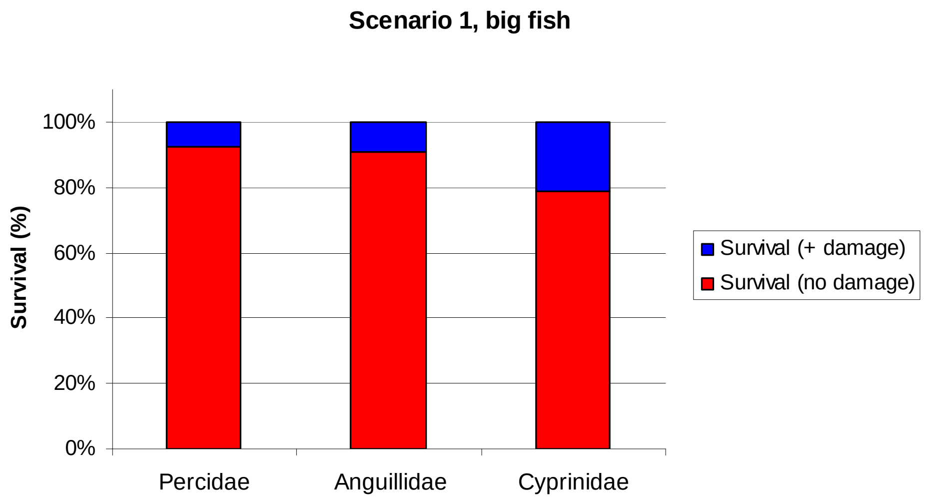
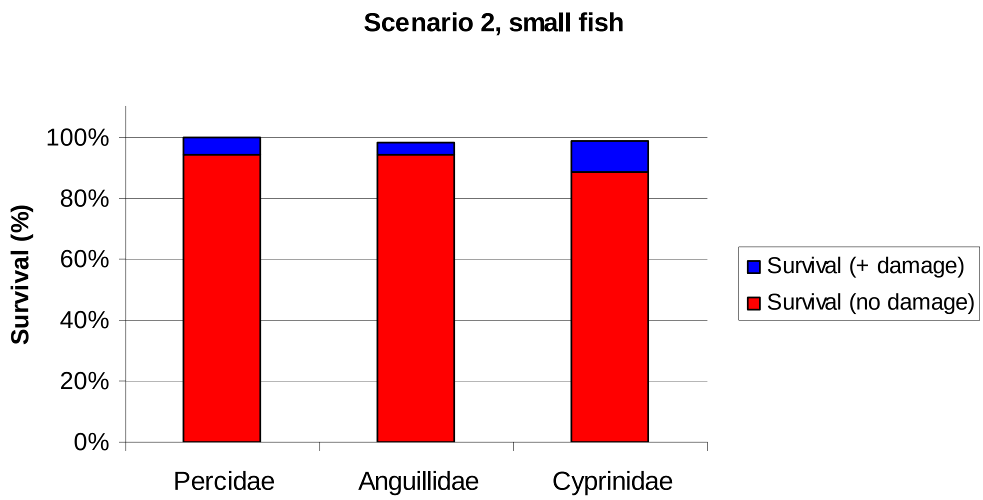


figure 4.1 *Overview survival rates of three fish group for small (above) and big fish (below).*

Except for the big cyprinids more than 90% of all other fish classes had passed the running pump completely undamaged (see also appendix V). It is also interesting to notice that there was not a large difference (again except for the big cyprinids) in direct damage between the small and the big fish that were exposed to the running pump. No eel was cut and the most severe damage that was observed was red staining of the ventral fins (belly side), which indicates an internal haemorrhage. These fish were internally examined, and no injuries due to the pump passage were observed. Especially for the big eel this is an interesting outcome, as these fish had a mean TL of 54±4.4 cm.

4.2.2 Test scenario 2 (425 rpm, 1.8 m^3/s)

100% of the small percids that were exposed survived the pump passage (figure 4.2 and appendix V), whereas this was 99% and 98% for small cyprinids and small eel, respectively (both delayed mortalities). Similar as in test scenario 1, but to a slightly larger extent caused by the 1.3x times higher rotation speed of the pump, the most severe damage to the cyprinids and percids was scale loss. Again the scale loss was largely due to the hard contact with the water after the fish left the outlet pipe of the pump and due to net contact. 94% Of the big percids that passed the running pump survived (6 % direct mortality occurred). 96% of the big cyprinids survived the running pump, and 98 % of the big eel did so (2% survived 48 hours, but were considered lost for the posterity). In test scenario 2 no eel was cut.



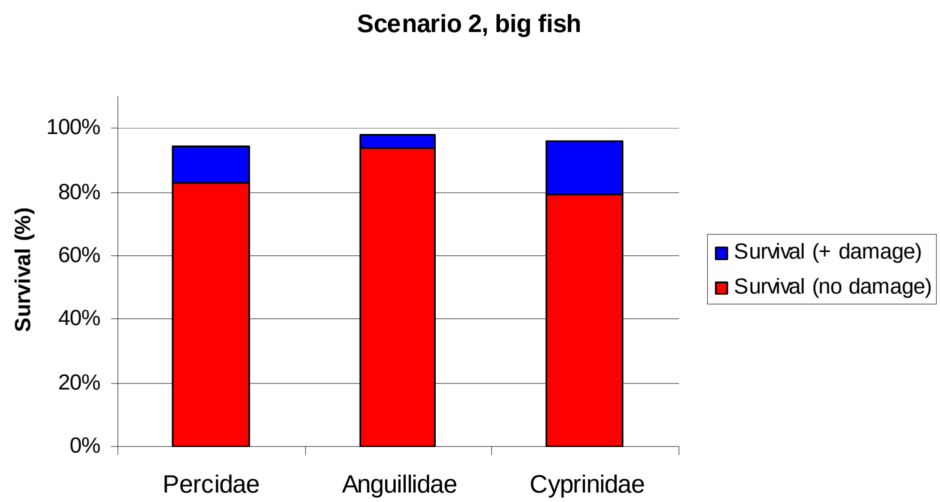
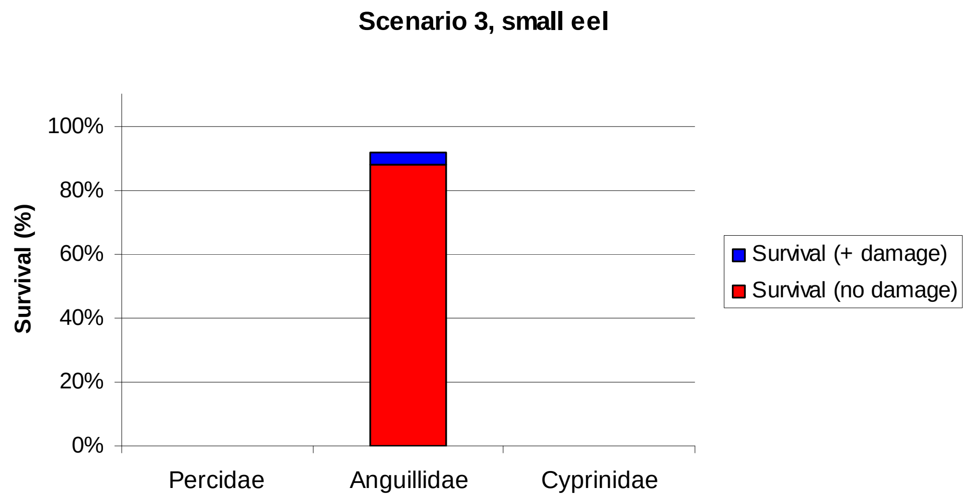


figure 4.2 Overview survival rate of three fish groups for small (above) and big fish (below).

