

FINAL REPORT

Management of silver eel: human impact on downstream migrating silver eel in the river Meuse

Impact assessment of hydroelectric power stations and commercial eel fisheries on the eel population in the river Meuse



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**Management of silver eel:
Human impact on downstream migrating
eel in the river Meuse**

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SUMMARY

Human impact on downstream migrating silver eel in European inland waters mainly consists of withdrawal of eel by commercial fisheries and extra mortality of eel due to passing turbines of hydropower facilities. These human activities are widespread in many European rivers and might have detrimental effects on the population level of the European eel. This project investigated to what extent damage to eel caused by hydropower stations and the impact of withdrawal of eel by commercial fisheries are a threat to the downstream migrating silver eel population in the Dutch section of the river Meuse. This has been achieved by monitoring downstream migration of silver eel by three methods: (1) a novel telemetry system, the Nedap Trail System[®], (2) monitoring of eel catches by commercial fisheries and (3) monitoring of turbine passage and assessment of mortality at a hydropower station. Furthermore there is the need to develop and optimise countermeasures to protect downstream migrating eels at hydropower stations. Therefore, the applicability of the Migromat[®], a novel Early Warning system, which can predict peaks of silver eel migration, was investigated in this project. The warnings provided by application of this Early Warning system enables protection of a substantial part of the downstream migrating silver eel by turbine management, i.e. to close down the turbines during downstream migration events and offer safe passage over the weir or fishway.

The Nedap Trail System[®] proved to be an appropriate system to monitor downstream migration of silver eel. The results clearly show that during the migration season of 2002, within the Dutch section of the river Meuse (260 km) from upstream Linne to the North Sea, each individual downstream migrating silver eel has a chance of at least 30% and probably about 40% to reach the North sea. The impact of the combined mortality by the two hydropower stations (direct mortality + delayed mortality: 15.8%, which is likely to be an overestimation) is smaller than the combined mortality by the commercial fisheries (anchored stow nets + fykenets: 22.2%, which is likely to be an underestimation). The total mortality by the two hydropower stations is likely an overestimation, because the eels that are considered to have passed the turbines and not being detected at downstream detection stations or are caught by fisheries, are not sure to all be lethally injured. Furthermore, the fisheries mortality is likely an underestimation because it is likely that an underreporting of transponders recaptured by fishermen occurred. Also, part of the unexplained mortality (25.3% in total) might be attributable to withdrawal by fisheries. The fisheries mortality is estimated to be up to a factor 2 higher than hydropower mortality.

In addition, it has been found by the transponder experiment that silver eel show a clear hesitation to pass the trash racks in front of the turbines, as well as an upstream orientated

escaping movement in front of trash racks. This typical behaviour will contribute to the possibility to divert eel into the direction of bypasses.

The correspondence of migration events in the river found by the different monitoring experiments with the warnings provided by the Migromats[®], verify that the system accurately registers the pre-migratory restlessness of eels, thereby predicting the downstream migration events of silver eels with high precision. Subsequently, a high percentage of downstream migrating eels can be saved and therefore the prediction of this early warning system enables an eel-friendly turbine operating management of hydropower facilities. During the migration season of 2002, the Migromat[®] predicted downstream migration events at 24 days in Linne and at 17 days in Alphen, representing respectively 10 and 15% of the total period. During these few days 66% of the transpondered eels passed through Linne, and even 73% passed Alphen. Application of the Migromat[®] throughout the migration season of 2002, would have reduced the total mortality by hydropower in the Dutch section of the river Meuse with maximal 69.4%, assuming that all eels pass over the weir or fishway without hesitation.

When hydropower facilities apply the Migromat[®] system, the resulting effect, i.e. an increased number of eel successfully passing by, is however reduced by increased fishery catches. Therefore, it is necessary to have a reduction of fishery catches by at least the fraction it catches of the eel saved from turbine mortality by means of turbine management, in order to have an overall better effect.

Both hydropower and commercial fisheries substantially reduce the number of silver eel that reach the sea. Therefore, management measures taken in each of these impacts will directly contribute to an increased size of the spawning population.

1 INTRODUCTION

During the last decades the population of the European eel (*Anguilla anguilla*) is strongly declining throughout its distribution area (Dekker, 2002). This phenomenon has been observed all over the world. In Germany, for example, the eel has been put on the federal list of threatened (gefährdet) species as well as in France. Large-scale surveys in the early eighties showed that, except in a few coastal streams of northern Spain, the eel had disappeared in more than 80 % of the Iberian rivers (Lobon-Cervia, 1999). A long-term monitoring (1986-1997) of eel numbers in the River Esva, a small river catchment where the species was abundant till the eighties, showed a steep decline of eel numbers. As inferred by a parallel decline in the commercial catches of elvers, no other cause than a reduced recruitment of elvers could be identified as responsible for the decline of the Esva eel. In Austria and Switzerland, the eel has almost disappeared, while in the Netherlands, it is placed on the endangered species list. Not only the number of adult eel went down, moreover the influx of glass eel dwindled.

Many hypotheses on the causes for this phenomenon have been put forward, ranging from climate change affecting the gulf stream and thus oceanic leptocephali drift, barriers hindering immigrating glass eel, habitat loss and severe fisheries during their up growing yellow eel stages in freshwater, fisheries and hydropower during the seaward downstream migrations of silver eels, exotic parasites affecting silver eel condition and chemical contaminants like PCBs stored in their fat tissue interfering with physiological processes during their metamorphosis to silver eel and migration to the spawning grounds and with reproduction itself. It is most likely that more hypotheses act simultaneously, as is mostly the case when a population sharply declines, but the relative impact of each factor is unknown as to yet.

Human impact on downstream migrating silver eel in European inland waters is caused by commercial fisheries and by mortality of eel passing the turbines of hydropower stations. These human activities are widespread in many European rivers and might have detrimental effects on the population level of the European eel. Therefore it is important to know to what extent damage to eel caused by hydroelectric power stations as well as the impact of withdrawal of eel by commercial fisheries are a threat to the population. Furthermore, there is the need to develop and optimise technical countermeasures to protect downstream migrating eels at hydropower stations. Governments of a number of countries (the Netherlands and Germany among others) require that power stations operators take protective countermeasures for downstream migrating fish species. In view of the decline of

the eel population as well as restoration of salmonid populations in European river systems these demands will increase.

1.1 The eel's life cycle

Eel is a catadromous fish, which means that they live a portion of their lives (during spawning) in seawater and the rest in freshwater. To date, the question of where and how eel are born has not been answered satisfactory. The Sargasso Sea (30° N.W., 65° W.L.) has been put forward as the most likely geographical position, however, no adult eel has ever been observed in this area. To reach their hypothetical breeding grounds, silver eels must undergo a massive migration of 6000 kilometres from inland freshwaters to the Sargasso Sea.

During their long migration following birth, the eels undergo various metamorphic transformations (Pennisi, 1989). The early larval stage is called leptocephalus and is characterised by a transparent, ribbon or leaf like nature. Upon hatching in the spawning area, the leptocephali (5 – 7 mm) ascend towards the surface and can be taken at an average depth of 50 meters during the day and 20 – 30 meters at night. These young eels are only captured from March to July, therefore the spawning period must begin in the spring and continue until mid-summer (about 5 months in length). The leptocephali (*Anguilla anguilla*) migrate pelagic, both actively and passively by the Atlantic Gulf stream to the north east and reach the coasts of Europe and North Africa after about 1 – 3 years (Tesch *et al.*, 1990). When continental Europe is reached, they are transformed into transparent glass eels, the so-called “elvers” (65 mm). These migrate into brackish water and swim up the rivers. During the following periods they enter inland waters in Europe; Morocco: September - October; Spain, Portugal, South France: November - December; North France: January - March; British Islands, The Netherlands: February - April and Scandinavia: April-may. Eventually, the elvers begin to develop some yellow pigment, and upon reaching a foot long due to growth they become known as yellow eels. These specimens have moved inland to freshwaters and continue to grow for some 8 – 15 years (males) up to 10 – 18 years (females). After this period of adult growth, in anticipation of their return trip to the spawning grounds, the eels transform into silver eel, which is accompanied by marked changes in morphology (Barni *et al.*, 1985), body constitution (Lewander *et al.*, 1974), fatty acid content (Dave *et al.*, 1974) and to a lesser extent haematology. In general, the eels cease eating and the digestive tract degenerates, a silvery glow appears ventrally on the flanks, the eyes become larger and the gonads start to develop. They also show a migratory restlessness, as they then begin to wiggle, float, and squirm their way back downstream to the ocean with the aid of several built in clocks (Boetius, 1967; Lowe, 1952).

1.2 **Commercial fisheries in the river Meuse, the Netherlands and Europe**

In the Dutch section of the river Meuse (Figure 1) in the upstream part from Borgharen (Belgian border) to Ohé en Laak, no commercial fisheries take place. Between Ohé en Laak and Lith three small fishing companies operate fishing with anchored stow nets at two locations (downstream Linne and Lith), using fykenets and electrofishing (mainly yellow eel). In the downstream area of the river Meuse, eight commercial fishery companies operate, fishing mainly with fykenets. Most companies are small with only 1 – 3 employed fishermen. Larger companies employ up to 10 fishermen. This is very similar to the eel fisheries in the rest of the Netherlands and in Europe (Dekker, 2002).

In the Netherlands, the Lake IJsselmeer is fished most intensively for eel, mainly yellow eel. At the current fishing pressure the escapement of female silver eels are very small (Dekker, 2000). The upstream parts of the Dutch rivers are only extensively fished. Most of the fishing pressure is located in the downstream parts. This might lead to a higher escapement of female silver eel migrating downstream the Dutch rivers. During the 1990's, total fishing yield of eel in lake IJsselmeer was estimated at 4,000 tonnes per year (Dekker, 2002).

Total fishing yield of eel in Europe and North Africa is estimated at 15,000 tonnes per year during the 1990s (Dekker, 2002). Glass eel fisheries are mainly concentrated in France, Spain and Portugal, whereas silver eel fisheries are relatively intensive in the Netherlands, Denmark, mediterranean France and Italy (Dekker, 2002). Therefore, both in yield and in importance of silver eel fisheries, the Netherlands can be considered as a more intensively fished area compared to other European countries.

1.3 **Hydropower in Europe**

The use of renewable energy and the absence of emissions by hydroelectric power generation clearly has environmentally advantages in comparison with fossil fuelled power stations. On the other hand hydropower stations have drawbacks especially in relation to upstream and downstream fish migration in rivers. In the near future protecting measures for fish can be expected as a result of the EC Water Framework Directive which requires an undisturbed migration for fish in European river systems. The total installed capacity of hydropower stations in Europe amounts 168,500 MWe (Anonymous, 2000). Mountainous countries with high annual precipitation like Norway, France, Switzerland, Austria and Sweden have installed a huge capacity of hydropower (Table 1).

Table 1 Installed capacity (MWe) and the electricity production (GWh/year) of hydroelectric power stations in European countries, situation 1999 (Hadderingh & Bruijs, 2002).

Country	Installed capacity (MWe)	Electricity production (GWh/year)
Norway	27,410	116,259
France	23,100	69,800
Spain	17,000	39,000
Sweden	16,204	68,300
Italy	15,267	51,636
Switzerland	11,980	34,485
Austria	11,500	37,560
Germany	4,331	17,200
United Kingdom	1,365	4,000
Belgium	102	385
Luxembourg	33	95
The Netherlands	30	60
other countries	40,178	113,220
Total Europe	168,500	552,000

Stations with capacities up to about 1000 MWe have been built in combination with large reservoirs. These reservoirs in general are not accessible for fish due to the great height of the dams. A second category of hydroelectric stations have been built in rivers in combination with a weir. These hydropower stations cause problems for downstream migrating fish, in particular for the diadromous species which maintain a two-phase life-history involving extensive migrations between sea and freshwater. In many European rivers like the Meuse and Rhine, numerous hydropower stations have been installed (Table 2). For the river Meuse development of some more stations have been planned in The Netherlands (3 stations) and Belgium (8 stations upstream from Namur).

Table 2 Number of hydropower stations in the rivers Rhine and Meuse, situation 2002.