4.2.3 Test scenario 3 (518 rpm, 2.3 m^3/s)

As, in consultation with the project manager from Bedford Pumps Ltd, it was decided that in this test only eel were going to be exposed, so no data are available for cyprinids or percids. In this scenario 49 small and 38 big eel were exposed to the running pump (518 rpm). For both the small and big eel 92% survived the forced exposure to the running pump (figure 4.3). In both cases there was 8% of the fish that were considered lost for the posterity. In test scenario 3 the percentage of eel that survived the passage of the running pump was lowest compared with test scenario 's 1 and 2. For big eel this difference was similar as for small eel (100%, 98% and 92% for scenario 1, 2 and 3, respectively). 88% of the small eel passed the running pump with no damage, whereas this was 82% for the big eel. In test scenario 3 no eel was cut. Two small eel and four big eel showed skin damage.



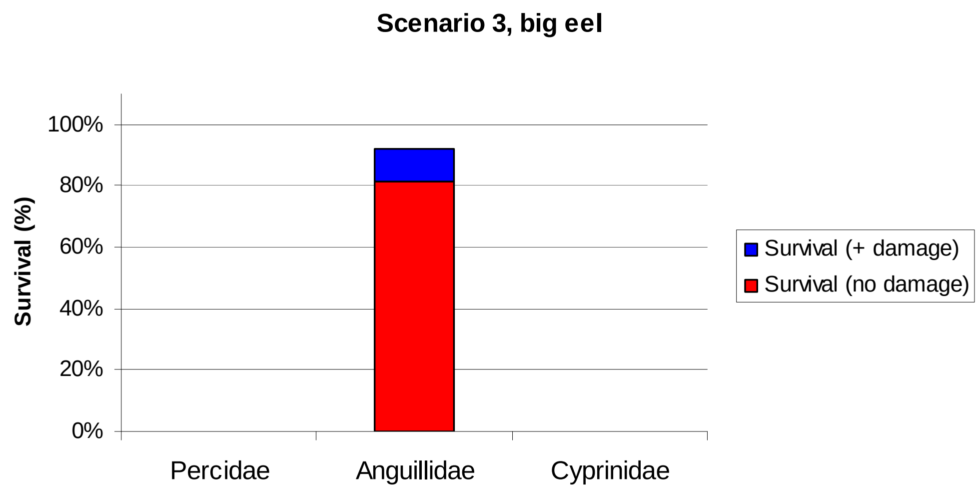


figure 4.3 *Overview survival rate of three fish groups for small (above) and big eel (below).*

4.3 Delayed mortality

Cyprinids and percids

After being exposed to the pump, the cyprinids and percids were kept for 48 hours in large fish tanks in order check them for delayed mortality. In test scenario 1 no delayed mortality occurred within 48 h after the test. In test scenario 2 one small cyprinid died in the first few hours of the 48 hour storage period as an result of passing the pump.

Important remark: Although there was little delayed mortality within 48 h after the experiment, still 10-15% of all cyprinids and percids eventually died after the 48 h period. These death can however not be attributed to the passage of the pump itself. There are several causes: 1) handling of the fish before the experiment (catching them, inserting them into the inlet pipe); 2) the constant contact with nets, prior to the experiment and after the experiment; 3) the hitting of the water when leaving the outlet pipe of the pump, 4) the higher water temperature at the moment of storage and testing, and 5) the storage itself. No fish likes being confined for 48 h, swimming freely is always a better solution. It is therefore that these delayed mortalities are mentioned, but are not included in the group of fish that did not survive the pump passage itself.

Eel

Compared with other fish species, eel are in general physically stronger. All eel responded well to the circumstances they were exposed to during the test. In test scenario 2 one small eel and one big eel were considered lost after 48 hours (spinal injury). In test scenario 3 four small eel and three big eel died within 48 h after finishing the test.

4.4 Fish survivability scores

4.4.1 Test scenario 1 (330 rpm, 1.3 m^3/s)

In table 4.3 the survival rates are shown for all fish categories that passed the running pump at 330 rpm, 1.3 m^3/s. The mortality amongst fish that passed the pump consists of both direct as well as delayed mortality after 48 h. In all categories the pump passage resulted in 100 % fish survival.

table 4.3 *Results survival rates Bedford Pumps SAF.90.05.12 test scenario 1.*

	Group	Length class (cm)	Weighing factor	Survivability classes (%)			
				Excellent	Good	Insufficient	Bad
1	Eel	0-45	0.15	100			
2		>45	0.25	100			
3	Cypri.	0-15	0.1	100			
4		>15	0.2	100			
5	Perc.	0-15	0.1	100			
6		>15	0.2	100			
	Score % survival			0.75-1	0.5-0.75	0.25-0.5	0.0-0.25

In figure 4.4 the sub- and end scores for each separate fish category are shown. It is obvious that Bedford Pumps SAF.90.05.12 pump scores the maximum score in all classes, so also in the end score, which is 1. This makes Bedford Pumps SAF.90.05.12 pump an appropriate pump for fish survivability when constantly running at 330 rpm (1.3 m^3/s) with a water elevating height of 2.9 m.

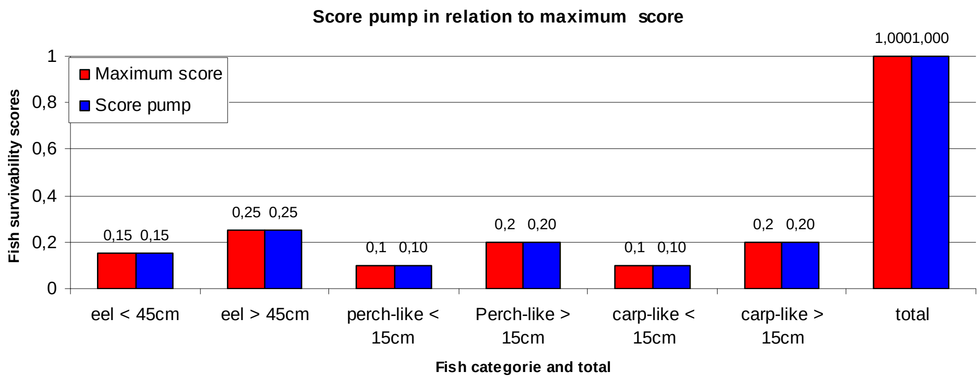


figure 4.4 *Sub- and end score fish survivability Bedford Pumps SAF.90.05.12 test scenario 1 (the scores are shown above the bars).*

4.4.2 Test scenario 2 (425 rpm, 1.8 m^3/s)

In table 4.4 the survival rates are shown for all fish categories that passed the running pump at 425 rpm, 1.8 m^3/s).