River stretch and tributaries		Number of power stations
Meuse	main course Belgium	6
	main course The Netherlands	2
	Semois (France)	1
	Ourthe (Belgium)	2

- table 2 continued -

Rhine	main course Schaffhausen – Basel (Switzerland)	11
	main course Basel – Karlsruhe (Germany)	6
	Neckar (Germany)	8
	Main (Germany)	34
	Moselle (German part)	12
	Saar (German part)	6
	Nederrijn (The Netherlands)	2

It will be clear that downstream migration will have great impact for fish species migrating downstream from the upper parts of these rivers to the sea. The operation of hydropower stations in rivers produces potential injury to downstream migrating fish if they become entrained in turbine-intake flow and pass through the turbine blades. Important reviews of results of investigations on fish damage at turbines have been published by Montén (1985), Eicher (1987), Davies (1988) en Larinier & Dartiguelongue (1989). Till present, information on eel mortality by turbines is only known of some individual hydropower stations in a limited number of rivers. Early reports of fish mortality at hydropower stations have been published by Von Raben (1955, 1957) and more recently by Berg (1985, 1986, 1987), Hadderingh & Bakker (1998) and Holzner (1999). In these studies, the average mortality rates for European eel, a species of concern throughout Europe and very susceptible to injury of turbine blades, ranged between 15 and 38%. However, no estimation has been made of the cumulative mortality caused by a series of hydropower stations. In the period 1990 - 2002, several investigations on downstream fish migration at hydropower stations have been carried out or are underway all over the world. On the 1st International Catadromous Eel Symposium held in St Louis (USA) in 2000 (EPRI, 2001) several presentations were dealing with problems of eel passage at hydropower stations in Canada, the United States, New Zealand and France. In Germany Holzner (1999) studied the impact of fish passage trough the turbines of Dettelbach hydropower station at the river Main a tributary of the river Rhine. In spring 2000 the efficiency of a surface bypass was tested with salmon smolts at the hydropower station at Lixhe (Belgium) at the Meuse (Prignon *et al.*, 2001). In The Netherlands fish passage mortality was studied by KEMA at Linne hydropower station at the river Meuse in 1990/1991 (Hadderingh & Bakker, 1998) and in 1999 (Hadderingh & Bruijs, 2002).

1.4 Countermeasures to protect downstream migrating silver eel

Every year numerous downstream migrating fish are lethally injured due to passage of the turbines of hydro power plants. Especially eels migrating downstream towards the ocean for reproduction are endangered. Due to the eels specific migratory behavioural pattern and morphology, conventional coarse screens and other procedures do not efficiently prevent the eels from being drawn into the hydropower plant intake structures and subsequent passage of the turbines. Consequently the probability for this fish species of being damaged in the intake areas or by turbines is particularly high. This problem is relevant in two different fields: river ecology and fisheries.

Fish protection at water intakes has traditionally been achieved by fine physical screens, but at high capital cost: they are costly in maintenance and may become blocked easily by waterborne organisms and debris, restricting water flow. Another option are deterrent methods, which are normally used where mechanical fish screening is impracticable, owing to the risk of fouling. Fish deterrent systems are sometimes known as 'behavioural barriers' or 'behavioural screens': essentially, they are a substitute for more conventional mechanical fish screens. Nevertheless, in and outside Europe, so far no functional and/or economical constructions and methods are available, which can prevent fish from being drawn into dangerous facility areas, enabling them to safely migrate downstream (ATV-DVWK, 2002).

A range of countermeasures to protect downstream migrating eels at hydropower stations are under research, e.g. bypass constructions and physical and behavioural fish screen technologies, however, due to lacking of proper functioning and moderate cost of fish protection facilities (deterrent and guidance systems) and downstream migration facilities (bypasses), different ways of fish protection are required. One possibility combines short-term feasibility and low cost with efficient fish protection, especially for the eel, a species which is particularly endangered. This particular optional countermeasure is turbine management, i.e. eel-saving operation of hydropower facilities. Turbine management comprises for example the reduction of approach velocity in front of trash racks and to close down the turbines during periods of peak migrating by silver eel and to offer them a save passage over the weirs. Closing down the turbines for longer migration periods, e.g. a number of months during the autumn being the main migration period for silver eel, means a substantial loss of electricity production for the electricity companies. Closing down the turbines for short periods with peak migration provides a better option. Prerequisite for such a eel-friendly operation management of hydropower facilities is an early and reliable prediction of downstream migration events.

1.5 **Project goals**

This study focuses on the downstream migration of silver eel in the Dutch section of the river Meuse with the aim to quantify the mortalities caused by commercial eel fisheries and hydropower stations. Furthermore, the applicability of the newly developed early warning system Migromats[®], which enables detection of timing of downstream migration events and the short-term peak migrations has been evaluated. A management system to protect eels from hydropower damage will be proposed, in combination with an estimate in what time frames which part of the population will be secured when temporarily closing the turbines during peak migrations. From the experiments an estimate of the different impacts on the population size of downstream migrating silver eels in the river Meuse will be attempted.

1.5.1 **Objectives of the project**

The project addresses the activity Energy, Environment and Sustainable Development under the Fifth Framework Programme. The main goal of this research project is to contribute to a sustainable eel fishery and a sustainable production of electricity by hydropower facilities in European waters. To achieve this goal a research programme has been developed for the river Meuse area with the following objectives:

- To monitor silver eel catches by commercial fisherman in the river Meuse;
- To monitor the cumulative mortality of downstream migrating silver eel passing two Dutch hydropower stations in the river Meuse on the basis of innovative telemetric methods (Nedap Trail System[®]);
- To assess the impact of hydropower stations and commercial fisheries on the eel population in the river Meuse system;
- To test the Migromat[®] early warning system for the prediction of the beginning of migration peaks of silver eel at the two Dutch hydropower stations Linne and Alphen in the river Meuse;
- To develop a turbine management system as a tool to protect silver eels for passing turbines in order to improve the sustainable aspect of hydropower stations on the basis of the early warning system.

2 MATERIALS AND METHODS

2.1 Monitoring commercial fisheries and telemetry

2.1.1 Monitoring of commercial eel fisheries

In the Dutch section of the Meuse, commercial fisheries were monitored at two locations in 2001 and at three locations in 2002 (Figure 1). Directly downstream Alphen hydropower station (river km 201), a commercial eel fishery (Lith-Alphen) with three anchored stow nets (dimensions: 3 x 6 m) that fished throughout May to November was monitored in both years. One out of these three nets was inspected daily and the number (and periodically also the phase) of the eels were recorded. At the river stretch between Reuver and Belfeld (river km 97-100), eel catches in four fykenets were monitored during May through October also in both years. On average, these fykenets fished for three days before they were checked.

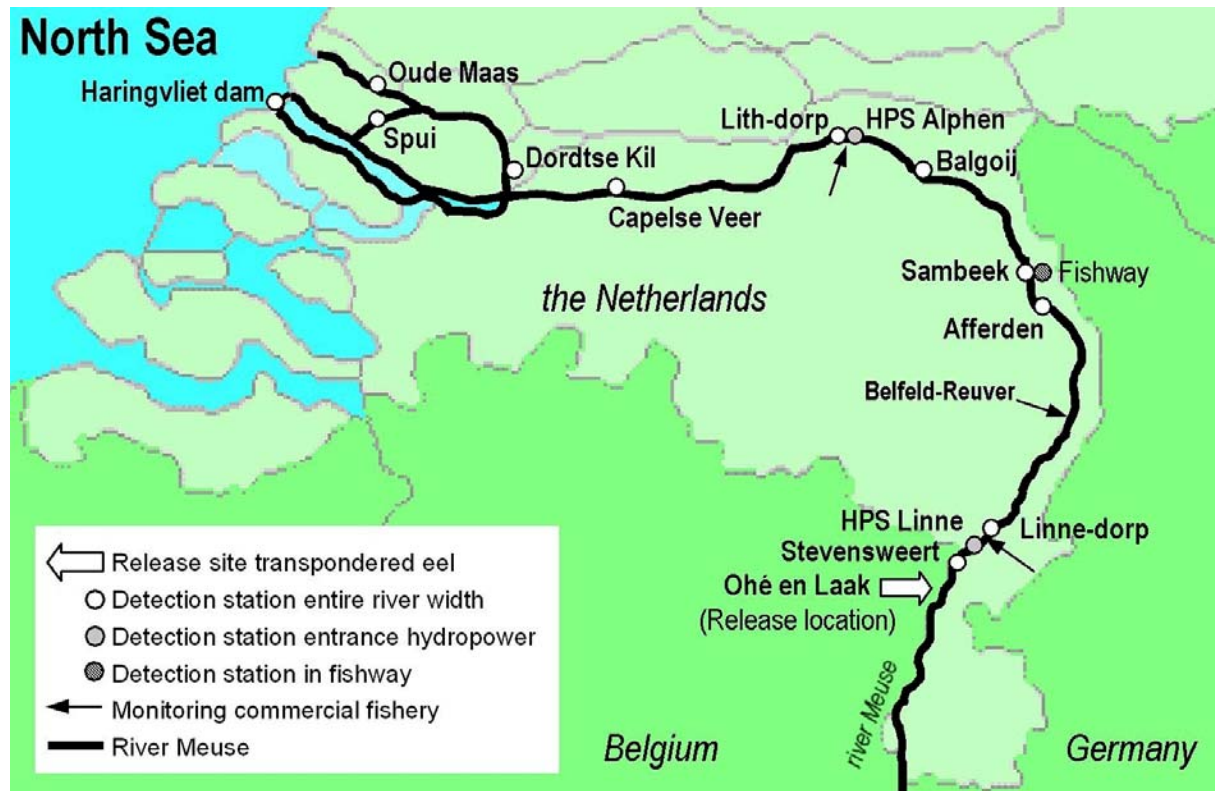


Figure 1 Map of the Dutch section of the River Meuse.

Directly downstream of the weir at the hydropower station at Linne (river km 69), a commercial eel fishery using one anchored stownet (dimensions: 3 x 6 m) started in 2002, after relocation from directly downstream of the weir at Belfeld (river km 101). This fishery was carried out at irregular intervals (5 July-14 July, 25 July-15 August, 23 August-2 September and 19 October-3 November). The net usually fished for one night before it was inspected. All nets had a stretched mesh size of 20 mm and total numbers of silver and yellow eels caught were recorded.

2.1.2 **Applicability of transponders to tag silver eel**

In 2001, a controlled tank experiment was carried out to test the suitability of using transponders (Nedap Trail System[®]) to tag European eel during their silver eel stage. Whereas most studies focus on indirect effects of implanting radio tags on behaviour, such as mortality, disease, wound healing and growth, in this individual activity was also measured continuously during the experiment, allowing to detect direct effects. In total 40 silver eels (600-1800 g) were caught at Ohé en Laak (river km 58) by commercial fishermen with fykenets. The surgical implanting procedure was similar to the one used successfully on European eel by Barras & Jeandrain (1998). All eels were anaesthetised with 2-phenoxy-ethanol (0.9 ml l⁻¹) and injected with a micro PIT-tag in the dorsal muscle near the head. In 20 of these, dummy transponders similar to Nedap-transponders in surface (glass), weight (25 g) and volume (63 x 12 mm), were surgically implanted by making a 20 mm incision in the ventral side of the posterior quarter of the body cavity. The incision was closed with Loctite[™] adhesive and a freshly cut 3-5 mm wide fragment of the eel's dorsal fin was applied over the drying adhesive to act as a biological bandage to the incision. This closing procedure was the best one among five different procedures tested by Barras & Jeandrain (1998).

All specimens were placed in a single Migromat[®]-tank with five interconnected compartments (see also § 2.3) covered by four antennae loops at the location of Alphen hydropower station. The Migromat[®] is placed in the open field, had transparent lids and was flowed through with river water, eels could respond to 'natural' environmental stimuli, e.g. water temperature, turbidity, light and moon phase. Movements between compartments were continuously registered during 11 weeks. Thereafter, each remaining individual was checked on length, weight, external and internal wound healing and loss of dummy transponder.

2.1.3 Telemetry field experiments

The Nedap Trail System[®], based on inductive coupling between an antenna loop on the bottom of the river and a ferrite rod antenna in a transponder type tag, as developed for a sea trout study in the Netherlands (Breukelaar *et al*, 1998; Bij de Vaate & Breukelaar, 2001), was used for the silver eel field experiments in 2001 and 2002. In addition to an already existing infrastructure of 10 fixed detection stations (Figure 2), each covering the entire width of the river at different sections, four new stations were built in 2002 (Table 3). These four comprised two detection stations covering the entire river width downstream the Alphen and Linne weirs/hydropower stations (at 2.1 km for Linne-dorp and 1.7 km and Lith-dorp, respectively) and two detection stations in front of the hydropower stations covering the total width of the intake channels (see also § 2.2.7). Because a commercial fishery exists too close to the tailrace of Alphen hydropower station, it was not possible to build the downstream station in-between the turbines and the fishery. After completion of the station downstream of the weir at Linne, a commercial fishery started here in the main stream of the river in-between the downstream detection station and the Linne hydropower station in 2002 also. Thus, at both locations a combined effect of turbines and fishery was present in the short stretches in between two detection stations.

Table 3 List of the detection stations present in 2002 and occurrence of hydropower stations (HPS) and fisheries on the stretches in between detection stations. Stations with river km in brackets are not included in stretch length.