Of both the small and big eel, 98 % survived the passage through the pump. Of the eel > 45 cm, 2 % of the individuals were considered lost after 48 hours due to spinal injuries. Both size groups scored *"Good"* in their fish category.
Of the big percids (> 15 cm) 94 % survived the passage through the pump, against 96% big cyprinids. This is surprising since percids are generally less vulnerable than cyprinids. Score: *"Excellent"*.
Of the small cyprinids, 99 % survived the pump passage. Score: *"Excellent"*.

table 4.4 *Results survival rates Bedford Pumps SAF.90.05.12 test scenario 2.*

	Group	Length class (cm)	Weighing factor	Survivability classes (%)			
				Excellent	**Good**	**Insufficient**	**Bad**
1	**Eel**	0-45	0.15		98		
2		>45	0.25		98		
3	**Cypr.**	0-15	0.1	99			
4		>15	0.2	96			
5	**Perc.**	0-15	0.1	100			
6		>15	0.2			94	
Score % survival				**0.75-1**	**0.5-0.75**	**0.25-0.5**	**0.0-0.25**

In figure 4.5 the sub- and end scores for each separate fish category are shown. As mentioned earlier, the 94% survival of big percids brings down the end score to 0.715. Still this end score fish survivability falls within the classification good (see table 3.2). Bedford Pumps SAF.90.05.12 pump is therefore also a good pump for fish survivability when constantly running at 425 rpm (1.8 m^3/s) with a water elevating height of 2.9 m.

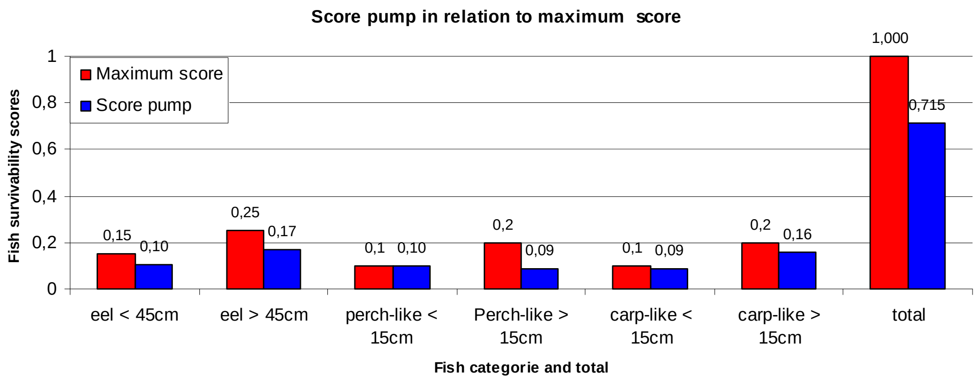


figure 4.5 *Sub- and end score fish survivability of Bedford Pumps SAF.90.05.12 test scenario 2 (the scores are shown above the bars).*

4.4.3 Test scenario 3 (518 rpm, 2.3 m^3/s)

In consultation with the project manager from Bedford Pumps Ltd, it was decided that in the last test only eel were going to be exposed, and no cyprinids or percids, in order to preserve the net. Therefore only eel survival percentages and sub score fish survivability are shown (table 4.5). There is no end score fish survivability available for this scenario. There was in both fish categories a 92 % fish survival. Both small and big eel score insufficient in their fish category.

table 4.5 *Results survival percentages eel Bedford Pumps model SAF.90.05.12 test scenario 3.*

	Group	Length class (cm)	Weighing factor	Survivability classes (%)			
				Excellent	**Good**	**Insufficient**	**Bad**
1	**Eel**	0-45	0.15	-		92	
2		>45	0.25	-		92	
	Scorel % death			**0.75-1**	**0.5-0.75**	**0.25-0.5**	**0.0-0.25**

4.4.4 End score

The end score fish survivability for Bedford Pumps model SAF.90.05.12 pump is a weighed average of the first two test scenario (330 rpm and 425 rpm) end scores, 1 and 0.715 respectively. This brings the end score at 0.86. Score: "*Excellent*".

The results of the mean fish survivability scores for the most common existing pumps in the Netherlands (see appendix III) show large difference between different types of pumps. In table 4.6 the mean end score fish survivability for different pump types is given. Only those pumps were included, that actually were tested under exactly the same conditions and with exactly the same fish group and length classes as described in this particular study. In the first column of table 4.6 is shown (between brackets) how many pumps were used to calculate the mean fish survivability. Needless to say is that the score runs from 0 ("*Bad*") to 1 ("*Excellent*"). The mean end

scores fish survivability of existing pumps are calculated by using the mean survival rates per group and per length class for each type of pump shown in appendix III.
It is obvious that mortars on average score the best, whereas closed screw pumps score the worst. It is good to notice that these end scores are just an indication and give a rough picture of fish survivability of different pump types. In the last row of the graph the score of Bedford Pumps model is shown.

table 4.6 *Indication of the mean fish survivability end scores per pump type. Between brackets: amount of pumps tested for calculating the score: --: Too little data available from these pump types to calculate end score fish survivability. Bottom line: end result of the test with Bedford Pumps model in this study.*

Pump type	Mean end scores fish survivability (0-1)
Turbine auger	--
Centrifugal pump	--
Mortar (5)	0.90
Screw centrifugal pump (5)	0.73
Hidrostal pump	--
Closed screw pump (2)	0.28
Open screw pump (2)	0.31
Closed screw compact (2)	0.30
Bedford Pumps submersible axial pump SAF.90.05.12	**0.86**

5 Conclusions

General

1. The end score fish survivability for Bedford Pumps model SAF.90.05.12 is a weighed average of the first two test scenario (330 rpm, 1.3 m^3/s; and 425 rpm, 1.8 m^3/s, water elevating height: 2.9 m) end scores, 1 and 0.715 respectively. This brings the end score to 0.86. Score: "*Excellent*".
2. With its end score of 0.86 for fish survivability Bedford Pumps model SAF.90.05.12 belongs to best pumps on the market concerning this subject!
3. The descaling of the cyprinids and percids during the experiment (and later their delayed mortality) was not due to the forced exposure to the running pump and the impeller itself, but was caused by: 1) the heavy impact of the fish on the water when they left the outlet pipe of the pump, 2) the contact with both the net to guide the fish into the inlet pipe of the pump and the Norwegian life net in which the fish where captured after the exposure, and 3) the storage of the fish during 48 h, the higher water temperatures. The 10-15% delayed mortality amongst this group can therefore not be attributed to the pump passage itself.
4. It is important to mention that at the top of the outlet pipe an inspection hatch was present. The hatch however was constructed in such a way, that passing fish could get hurt. It is however unclear to what extent this inspection hatch contributed to damaged or even dead fish. An improvement of this hatch would solve this problem.

Test scenario 1

5. All of the 253 small fish and 120 big fish that were exposed to the running pump survived their way through the pump (so 100% survival).
6. Except for the big cyprinids more than 90% of all other fish classes had passed the running pump completely undamaged.
7. No eel was cut and the most severe damage that was observed was red staining of the ventral fins (belly side), which indicates an internal haemorrhage.
8. Concerning the fish survivability score Bedford Pumps model SAF.90.05.12 pump scores the maximum score in all classes, so also in the end score, which is 1. This makes Bedford Pumps model SAF.90.05.12 pump a good pump for fish survivability when constantly running at 330 rpm (1.3 m^3/s) with a water elevating height of 2.9 m.

Test scenario 2

9. 100% of the small percids that were exposed survived the pump passage, whereas this was 99% and 98% for small cyprinids and small eel, respectively (both delayed mortalities).
10. Similar as in test scenario 1, but to a slightly larger extend caused by the 1.3x times higher rotation speed of the pump, the most severe damage to the cyprinids and percids was scale loss, though not due to the forced exposure to the running pump.
11. Of the big percids, 94% survived the passage through the pump.

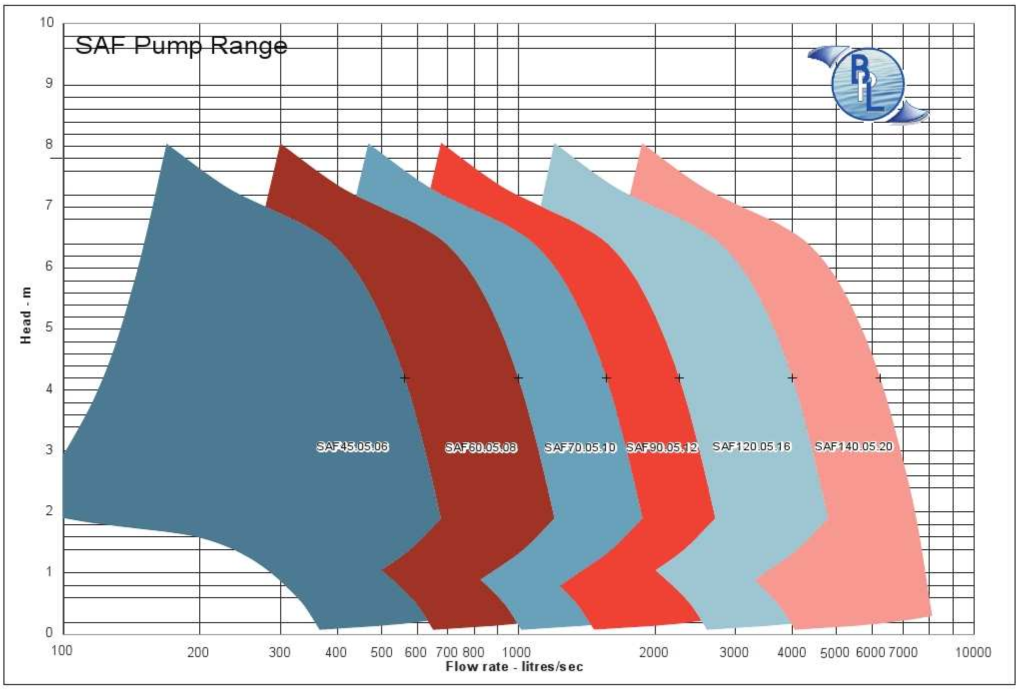
12. 96% of the big cyprinids survived the running pump (4% direct mortality), and 98 % of the big eel did so (2% delayed mortality).
13. No eel was cut.
14. Similar as in test scenario 1 it appeared that proportionally more big fish than small fish were damaged directly after the test.
15. Concerning the fish survivability score the end score is 0.715. A 6% direct death of the percids > 15 cm brings down the end score to 0,715. Still this end score fish survivability falls within the classification good. Bedford Pumps model SAF.90.05.12 pump is therefore also a good pump for fish survivability when constantly running at 425 rpm (1,8 m^3/s) with a water elevating height of 2.9 m.