Detection station name	Entire river width	River km	Stretch N ^o *	Stretch Length (km)	HPS	Commercial eel fisheries
Ohé Laak (release)		58.0				
			1	3	n	Fykenet & electro-fisheries
Stevensweert	y	61.0				
				7.3	n	Fykenet & electro-fisheries
HPS Linne*	n	68.3				
			2	2.1	y	Anchored stow net (1)
Linne-dorp*	y	70.4				
			3	74.6	n	Fykenet & electro-fisheries

* as used in the survival estimates with MARK-models (§2.1.4)

- table 3 continued -

Detection station name	Entire river width	River km	Stretch N ^o *	Stretch length (km)	HPS	Commercial eel fisheries
Afferden	y	145.0				
Sambeek fishway	n	(145.4)	4	0.5	n	No fisheries
Sambeek	y	145.5				
			5	31.5	n	Hardly no fisheries
Balgoij	y	177.0				
			6	23.8	n	Hardly no fisheries
HPS Alphen*	n	200.8				
			7	1.7	y	Anchored stow nets (3)
Lith-dorp*	y	202.5				
			8	38.5	n	Some fykenet & electrofisheries
Capelse Veer	y	241.0				
			9	74	n	Intensive fykenet fisheries
Dordtse Kil	y	(278)				
Spui	y	(303)				
Oude Maas	y	(319)				
Haringvliet dam	y	315				

* as used in the survival estimates with MARK-models (§2.1.4)

In 2001 when the four extra detection stations were not yet active, a pilot study with 10 silver eels, caught at Ohé en Laak by professional fishermen with fykenets, was carried out using the implantation method for the Nedap Trail transponders as described for the tank-experiment. In 2002, five batches of in total 150 silver eels were caught at the location, implanted with transponders and released on 6 (n=33), 11 (n=27), 12 (n=14), 24 (n=51) and 25 (n=25) September near the catch site in a small, stagnant side channel of the river Meuse, 200 m from the river. The eel were not released in the river itself to ensure that the eels could choose themselves to swim downstream rather than being pressed to drift downstream directly after release. Tagged specimens had no outside marking, except for the operation wound, to ensure an almost similar treatment compared to untagged eels by fishermen. When preparing eels for consumption the tag with a label with clearly readable instructions should easily be discovered. A high reward was put on tag recovery to ensure a maximum return rate of 'caught' transponders, enabling an as high as possible minimum estimate of fisheries mortality.

Passages of individual transpondered eel were recorded to an accuracy of minutes. Directly after first replying to a station, the transponder is automatically inactivated for 2 minutes to save batteries. A series with 2 – 3 minute intervals between observations were treated as one passage, whereas series with 4 or more minutes intervals were treated as subsequent passages of the detection stations, downstream and upstream. The detection stations at turbine entrances were located at such distances that it would take eel more than two minutes to return from the trash racks in front of the turbines to reach the detection station again. The gaps between the bars of the trash racks (10 cm) were sufficiently large to let all sizes of eel pass.

2.1.4 Survival estimates

Because of (i) occasional high discharges when the river flowed outside its banks (thereby allowing fish to pass alongside the antenna) and (ii) loss of function of at least one detection station (Stevenweert), chance of detection of marked eel at different detection stations was expected to be high, but smaller than one. Therefore, capture-recapture methodology was used to get unbiased estimates of survival rate (Lebreton *et al.*, 1992). This methodology accounts for detection probability to separate individuals that were not detected but alive, from those that had been lost in the interval. Analyses were carried out using the program MARK (White & Burnham, 1999) according to the procedures of the standard Cormack-Jolly-Seber (CJS) model to estimate survival rate (Φ) and detection probability (p).

Detection probability and survival rate were analysed as a function of river stretch between two detection stations (s , comparable to time t in the standard CJS-models), and we distinguished two groups (g): eels that went through the first hydropower station at Linne and eels that bypassed this HPS over the weir or through the fishway. After selecting the best model by testing for significant contributions of stretch and hydropower station passage (group effect), it was examined whether differences in survival rates between stretches could be attributed to stretch length (km), presence of a hydropower station and presence/absence of commercial fisheries. Finally, the model fit was tested with survival rates as a function of the individual covariates length (cm) and weight (g). MARK standardises the values of the covariates c ($\sigma_c = (c - \text{avg}(c)) / \text{SD}(c)$) to obtain values between -1 and 1 , which is necessary for a good functioning of the survival analysis algorithms. Selection of the most parsimonious model was based on a variation of Akaike's Information Criterion (AICc) (Akaike, 1985). The first, general model, and the final model without the covariate were assessed for fit to the data by a bootstrap simulation procedure with 100 repeats. The probability of observing the deviance of the model from the original data is determined as the relative rank of this deviance among the deviances from the simulated data.

2.1.5 Population estimates based on Mark-Recapture experiments

At three locations, eels with transponders could be recaptured within a registered total number of eels: in the turbine fyke catches at Linne (by KEMA 2002), in the anchored stow net in the main stream directly downstream of the weir and hydropower station of Linne and in the three stationary trawls in the tailrace of Alphen hydropower station. At the fykenet fisheries at Reuver-Belfeld, total catch was not known, a variable total number of nets was used depending on catches and only four were monitored. Based on the unbiased modified Lincoln-Petersen method, which assumes that the ratio of marked individuals (M) to population size (N) is equal to the ratio of recaptured fish (R) to the catch taken for census (C) (Ricker, 1975; Pollock *et al.*, 1990), an estimate of the total population passing during the period when transpondered specimens have a chance to be caught, i.e. after the release date, could be calculated:

$$N = (M+1) \cdot (C+1) \cdot (R+1)^{-1}$$

To calculate SD, R was treated as a binomial variable when low numbers of eels (< 25) were recaptured and the variance V (with $SD = \sqrt{V}$) was estimated according to Seber (1970):

$$V = ((M+1) \cdot (C+1) \cdot (M-R) \cdot (C-R)) / ((R+1)^2 \cdot (R+2))$$

2.1.6 Overall impact by hydropower-, fisheries- and unexplained mortality

In order to assess the relative impacts of the different sources of mortality, a comparison has to be made between numbers of specimens removed from the population, accounting for a varying number of specimens in the population at large. In analogy to the Virtual Population Analysis VPA (Beverton & Holt, 1957; Gulland, 1965), the following spatial equivalent can be derived. In the standard VPA, mortality is assumed to be constant over time. In the current setting, it seems more plausible to assume, mortality is related to the distance travelled downstream, which is a crude approximation to the number of fykenets passed, to the time spent migrating exposed to predators, etc. The change in abundance per kilometre travelled will be proportional to the fishing intensity, and to other mortality sources, according to a dynamic pool model:

$$\frac{dN}{dkm} = -(F_{km} + M_{km} + O_{km}) \times N_{km}$$

where:

N is the number of specimens in the cohort at river position km	[number]
F is a coefficient of mortality due to fisheries	[km ⁻¹]
M is a coefficient of mortality due to natural causes	[km ⁻¹]
O is a coefficient of mortality due to other causes	[km ⁻¹]
km is the distance travelled	[km]

This model constitutes an exact, spatial analogue to the standard, temporal VPA. Under the assumption that F_{km} , M_{km} and O_{km} are constant over any infinitesimal short river stretch $[km_0, km_0 + \Delta km)$, it follows that the catch over that river stretch equals:

$$C_{[km_0, km_0 + \Delta km)} = \frac{F_{km_0}}{F_{km_0} + M_{km_0} + O_{km_0}} \times \left(1 - \exp^{-(F_{km_0} + M_{km_0} + O_{km_0}) \times \Delta km}\right) \times N_{km_0}$$

The classical model of Beverton & Holt (1957) assumes mortality sources to be constant during an interval of one calendar year, with changes in mortality rates in-between the years. In reality, F and M will not at all be truly constant during any time interval. The discretised estimate of F thus only represents a kind of time-averaged approximation to the true but volatile value of F during the whole time interval. This translates for the current spatial model into mortality estimates, averaged over given river stretches, where the true mortalities will vary from place to place. Using the above equation, estimates of mortality rates per river length can be calculated from catch data per river length.

2.2 Turbine passage of silver eel at Linne hydropower station

In the current project, silver eel passage and turbine-related injuries at Linne hydropower station have been estimated in two different ways:

The first method is the conventional method by netting eels directly at the outlet of turbine 4 of Linne hydropower station, as described below in § 2.2.4. Eel passage and turbine-related injuries have been investigated earlier at Linne hydropower station in 1990/1991 (Hadderingh & Bakker, 1998) and in 1999 (Hadderingh & Bruijs, 2002) by means of netting behind one or more turbines.

The second method is a novel telemetry method based on the transponder technique (Nedap Trail System[®]) as described in § 2.1.3 and 2.2.5. For this 150 silver eels have been tagged with individually coded transmission tags (transponders). The results of the telemetry method provides valuable information on the cumulative damage due to passage of the two hydropower stations at Linne and Alphen.

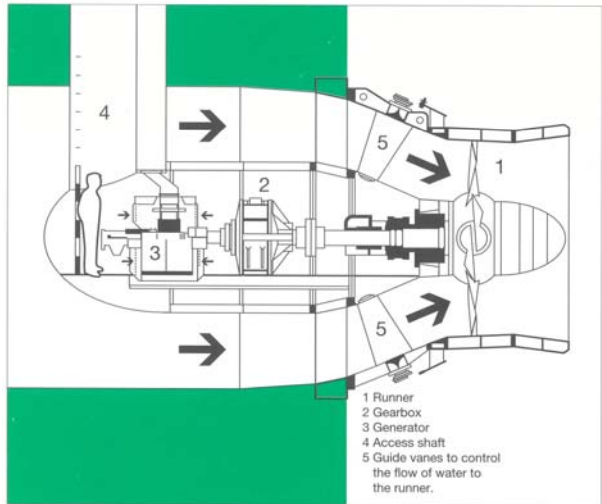
The information on turbine passage based on these two methods is used for the assessment of the impact on the silver eel population in the river Meuse by hydropower and commercial fisheries. The monitoring data also produces information on timing and intensity of the downstream migrating pattern which is used to validate the Migromat[®] system.

2.2.1 Linne hydropower station

Linne hydropower station is situated on the river Meuse at 68 river kilometres downstream from the Belgian border. It is located next to the weir where the average difference in water level is about 4 m. The hydropower station has 4 horizontal Kaplan-bulb turbines, each of 4 m diameter with a normal capacity of 2.87 MWe (maximum power of 3.5 MWe). In principle, the plant has a maximum output of 11.5 MWe at a head across the turbines of 4 m and a water flow of $450 \text{ m}^3 \cdot \text{s}^{-1}$. The flow per turbine may vary between 25 and $120 \text{ m}^3 \cdot \text{s}^{-1}$. Each turbine is connected to the generator by a gearbox which converts the 88.23 rpm of the turbine into the 750 rpm necessary to drive a generator. At average conditions, the plant should produce about 52 GWh of electricity per year. More details and a section view of Linne hydropower station are provided in Table 4 and Figure 3.

Table 4 Technical details of Linne hydropower station.

General	
Upstream level	20.80 m
Maximum head	4.00 m
Average river flow	250 m ³ ·s ⁻¹
Maximum flow through station	450 m ³ ·s ⁻¹
Total rating (MWe)	11.5 (max 14)
Units (MWe)	4 x 2.87 (max 4 x 3.5)
Transmission	
Single-stage planetary gearbox	
Turbine	
Horizontal, dual control Kaplan	
Runner diameter	4 m
Maximum power	3.5 MW at 102.5 m ³ ·s ⁻¹
Speed	88.23 rpm
Blade velocity	18 m·s ⁻¹
Generator	
Rating	4175 kVA
Voltage	10.5 kV
Speed	750 rpm