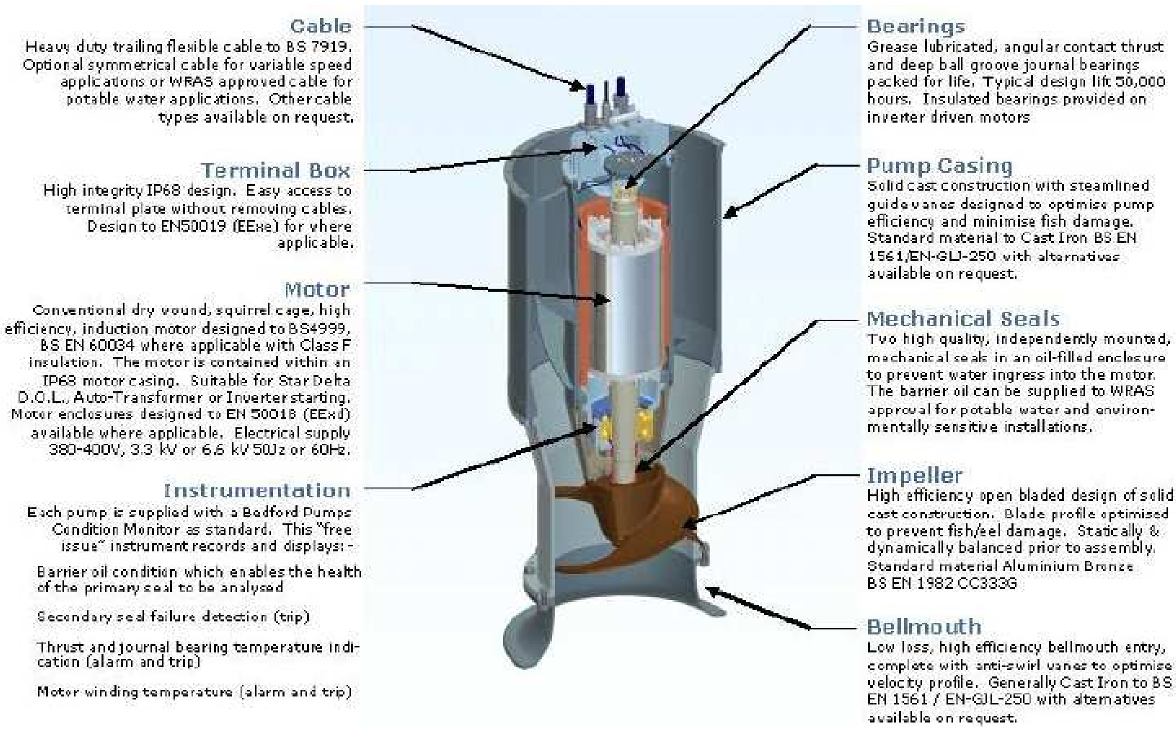
Test scenario 3

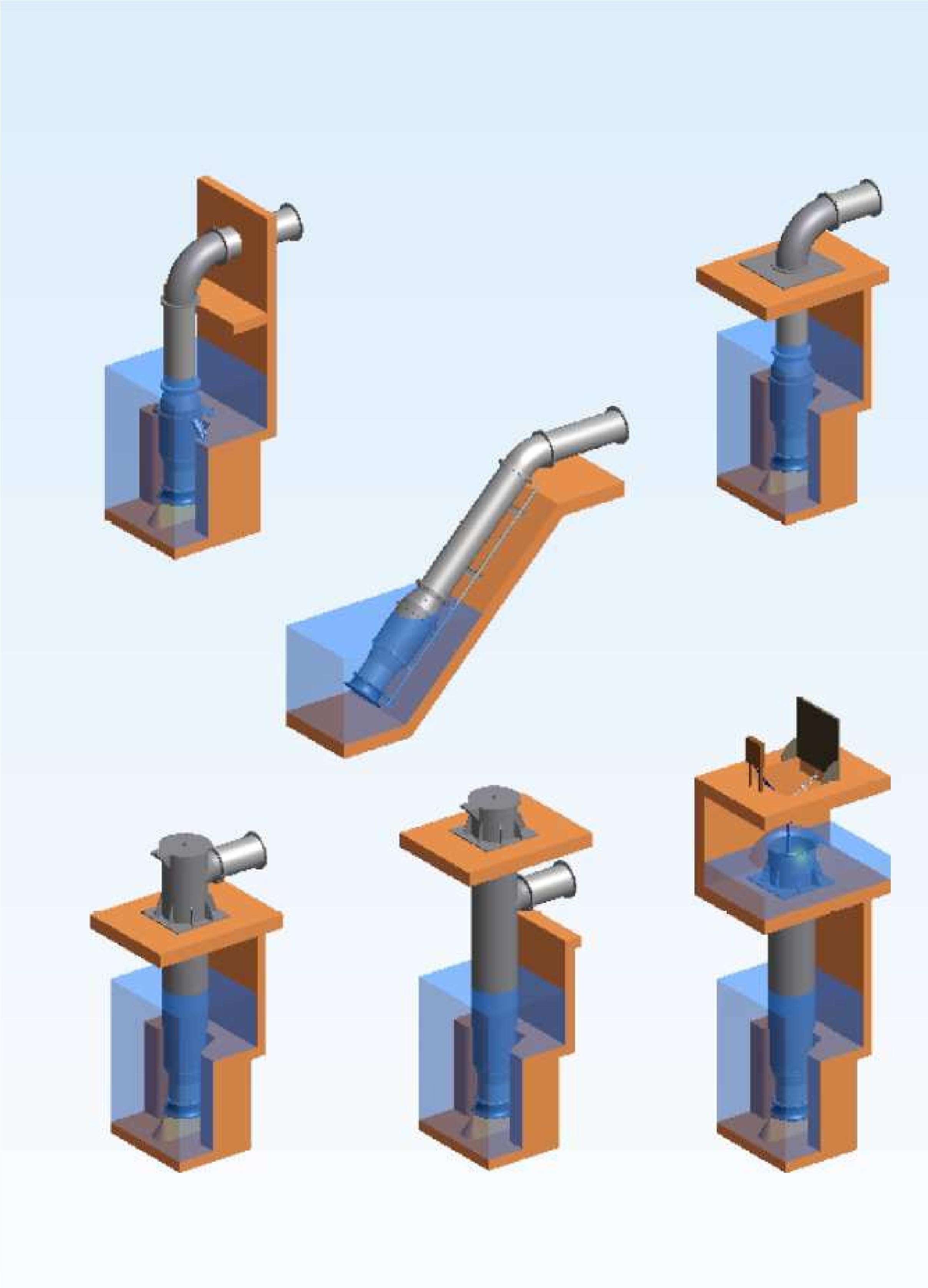
16. For both the small and big eel 92% survived the forced exposure to the running pump (8 % direct mortality occurred).
17. In test scenario 3 the percentage of eel that survived the passage of the running pump was lowest compared with test scenario ‘s 1 and 2.
18. No eel was cut. Two small eel and four big eel showed skin damages.
19. There is no end score fish survivability available for this scenario. There was in both fish categories a 92 % fish survival, which led to a score ‘insufficient’ in their fish category.