Section through a kaplan turbine as installed at linne

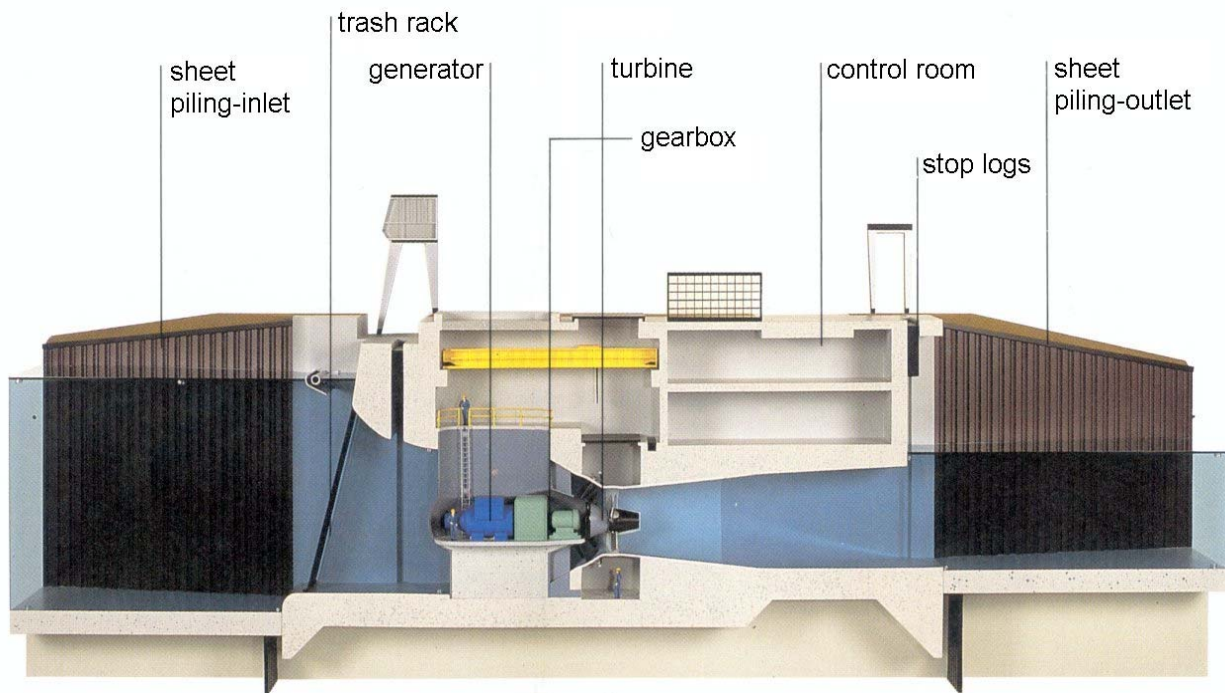


Figure 3 Section through Linne hydropower station

2.2.2 River Meuse discharge, turbine flows, water temperature and turbidity

Discharge of the river Meuse

The data of the of the river Meuse (average daily discharge expressed as $\text{m}^3 \cdot \text{s}^{-1}$) for Linne and for Alphen were provided by Rijkswaterstaat. The discharge data for Linne was measured at location Borgharen-Dorp (river km 16), and for Alphen at location Megen (river km 190.8).

Turbine flows of Linne hydropower station

The flow per turbine, the total flow through the station and the flow over the weir were automatically registered (each second) by measuring equipment of Linne hydropower station. From the data during the project period, the daily averages per turbine and the total flow of Linne hydropower station were calculated. During the samplings the flow of the sampled turbine (turbine 4) was kept on a fixed value (manual tuning) as much as possible in order to be able to assess the effect of turbine flow on the damage percentage. During the whole sampling period four turbines were in operation as turbine 2 was out of order for revision.

Water temperature and turbidity at Linne hydropower station

After each sampling, the temperature and turbidity were measured at the beginning of the inlet channel. The temperature was measured to an accuracy of 0.1 °C. The turbidity has been determined by means of a Secchi-disc (white disc with black facets) and was expressed as sight depth in cm. The disc is lowered by a measuring rope in the water until the difference between the white and black facets becomes indistinguishable.

2.2.3 Monitoring turbine passage

Sampling was carried out with a 35 m-long net, installed directly behind turbine 4, which is the turbine located nearest to the land side (Figure 4). The first 28 metres of the net have a stretched mesh size of 28 mm and the last part of the net has a stretched mesh size of 20 mm. This last part was constructed as fyke net, so that the fish could not swim back and to easy the emptying of the net from the boat. The net was mounted on a frame and lowered by a crane in the slot normally used for the stop logs in the outlet gate of the turbine, such that no fish passing the turbine could escape. The net was fixed by ropes in order to prevent damaging grating of the net against the sheet piling. At the sheet piling side of the net, a protective cover net was fixed.

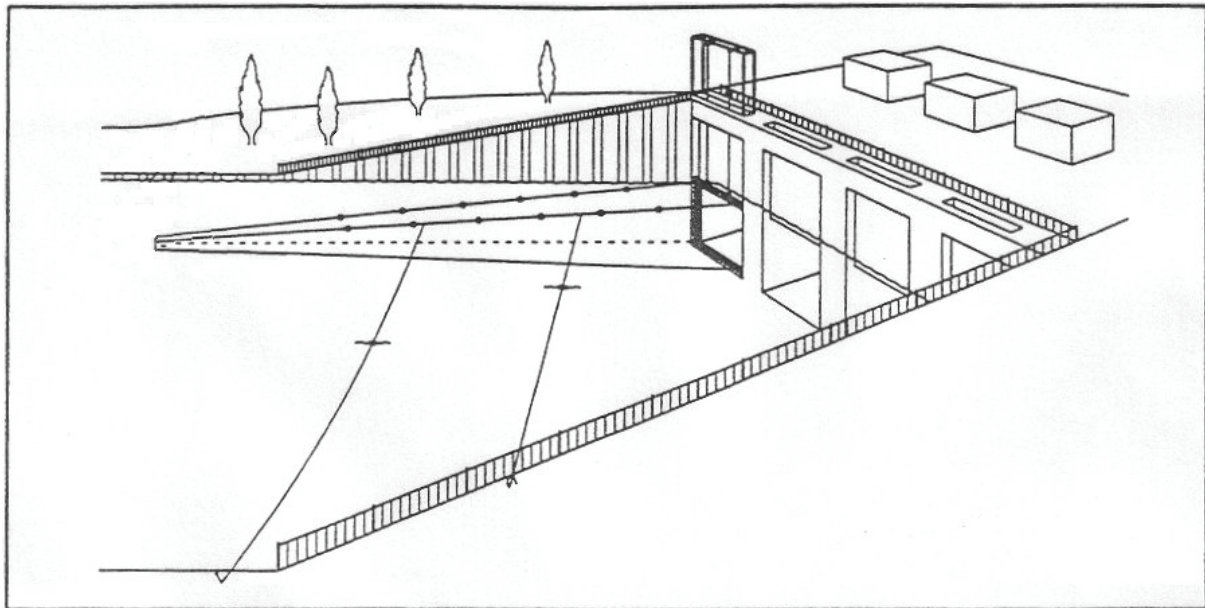


Figure 4 Schematic view on net position behind turbine 4 of Linne hydropower station.

The fish samplings at Linne hydro power station have been conducted from September until October 2002. In this period, 30 samplings had been scheduled at three days intervals. Decisions for any adjustments of this schedule were each time made at the day of installation of the net, anticipating on the actual river flow conditions and prospects for the following 24 hours. For each sampling, which took place overnight, it was attempted to install the net behind the turbine at around 15:30 pm and to lift it for emptying the next morning at about 8:30 am. During the sampling of 23 – 24 October, the net was emptied every 2 hours in order to assess the nocturnal timing of eel migration (night partitioning), see Table 5.

Table 5 Schedule of the 2-hourly sub-samplings during the night of 23 – 24 October.

Sub-sampling	Start time	End time	Total sample time (hr)
A	15:15	18:30	3:15
B	19:30	20:30	1:00
C	20:30	22:00	1:30
D	22:00	0:00	2:00
E	0:00	2:00	2:00
F	2:00	4:00	2:00
G	4:00	6:00	2:00
H	6:00	8:00	2:00

2.2.4 Assessment of injuries and mortality rate

The injury of the eel passing the turbines has been investigated from September 2 until October 22. Injuries and mortality were established directly after emptying of the net. Mortality can be defined as direct mortality. Delayed mortality, for example mortality after 24 hours, can not be excluded, but was not investigated. So the mortality percentages presented are minimum values.

After collection of the eel from the net, which always took place in the morning, the eels were distinguished in yellow eel and silver eel and selected into the two groups, damaged and non-damaged eels. The damaged eels were subsequently distinguished for lethal and non-lethal damages. For some eels it is difficult to see whether they have been lethally injured, for example showing lethargic behaviour, slight colour differences (pale) or haemorrhages. These eels were operated to check for lethal internal injuries, i.e. for example severe haemorrhages, torn liver or broken vertebra. If lethal injury was found, the eel was distinguished as 'lethal after check'. It may occur that a single specimen shows two or more types of damage. In case an eel has both lethal and non-lethal damages, it was distinguished as one lethal occurrence. In case an eel showed only non-lethal damages, it was distinguished as one non-lethal occurrence. Summarising, the eels caught at Linne hydropower station were divided into the following 8 groups (these are describe below):

1. undamaged
2. red fins and/or skin slashes
3. haemorrhages on head/abdomen
4. lethargic behaviour
5. complete and partially bisections
6. vertebral damage (visible by haemorrhage and/or bents)
7. crushed head
8. lethal after check

Of the first two groups it is assumed that specimens will largely survive the passages of the turbine. Postponed mortality may occur in group 2, but the expectations are that this is only to a small degree. Investigations on the mortality of silver eel at Dettelbach hydropower station in the river Main (Germany) by Holzner (1999), it was shown that 18% of the non-lethal damaged specimens still died. To what extent this percentage holds for Linne hydropower station is not known, because the two stations differ with respect to the speed and runner diameter of the turbine and the head. In addition, the damage in group 2, particularly the symptom of 'red fins', will be partially caused by contact with the net, as found in earlier investigations at Linne by KEMA in 1990. During this research, eels that had been

in the net for three days showed a higher percentage of light damage (42%) than the eel that had been in the net for 1 day (5.4%), as calculated over the total catch. Groups 3 and 4 were operated to check if the eels were lethally injured. In that case they were assigned to group 8, if not they remained in groups 3 or 4. specimens of group 5 and 7 have already died, or will die eventually. Of the eels with vertebral damage (group 6), it is assumed that these will die in time, although eels have been found which had recovered vertebral injury, visible by a local deformity (intergrowth or curvature of the spine) and thickening. It is not known whether these recovered injuries are applicable to previous passage of turbine of upstream hydropower stations. Thus, the percentage of mortality found at Linne hydropower station is based on the amount of eels that certainly have died or are still alive but expected to die due to injuries by passage of the turbine eventually. However, as of the latter group some individuals might survive and overcome their injury, the mortality percentage presented is thus a maximum.

The percentage of mortality at Linne hydropower station due to passage of the turbines is determined by dividing the number of eels of groups 5 + 6 + 7 + 8 by the total number of eels. This method is the same as used in earlier investigations in 1990/1991 and 1999 (Hadderingh & Bakker, 1998; Hadderingh & Bruijs, 2002).

2.2.5 Assessment of silver eel turbine-passage by means of telemetry

The telemetric method for determination of the mortality of silver eel is based on the Nedap Trail™ inductive coupling radio telemetric method (Nedap Trail System®). 150 silver eels were surgically implanted with individually coded transmission tags (transponders), of which, when a transpondered silver eel passes a detection station, an individual signal is sent to the antenna of the detection station (Figure 6).

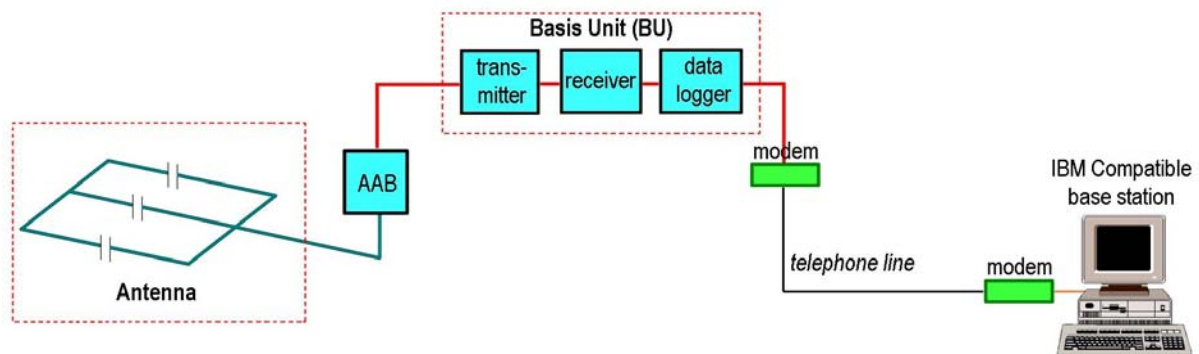


Figure 6 Schematic overview of a detection station.

A detection station consists in the following components: an antenna existing in three parallel cables with 10 m distance laid on the bottom of the river, which receives the response-signal of the transponder. The antenna is connected through a so-called 'Antenne Aansluit Box' (AAB) which is located at the river bank, to a data logging and transfer unit (receiver / transmitter), called together the Basis Unit (BU). The BU is located on the riverbank (for the two downstream detection stations) and inside the hydropower stations (for the two detection station at Linne and Alphen hydropower stations). Telephone lines have been installed to send the signals to a IBM compatible base station. The data were collected daily by using data telecommunication between base station at KEMA and the BU.

Detection of transpondered silver eel passages at hydropower station in the Dutch part of the river Meuse was made possible by installation of 4 detection stations at the two hydropower stations at Linne (river km 68.3) and at Alphen (river km 200.8). At each location, 2 detection stations covered the total width of the intake channel and 2 detection stations were located downstream these hydropower stations (respectively at river km 70.4 and 202.5), covering the total width of the river (Figure 7). From the detections it is derived which specimens passed the turbines. When an specimen is not observed at the hydropower station, but only at the downstream location, it must have been passed by the weir or the fishway.