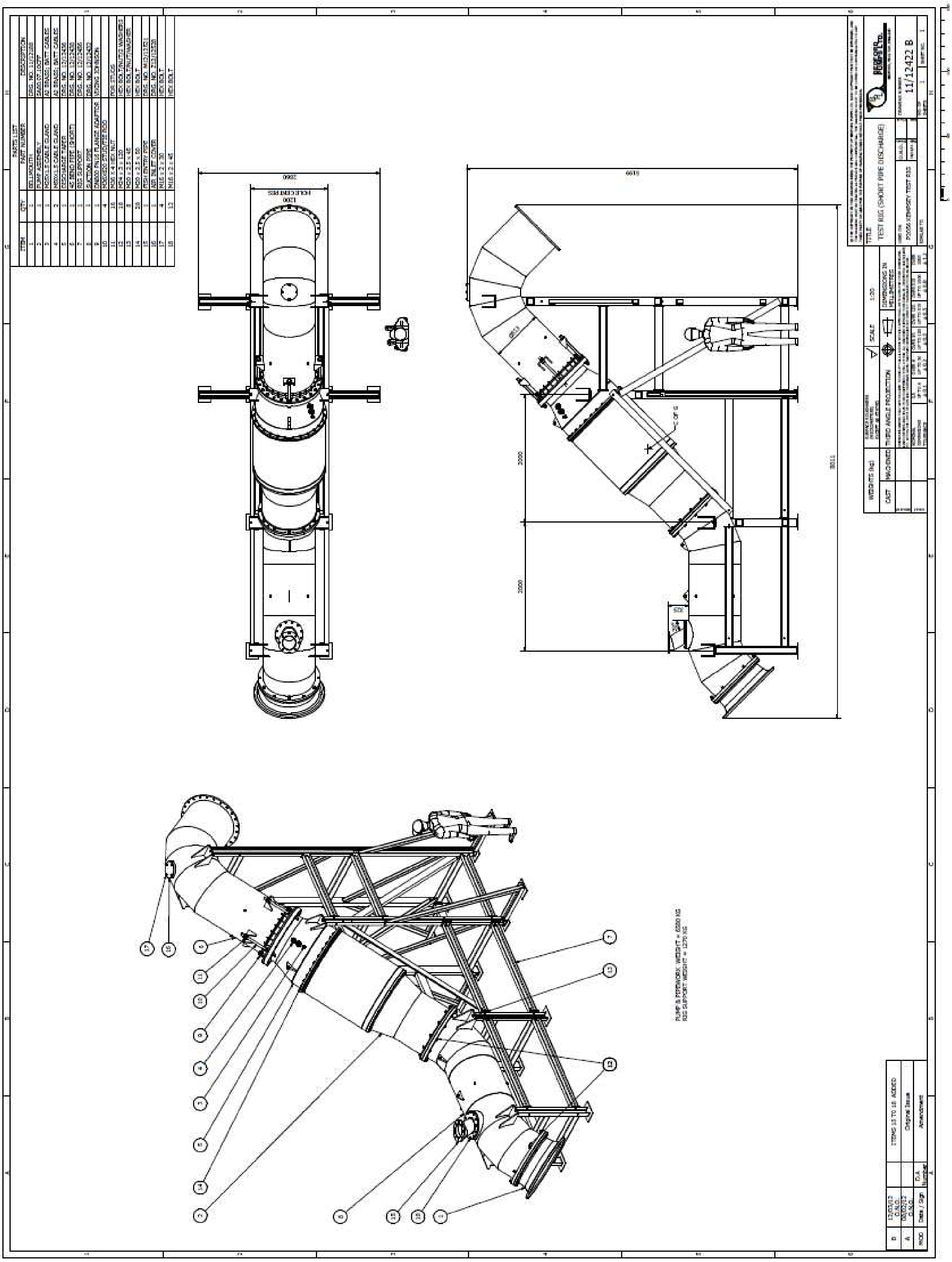
Appendices

Appendix I Detailed specifications Bedford Pumps SAF range









Appendix II Approval Animal Experimental Committee

WAGENINGEN UR
For quality of life

VISADVIES B.V.
t.a.v Dr. Ir. I.L.Y. Spierts
Twentehaven 5
3433 PT NIeuwegein

DATUM
30 mei 2012
ONDERWERP
Beoordeling OZP VA2011_28
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8200AB
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BEZOEKADRES
Edelhertweg 15
8219 PH
Lelystad
CONTACTPERSOON
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+31 (0)320.238561
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P.kroon@wur.nl

Betreft Onderzoeksplan 2011_28

Titel Onderzoek visvriendelijkheid axiaalpomp Bedford Pumps UK

Aantal dieren 300,300,300

Diersoort: aal (Anguilla anguilla), baars (Perca fluviatilis), brasem (Abramis brama)

Risico van ongerief matig (3)

Artikel 9 functionaris: Dr. Ir. I.L.Y. Spierts

Periode advies: 1 juni 2012 tot 1 september 2012

Discussie en aanvullende vragen

De DEC complimenteert de onderzoeker met het duidelijke proefplan.
De DEC spreekt zijn waardering uit voor het gebruik van dummy's en zou voor haar beeldvorming graag meer informatie willen hebben over deze dummy's en het gebruik hiervan in proeven. De DEC heeft begrepen dat dummy's vol electronica zitten en wil graag weten wat er mee gemeten kan worden. Verder wil de DEC weten of men meer aan modelontwikkeling/correlatie-analyse kan doen met gebruik van dummy's zodat in de toekomst alleen het gebruik van dummy's voldoende is.
Figuren over de aantallen kloppen niet met de tekst. Hoe komt de onderzoeker aan het aantal van 50 vissen per testscenario.

Afweging

- Het proefvoorstel is getoetst aan de hand van de eisen die gesteld worden ten aanzien van de 3 V's. en Art 2a van het Dierproevenbesluit
- Het doel van de proef. wordt onderschreven. Het belang van de proef weegt op tegen het ongerief van de betrokken dieren en er zijn geen alternatieven beschikbaar..
- De uitvoering is verder niet in strijd met andere ethische overwegingen m.b.t. het gebruik van proefdieren.

Voorwaarden

- De indiener dient iedere wijziging van het proefplan ten opzichte van dit advies alsmede onverwachte gebeurtenissen, onverwijld te melden aan de proefdierdeskundige

- Indien het ongerief tijdens de proef afwijkt van het opgegeven (verwachte) ongerief dient dit een welzijnsevaluatie na afloop van de proef te worden gemeld
-

Opmerkingen:

-

Advies : Positief

Met vriendelijke groet,

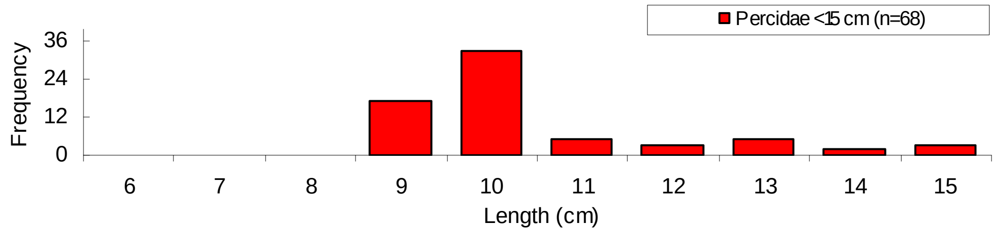
P.S. Kroon
Proefdierdeskundige / Veterinair

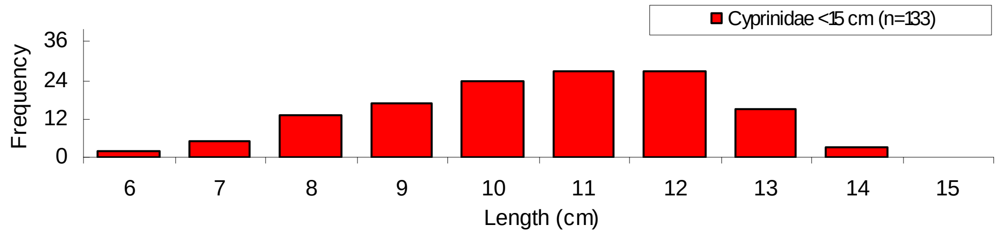
Appendix III Overview death % of already tested pumps

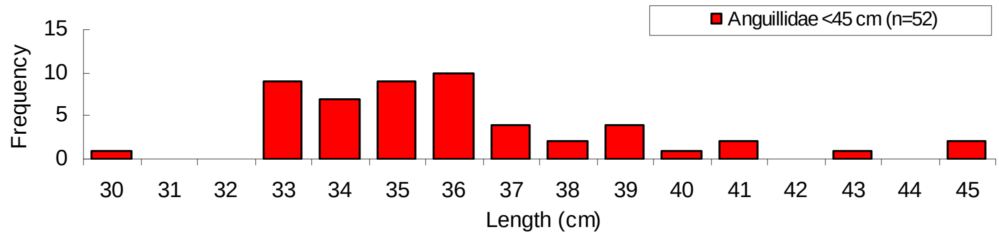
Pomptype	Kenmerken			Visoverleefbaarheid (schadepercentages)				
	Capaciteit (m3/min)	Opvoerhoogte (m)	Toeren	Aal	baarsachtigen < 15cm	baarsachtigen > 15cm	karperachtigen < 15cm	karperachtigen > 15cm
Vijzels				Sterftepercentage (%)				
Buisvijzel	0,6	1	57	0				
Buisvijzel	10	1,05	42		2		0	
Vijzel	23	0,73			0		2	
De Witvijzel	42	0,7	42		0	0	0	2
Vijzel	120	0,3-1,5	29		0	0	0	13
Vijzel	500	2,2	17	2	0	0	0	1
De WitVijzel	660	0,3	22	0			0	
Vijzel	660	0,3	22				0	
Vijzel	660	0,3	22					1
Centrifugaalpompen								
Centrifugaalpomp	38	3,5	368		0		1	2
Centrifugaalpomp	400	0,9	205		0			
Centrifugaalpomp	1080	1,7 [3]	59	0				
Schroefcentrifugaalpompen								
Schroefcentrifugaalpomp	12,5	1,5	480	0			0	0
Schroefcentrifugaalpomp	22	1,15	735	0				
Schroefcentrifugaalpomp	24	1,15			0		1	
Schroefcentrifugaalpomp	25	1,5	400	0			0	0
Schroefcentrifugaalpomp	25	0,15	1000		4		7	
Schroefcentrifugaalpomp	85		416		4		16	43
Schroefcentrifugaalpomp	170	1,52		0	0	0	1	
Schroefcentrifugaalpomp	350	2,8	115		3	6	4	
Schroefcentrifugaalpomp	505	2,4 [1]	143	0			0	
Schroefcentrifugaalpomp	505	2,4 [1]	143					
Hidrostal pompen								
Hidrostal	0,6	10	890-1204	0				
Hidrostal	21	3,6	577		4			
Hidrostal	42,5	3,5	552		8		8	
Gesl. Schroefp. (compact)	45	2,54	592		3		15	
Gesl. Schroefp. (compact)	90	2,7	364		35	26	81	90
Gesl. Schroefp. (compact)	105	2,2	291		3		21	
Gesl. Schroefp. (compact)	135	0,5-1	307		1	9	3	
Gesloten schroefpomp								
Gesloten schroefpomp	26	3,08			2		25	
Gesloten schroefpomp	60	0,8	355	32	7	8	20	
Gesloten schroefpomp	81	1	333	0				
Gesloten schroefpomp	1500		50	5				
Open schroefpompen								
Open schroefpomp	24	0,98			0		45	
Open schroefpomp	40	1,67	580		0			
Open schroefpomp	76				0			
Open schroefpomp	120	0,1			5		18	42
Open schroefpomp	200	0,6	165	8				