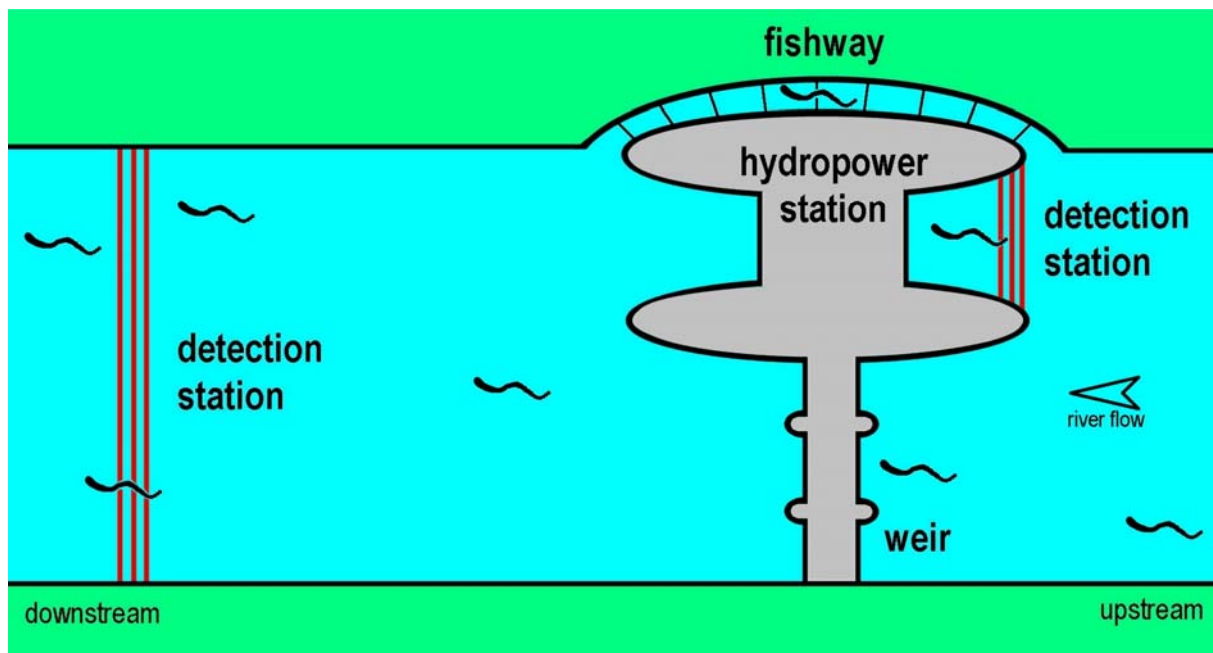


Figure 7 Schematic set-up plan for the (in total 4) detection stations for Linne and Alphen hydropower stations. At both locations fisheries take place between the weir/hydropower station and the downstream detection station

2.3 Monitoring of downstream migration activity by means of the Migromat[®] system

A fish-friendly operational management of hydropower plants, such as reducing or stopping the turbines during the periods of downstream migration of eels could be used as an alternative strategy for saving downstream migrating silver eel. A necessary prerequisite for this is an early and reliable detection of downstream migration events, which are spread over the year, but concentrated in some nights. Several projects have been initiated to detect environmental factors that cause the downstream migration of eels. However, no correlations between the migration events and river discharge, water temperature or moon phase could be found to develop a method for the prediction of downstream migration events of silver eels. Moreover the power supply companies do not accept the risks of negative alarms or long-term turbine flow reduction.

In Opposite to these trials, the Migromat[®] system pursues the idea of biomonitoring, by an automated observation of the behavioural pattern of indicator organisms: the changes of the activity level of eels kept in a closed container system provides accurate information about the state of their premigratory-restlessness and the time when the start of a migration will occur. To operate the Migromat[®], the tanks are stocked with wild living eels that are caught in the river Meuse by means of electrofishing. These eels are tagged by subcutaneous injection of an individual coded PIT-tag (Passive Integrated Transponder, TROVAN[®]) (Figure 8). The eels are kept in two containers situated on the riverbank close to the hydropower stations Linne and Alphen (Figure 9). The continuous supply of river water through the containers was provided by two pumps (Figure 10).

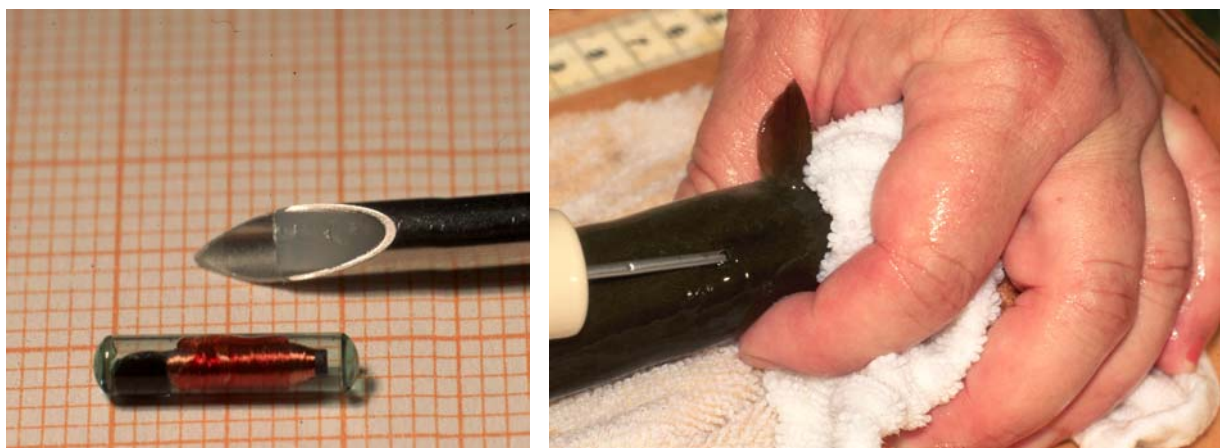


Figure 8 PIT-tag with injection tube (left) and the dorso-lateral subcutaneous injection of a PIT-tag (right).



Figure 9 Migromat® at Linne with fence (left) and the Migromat® at Alphen (right): the container stores the reading devices and the computer equipment.



Figure 10 Pumps and outlet of the Migromat® at Alphen hydropower station.

Displacements of the PIT-tagged eels between the compartments inside each tank are registered by a system of four frame-antennae around the openings in the walls between the five tank compartments (Figure 11). The electromagnetic induced signals are decoded by reading devices, achieved by means of one PC per location. A displacement in sense of “activity” is registered when a specimen passes two antennae during a period of two minutes. The existing software of the computers was adapted to co-operate with DOS-based remote control software. The electrical and computer equipment was stored in a separate, well air-conditioned container, which could be locked. The recorded data of the eel activity has been

transferred by modem to the IFÖ (Germany), where the analysis of the behavioural pattern of the eels was performed by means of specific software tools.

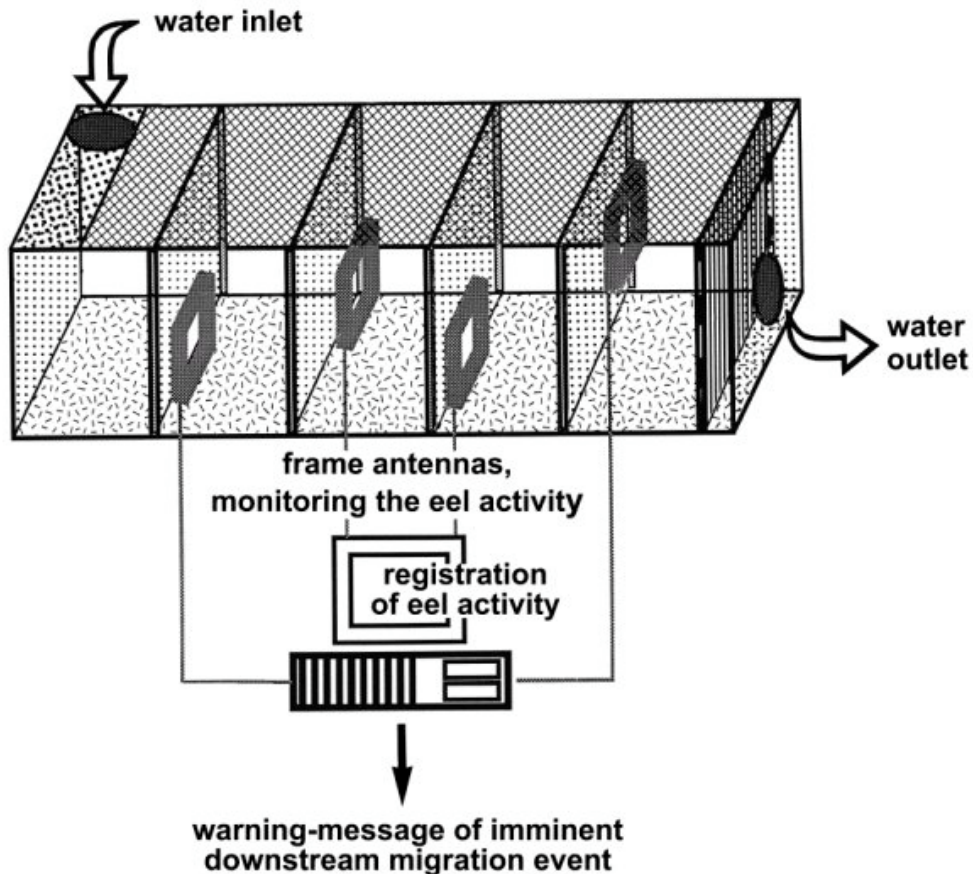


Figure 11 Schematic overview of the Migromat® system registering eel activity.

Further investigations have proven that the Migromat® documents eel activity (pre-migratory restlessness) prior to natural migration events of silver eel in the river at which it has been installed (Adam 2000). To check the reliability of the prediction of the Migromat®, the monitoring of commercial fisheries catches, the transponder experiment and monitoring of eel passage at Linne hydropower station investigated the actual migration pattern in the river Meuse.

3 RESULTS

3.1 Monitoring commercial fisheries and telemetry

3.1.1 Commercial eel catches

In 2001, silver eel started to move downstream in late July, early August, but the majority started from 14 September onwards on both locations (Figure 12a). At Belfeld-Reuver, peak was sharper and lasted shorter than at the downstream location Lith-Alphen, where the September peak was followed by an early October peak. The anchored stow nets caught mainly silver eel, whereas the fykenets at Reuver-Belfeld caught a relatively large amount of yellow eel during summer.

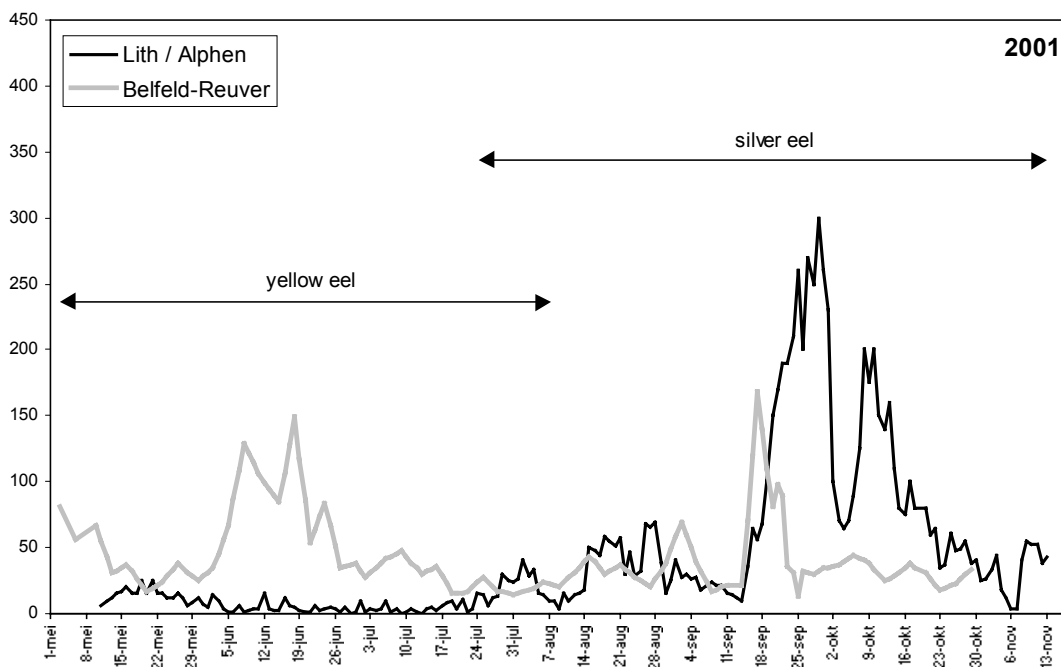


Figure 12a Commercial eel catches expressed as total numbers caught per set of monitored nets per day at two locations in the River Meuse during 2001 (see Figure 1 for locations).

In 2002, downstream migration started in early August, with peaks during the end of August, end of September to early October and end of October to early November (Figure 12b).

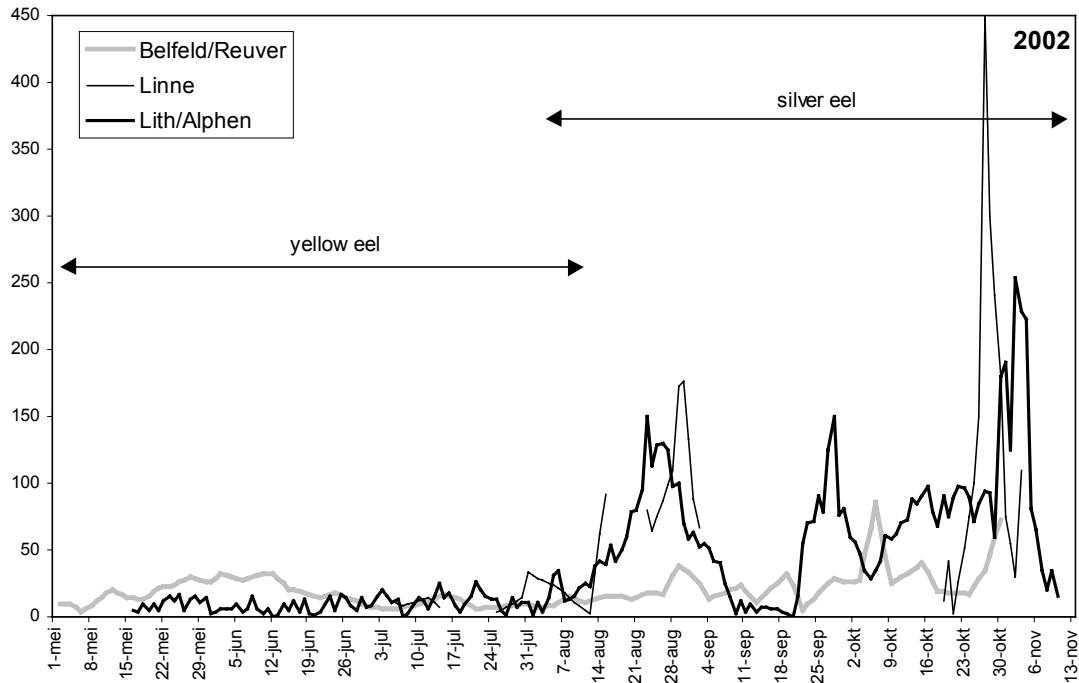


Figure 12b Commercial eel catches expressed as total numbers caught per set of monitored nets per day at three locations in the river Meuse during 2002 (see Figure 1 for locations).

Even though fishing effort at Linne was irregularly distributed over the season, a clear peak could be observed at 27 October. A total 1,639 eels were caught at Linne and 4,316 in one anchored stow net at Lith-Alphen (12,948 in total when assuming equal catches in each of the three nets).

As an indication to what extent eels might be protected by closing the turbines for an increasing number of days, assuming that days with peak migrations can be predicted with high precision, the catches at the location Lith-Alphen were sorted from high to low and the cumulative fraction was calculated per day for each year during 1997-2002. In most years about 20 days yield 50 % of the silver eels, but in one year just 10 days yielded more than 60 % of the total catch (Figure 13).

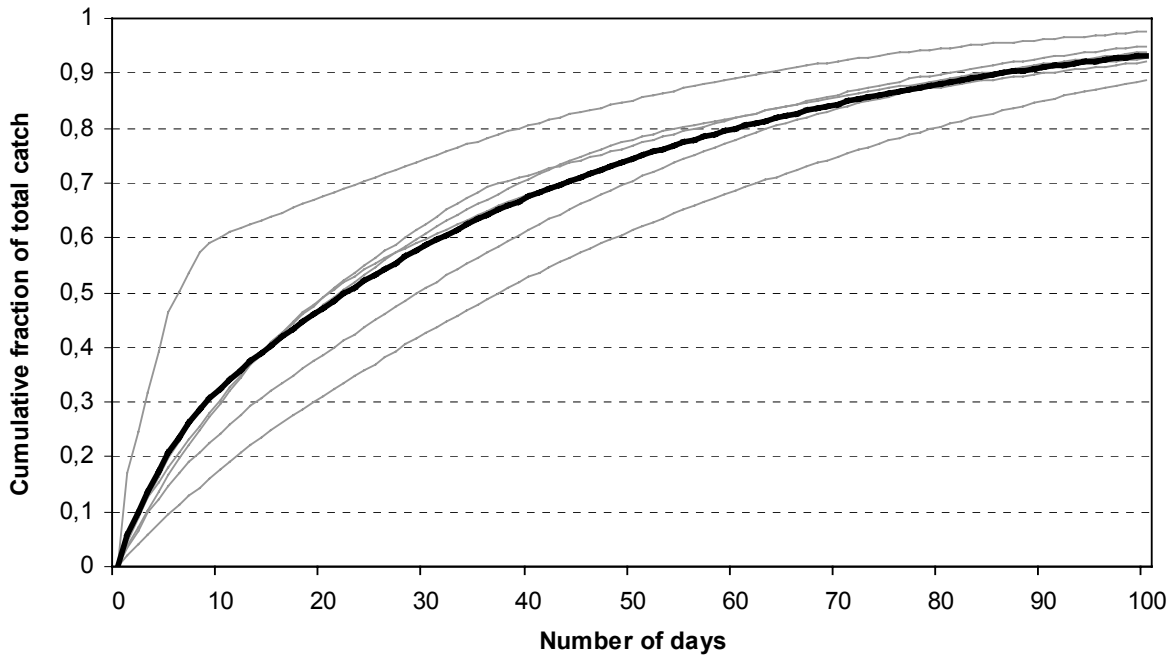


Figure 13 Cumulative fraction of silver eel catches at location Lith-Alphen when daily and yearly observations were ranked in decreasing order. Distributions of individual years during 1997–2002 (—) and the average distribution (—).

3.1.2 Applicability of transponders in silver eel

The tank experiment in 2001 started with 20 eel in both the control group and in the group with implanted dummy transponders. All eels of both groups had PIT-tags. In both groups one eel died during the experiment. Three eels; one from the group with transponders and two from the control group, severely infected with *Saprolegnia* that were about to die, were removed from the tanks (Table 6). Adding these to the mortality makes 10 % for the group with dummy transponders against 15 % for the control group.

Table 6 Results of the controlled tank experiment during 11 weeks after 10 October 2001. The eels that were removed were dying of severe *Saprolegnia* infections.

Group	Number	Dead	Removed	PIT-tag loss
Control with only miniature PIT-tags	20	1	2	1
Implanted with dummy transponders & PIT-tags	20	1	1	1

In both groups, one eel lost its PIT-tag. These two PIT-tags were only active during the first few days, after which they were presumably lost. Another control group eel escaped to tank number E after some weeks, but data on its behaviour was received throughout the period and included in the experiment. None of the eels had lost its transponder, and all transponders were lying free in-between the organs in the body cavity. At the end of the experiment, all specimens had closed wounds varying from fat tissue incorporated in the closed wound to a complete closing of the skin. Only few and minor inflammations were observed. Nearly all individuals had internal tissue grown to the wound.

During most of the period, the control group showed a higher activity (as measured by the number of passages of the windows between tank segments, than the group with dummy transponders (Figure 14), which proved to be significant based on the generalised linear model (Table 7). Visually, the experimental period can be split into three periods; a starting phase (1) characterised by a high activity for a prolonged period, a peak period (2) with a short and steep rise of activity, and less active periods before and after this peak (3). In periods with an increased activity (period 1 & 2) a consistently higher activity pattern was observed for the control group eels compared to the eels with dummy transponders. During the period with low activity this difference was not significant (Table 7), although Figure 14 suggests extremely low activity among dummy transpondered eels after the second peak.

Table 7 Significance levels of effect on activity between control group and transpondered group for the entire period and divided in three periods (see Fig. 14).

Period	Entire period	Starting Phase (1)	Peak (2)	Baseline (3)
P-Value	0.026	0.047	0.027	0.71

A clear diurnal pattern was observed in both groups (Figure 15). During night time, especially between 17 and 20 hours, activity was higher. Again the control eel show a significantly higher activity than eels with dummy transponders ($p = 0.01$).

In contrast to activity, timing of activity is very similar between both groups during the different periods as well as during the day, and differences were not significant.

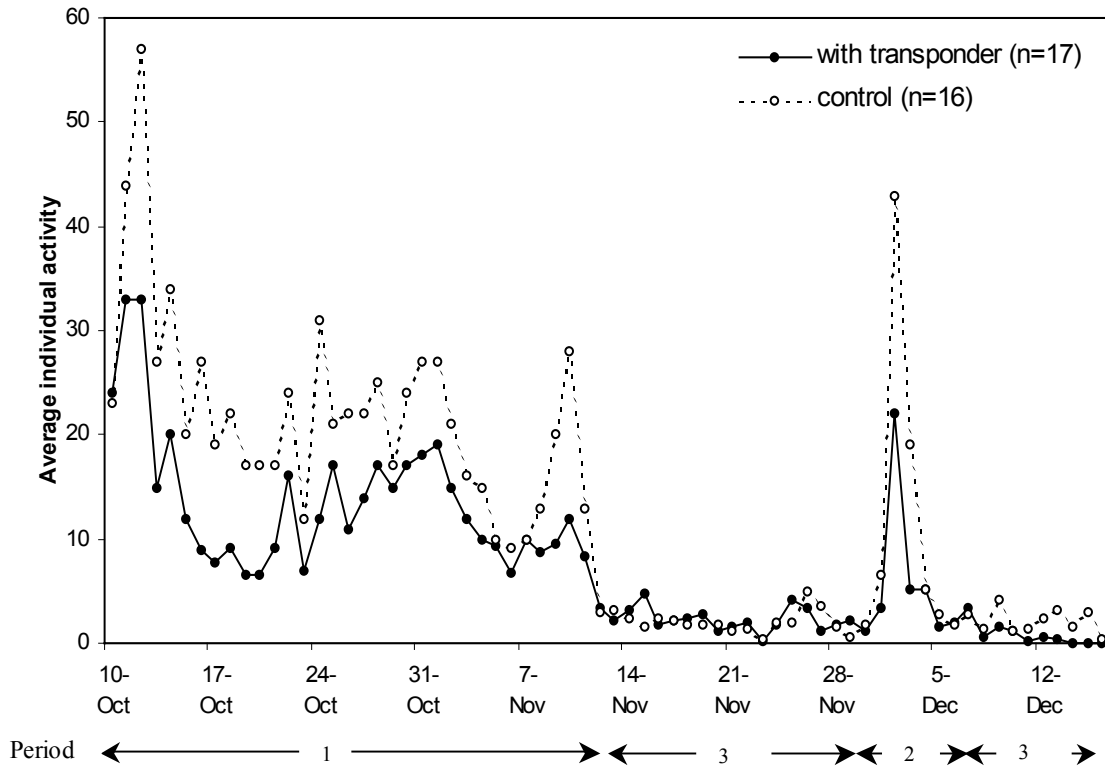


Figure 14 Average individual daily activity during the tank-experiment in 2001 for the control group and the transpondered group.

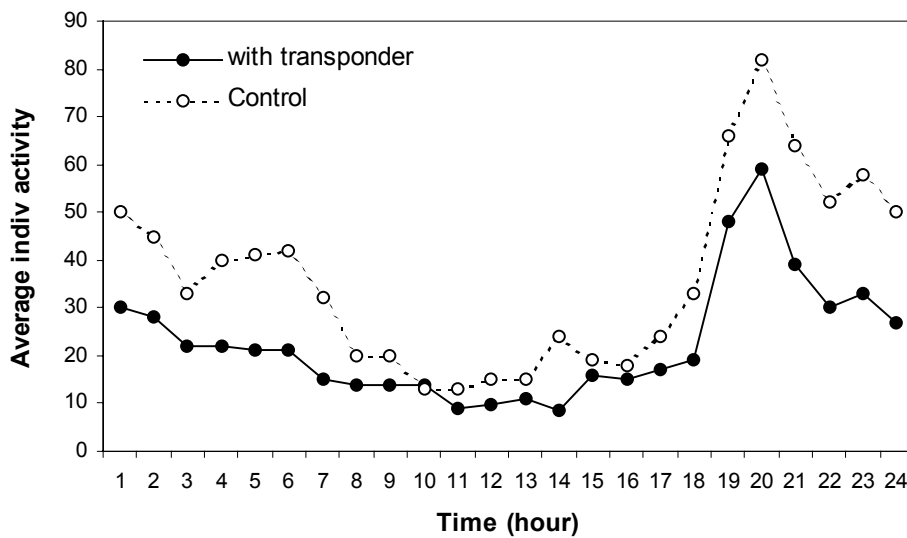


Figure 15 Diurnal pattern of individual activity in the tank-experiment of 2001 in the untagged control-group and the group with dummy transponders.