Appendix IV Length frequency distribution diagrams

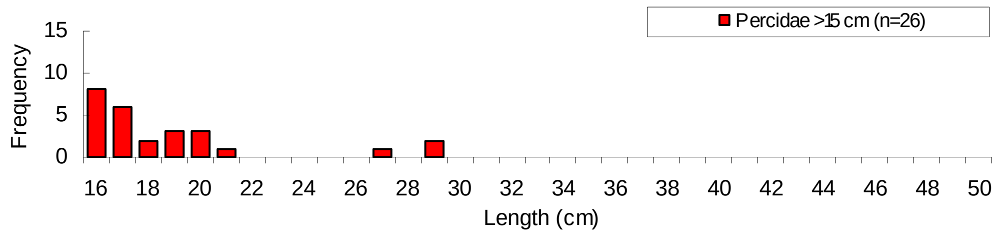
Scenario 1: small fish

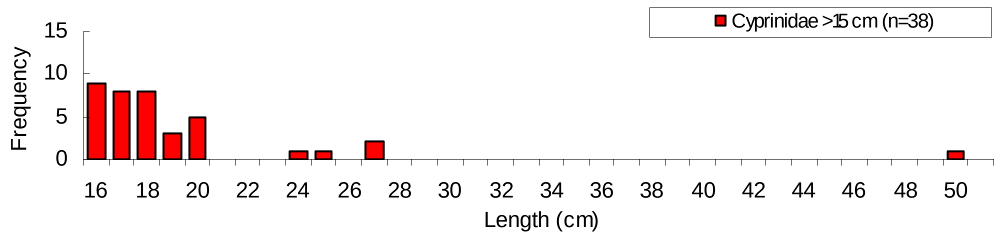


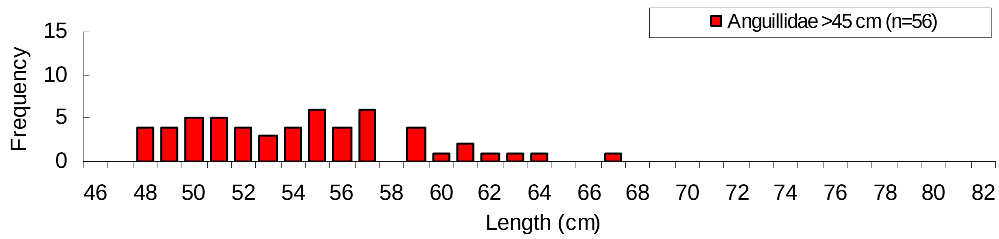




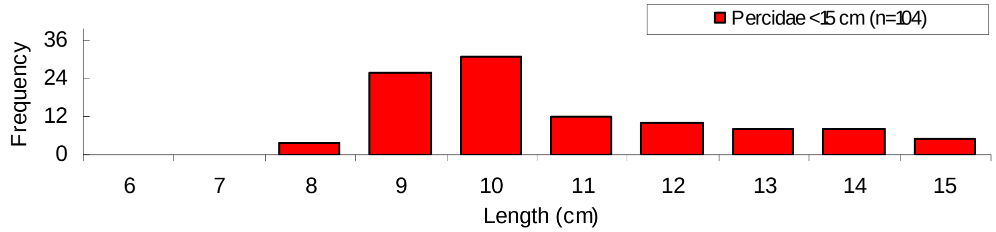
Scenario 1: big fish

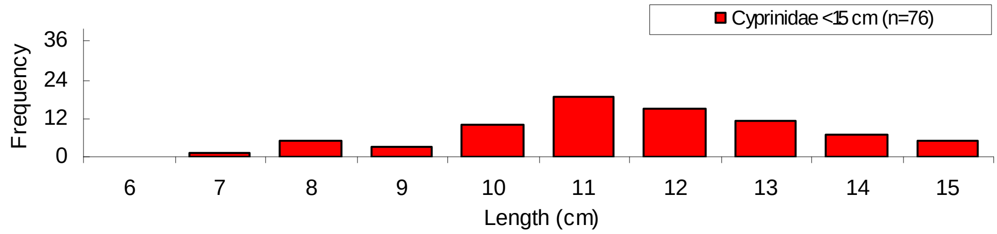


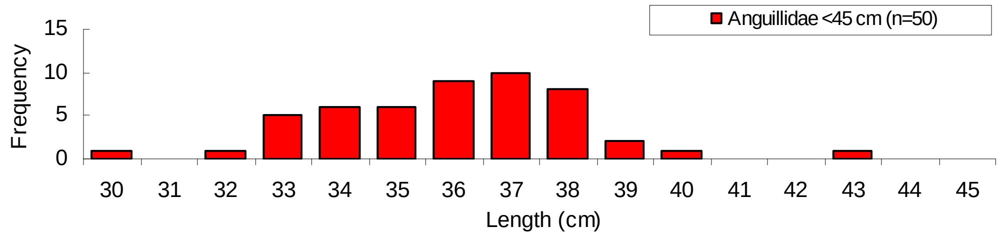




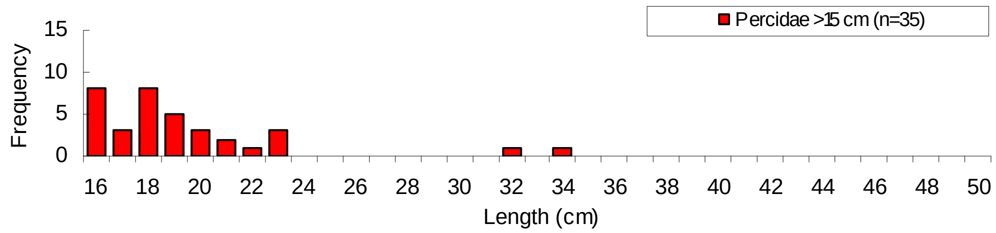
Scenario 2: small fish

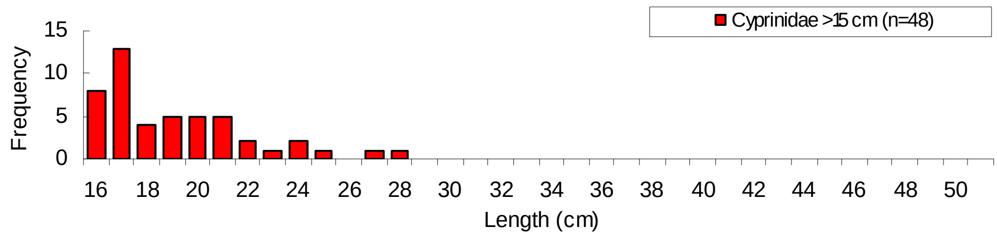


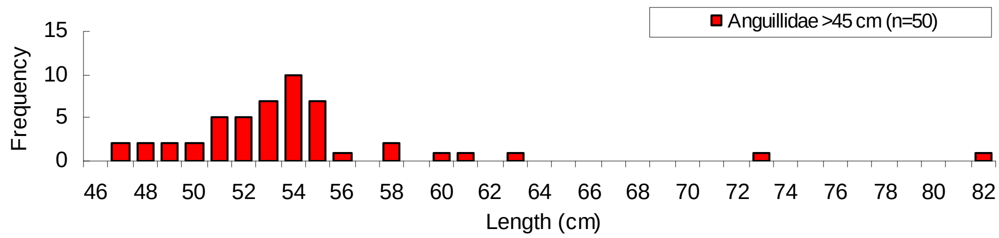




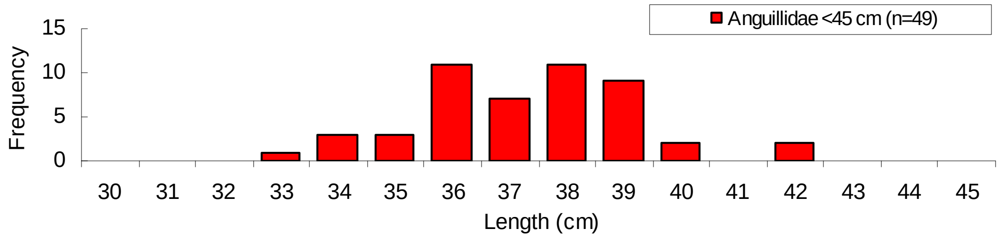
Scenario 2: big fish

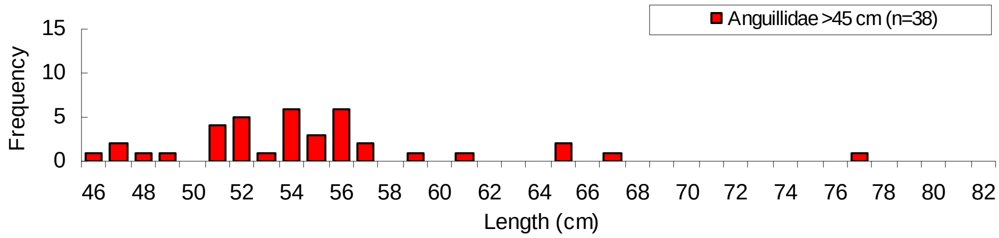






Scenario 3: small eel





Appendix V Percentages fish survival and damages

		N	Survival (no damage)	Survival (+ damage)	Survival (after 48h)
Exp. 1, small fish	Percidae	68	96%	4%	100%*
	Anguillida	52	92%	8%	100%
	Cyprinida	133	93%	7%	100%*
Exp. 2, small fish	Percidae	104	94%	6%	100%*
	Anguillida	50	94%	4%	98%
	Cyprinida	76	88%	11%	99%*
Exp. 3, small fish	Percidae	0	n.a.	n.a.	n.a.
	Anguillida	49	88%	4%	92%
	Cyprinida	0	n.a.	n.a.	n.a.
Exp. 1, big fish	Percidae	26	92%	8%	100%*
	Anguillida	56	91%	9%	100%
	Cyprinida	38	79%	21%	100%*
Exp. 2, big fish	Percidae	35	83%	11%	94%*
	Anguillida	50	94%	4%	98%
	Cyprinida	48	79%	17%	96%*
Exp. 3, big fish	Percidae	0	n.a.	n.a.	n.a.
	Anguillida	38	82%	11%	92%
	Cyprinida	0	n.a.	n.a.	n.a.

- Eel: 100 % survival. All eel that survived the 48 h storage period, but showed haemorrhages and irregularities were killed and internally examined for spinal injuries. In case of a broken spine, the eel is considered lost for the posterity and fall in the category “Survival + damage”.
- Percids and cyprinids. Although there was little (small cyprinids test 2) or no delayed mortality within 48 h after the experiment, still 10-15% of the cyprinids and percids eventually died after the 48 h period. These death can however not be attributed to the passage of the pump itself (explanation: see § 4.3).

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