3.1.3 Telemetry experiments: pilot study 2001 and full scale experiment 2002

3.1.3.1 Telemetry pilot study 2001

Of the total 10 silver eels released with a transponder in the pilot study in 2001, eight passed the detection station at Stevensweert and two made it finally to the sea (Table 8). More passages were seen at night (n = 24) than during the day (n = 4). During the pilot study, the four detection stations at the hydropower station where not active yet.

Table 8 Dates and times of the passages of detection stations (river km) by ten transpondered silver eels during the 2001 pilot study.

No	Stevensweert (km 61)	Afferden (km 147)	Sambeek (km 152)	Balgoij (km 178)	Capelse Veer (km 241)	Haringvliet/sea (km 315)
1	Sept 23 05:29	Nov 10 05:03	Nov 10 05:36	Nov 11 00:50	Dec 2 00:42	Dec 6 06:57
2	Nov 8 19:01	Nov 10 04:12	Nov 10 04:37	Jan 27 (2002) 20:16	Jan 29 (2002) 03:54	Jan 31 (2002) 23:24
3	Sept 22 20:28	Sept 24 21:41	missed	Sept 25 06:29	Sept 29 15:38	-
4	Sept 23 06:07	Sept 26 23:17	missed	Sept 28 01:57	-	-
5	October 7 23:13	Feb 3 (2002) 05:37	missed	Feb 4 (2002) 05:55	-	-
6	Sept 21 13:04	Sept 23 15:36	Sept 24 00:16	-	-	-
7	Sept 22 23:46	Sept 09:08	-	-	-	-
8	Sept 23 01:44	-	-	-	-	-
9	No detection	-	-	-	-	-
10	No detection	-	-	-	-	-
total	8	7	6	5	3	2

3.1.3.2 Telemetry field experiment 2002/03

In the full scale telemetry field experiment 2002/03, the 150 female silver eels released at Ohé en Laak, varied in length between 64 and 93 cm. Figure 16 shows the length frequency distribution of these 150 silver eels.

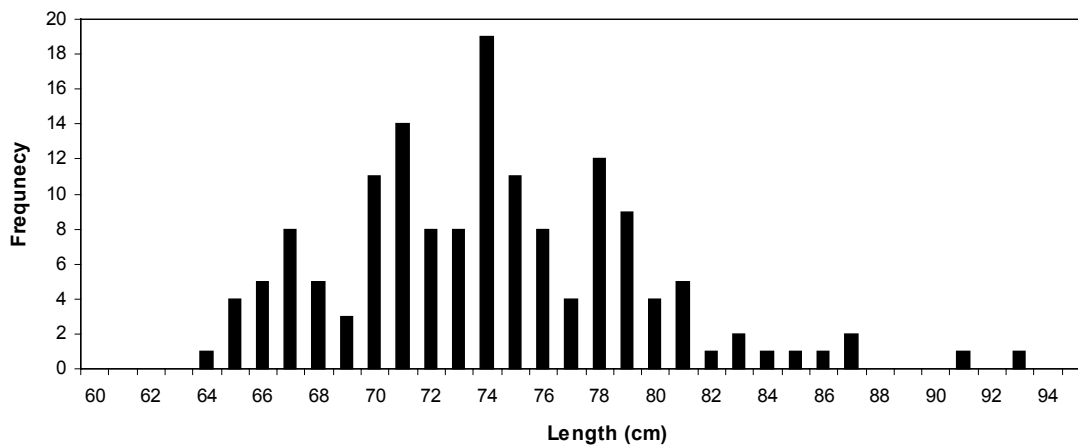


Figure 16 Length-frequency distribution of the 150 transpondered silver eels (2002/03)

A schematic overview of the transponder experiment results is shown in Figure 17. In this figure, the detection stations in the Dutch section of the river Meuse (14 in total) are shown by bold orange lines. **Bold**: number of eels that have passed the detection stations. Because some passages were missed, i.e. eels that were registered at a detection stations, but which were not detected at the nearest upstream detection station, these bold numbers have been corrected for known missed passages. **(Bold)**: number of eels that bypassed a hydropower station over the weir or fishway, assuming that no eels disappeared in the small stretch between the weir or fishway and the downstream detection station. *Italic*: number of eels that disappeared in the stretch between two successive detection stations. *(Italic)*: number of eels that were recaptured by commercial fishermen.

Of the 150 eels released at Ohé en Laak, 125 have passed the first detection station at Stevensweert and at least 32 silver eels reached the sea (Figure 17). Especially in the first three stretches between Ohé en Laak and Afferden, a relative high number of eels disappeared, respectively 25, 31 and 22, of which at least 6 were recaptured by commercial fishermen. In the following two stretches, from Afferden to Sambeek and to Balgoij, only 3 eels disappeared, but these stretches are short without hydropower stations and hardly any fisheries. In the downstream part of the river Meuse from Balgoij to the two detection stations at the Haringvliet dam and Oude Maas, 37 eel disappeared of which 10 were recaptured by

commercial fishermen. 32 transpondered eels have reached the sea for sure. However, when assuming that a similar missing chance as found for the other stations was present at the sea stations, the number of eels that reached the sea is likely to be 38.

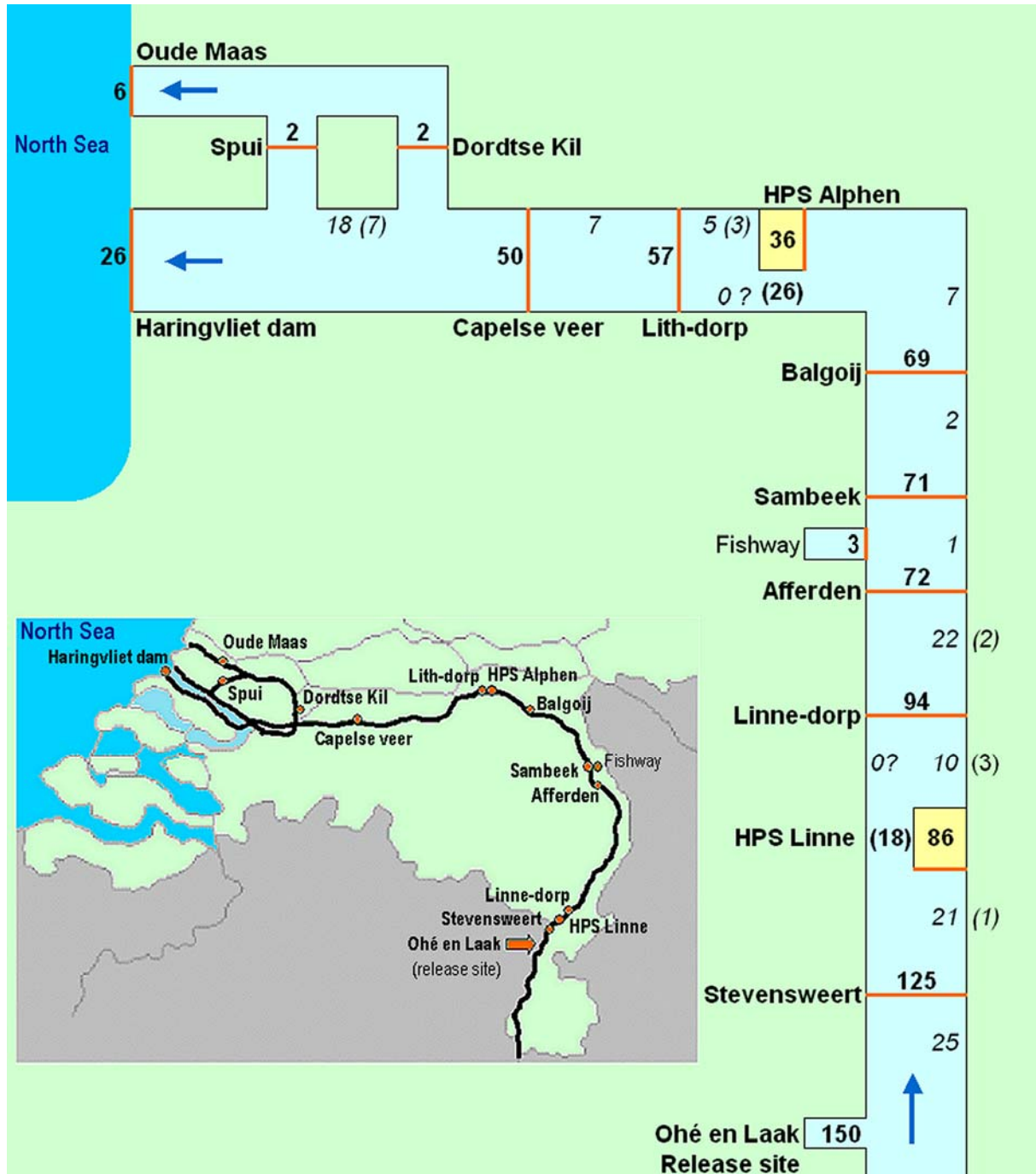


Figure 17 Schematic overview of the results of the telemetry field experiment in the river Meuse in 2002 (see text for explanation).

3.1.3.3 Assessment of turbine passage & mortality by means of telemetry

Of the 86 eels registered at the intake of Linne hydropower station, at most 7 (8.1 %) died directly and 3 undamaged eels were recaptured directly downstream by the anchored stow net. At Alphen hydropower station, 36 eels were detected at the intake and 5 were never detected again (of which 3 were recaptured by anchored stow nets directly downstream), giving at maximum 5.5 % that died directly owing to turbine passage. However, it is uncertain whether all these 86 at Linne and 36 eels at Alphen all have passed the turbine, because they may have chosen to return and pass over the weir instead. Only for those 22 eels that were recorded at the downstream stations at Linne-dorp and Lith-dorp within a very short time interval (up to 30 min) after their last detection at the intake of the turbine, it can be safely assumed that they have passed the turbine.

3.1.3.4 Behaviour of silver eel in front of Linne hydropower station

When passing a detection station a tagged silver eel the transponder will send a signal to the cables only once. As mentioned above, silver eels detected only once at the intake of Linne hydropower station and soon after at Linne-dorp, clearly passed the hydropower station and migrated further downstream. However, it has been found that it is possible that a silver eel remains for a period of time within the detection range of the detection station, sending a signal from the transponder every two minutes. This situation has been defined as stationary position. Another possibility found is that a silver eel is detected more than once but with a time interval of more than two minutes, indicating that the silver eel remained in the neighbourhood of the detection station for a longer period, entering the detection range at longer intervals. This behaviour has been defined as recurrence behaviour. Of silver eels showing stationary or recurrence behaviour, it is uncertain if they went downstream through the hydropower station or went back upstream and bypassed the hydropower station through the weir or the fishway, or even remained upstream for longer periods. Furthermore, even in the group with only one detection at the detection station at the intakes (Table 9), it is not absolutely certain that the turbine has been passed, because two specimens with only one detection at their first visit were nevertheless detected repeatedly at the intake station after large time intervals, up to one month later. Thus, these eels must have returned into upstream direction. Indeed, another individual showing repeated visits to the entrance of the turbines at Linne was later detected at Stevenweert, 7.3 km upstream. The stationary and recurrence behaviour of transpondered silver eels at Linne and Alphen hydropower stations and Linne-dorp and Lith-dorp are shown in Table 9. From these results it can be concluded that eels show a clear hesitation to pass the hydropower station.

Table 9 Number of eels that were registered at the intake of a hydropower station divided in three groups: eels with one detection only, showing stationary behaviour and eels showing recurrence behaviour. Of the total of detected eels, the number of eel caught by commercial fisherman are shown brackets.

Hydropower station (including fishery)	Number of eels detected at the intake		
	One detection	Stationary	Recurrence
Linne	47	11	28
<i>Seen within 1 hour at Linne-dorp</i>	20	3	8
<i>Seen within 1 to 2 hours at Linne-dorp</i>	6	0	5
<i>Seen within 2 to 24 hours at Linne-dorp</i>	11	5	4
<i>Seen after > 24 hours at Linne-dorp</i>	8	2	3
<i>Never seen at all at Linne-dorp</i>	2 (2)	1	7 (1)
<i>Not seen at Linne-dorp but further downstream</i>	0	0	1
Alphen	26	7	3
<i>Seen within 1 hour at Lith-dorp</i>	14	5	2
<i>Seen within 1 to 2 hours at Lith-dorp</i>	0	0	0
<i>Seen within 2 to 24 hours at Lith-dorp</i>	3	1	1
<i>Seen after > 24 hours at Lith-dorp</i>	2	0	0
<i>Never seen at all at Lith-dorp</i>	4 (3)	1	0
<i>Not seen at Lith-dorp but further downstream</i>	3	0	0

3.1.3.5 Timing of migration events

Directly after releasing the batches at Ohé en laak, an increase in numbers passing the first two detection stations could be observed (Figure 18). This may be at least partly due to the treatment of the eels rather than reflect natural migratory behaviour. Especially at Stevensweert many repeated detections per specimen were observed, indicating that the eels were potentially ‘searching’ for a site to settle.

In the last week of October, many eels suddenly started to migrate downstream. At all detection stations, a substantial part of the total numbers pass during this week, which coincides with large catches in commercial fisheries. The river discharge at both Linne and Alphen hydropower station (upper panel Figure 18) show the same trend, however changes firstly occur upstream at Linne. At October 22 – 30 a clear peak of detections is observed at both hydropower stations simultaneously, showing up firstly at Linne. It is clearly visible that these detection peaks (migration events) coincide with an increase of river discharge, also starting from October 22. Moreover, during the monitoring of eel passage at Linne hydropower station, the highest number of eels are found at the samplings of October 21 –

22 and October 24 – 25, which is exactly the same period (§ 3.2.5). Unfortunately no eels were caught during the sampling of October 26 – 27, as the net broke down due to a high amount of debris in the river in combination with a very high flow through the net. However, it is expected with certainty that during this night the amount of eel through Linne hydropower station has been the largest, considering both the detection rate of transpondered eels and the result of the Migromat® (§ 3.4) during this night.

During the first half of November, at all detection stations the number of eel detections keep increasing, but then stops. End December and early January the number of detections increase again, especially in the downstream part of the river Meuse. These periods with high migration activity appear to be associated with an increase in water discharge rather than with lunar phase (Figure 18), although the first large migratory wave at the end of October occurs during waning of the moon.

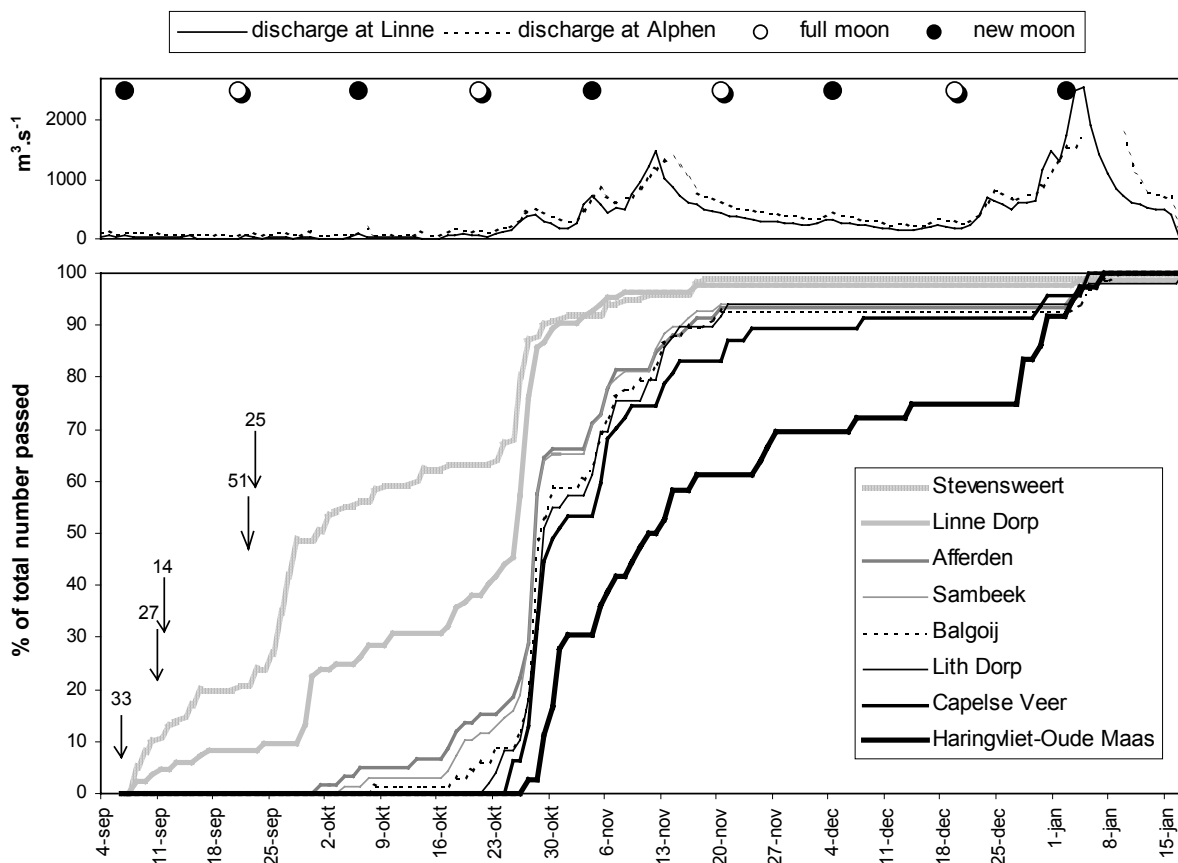


Figure 18 Cumulative percentage of total passages of transpondered eels per detection station (bottom panel), compared with the river discharge at Alphen and Linne and lunar phase (∇ = full moon, ● = new moon) (top panel). The arrows indicate the timing and number of eels released at Ohé en Laak.

Furthermore, the timing of migration activity at 24 hours scale, shows a higher activity during the night than during the daytime (Figure 19) and most of these detections took place after sunset and before midnight. This time frame in which the eels are most active has also been observed during the sampling of turbine passage (§ 3.2.5.1), when most eels pass between 19:00 p.m. and midnight, as well as in the Migromat® (§ 3.1.2).

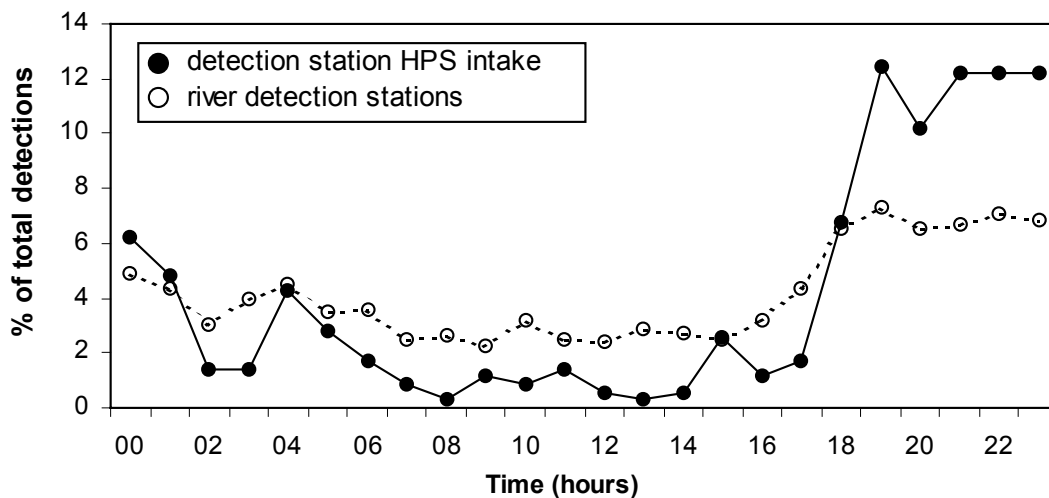


Figure 19 Percentage per hour of total detections for the 2002 transponder experiment (24 hour scale).

The diurnal differences (Figure 19) shows to be stronger at the detection station in front of the hydropower stations intakes, indicating a hesitation of the eels to pass the hydropower station. At the detection stations at the hydropower intakes 63 % of all detections took place between 19:00 – 24:00 p.m (CET), while at the river detections stations 35 % of all detections occurred between 19:00 – 24:00 p.m. (CET).

The individual patterns show that many eels perform a stepwise downstream migration with fast downstream movement alternating with periods of inactivity even of up to two months (Figure 20). Most of these fast downstream movements took place in late October 2002 and early January 2003.

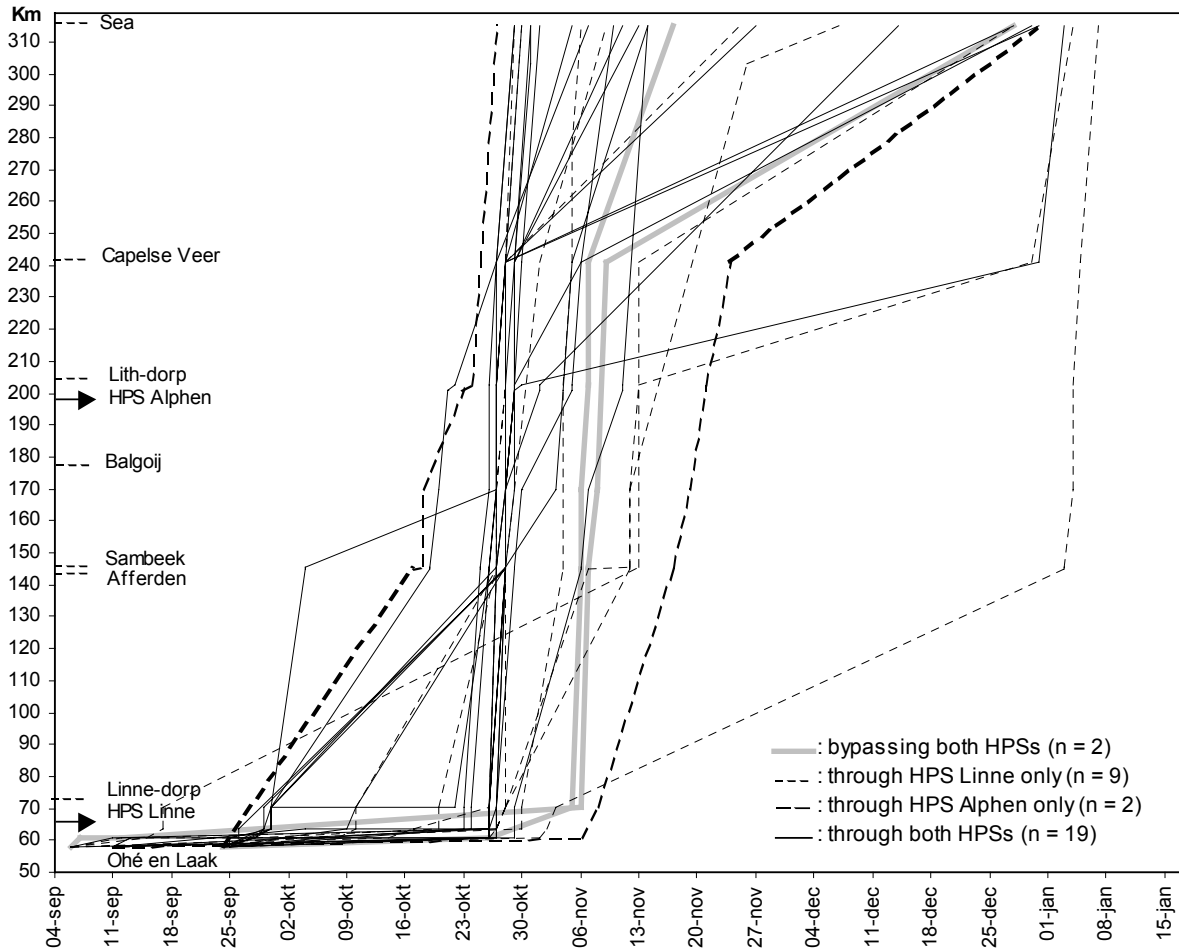


Figure 20 Individual downstream migration patterns of the 32 eels that reached the sea successfully during the 2002 transponder experiment. Each line represents one specimen, type of lines are clustered in four groups (see legend).

3.1.4 Survival rate estimation by MARK modeling

Because eels were missed at some stations, i.e. detected at a more downstream location after not been detected at a previous station, models examining the combined effect of 'survival' rate and missing stations were used. To assess whether detection probability differed by detection station ($p(s)$), or was best described by a constant probability ($p(.)$), a comparison was made between two models with constant survival ($\Phi(.)$) but differing in p accordingly were compared. The model with constant detection probability yielded a value of 0.86 ± 0.01 (mean \pm SE), but the model with $p(s)$ had lower AICc (Table 10). We continued model selection with $p(s)$. Then it was tested whether survival differed per stretch ($\Phi(s)$).

Model Phi(s)p(s) proved to be the best description of the data at this point in the analysis. Survival rates towards the detection stations are depicted in Figure 21. Overall survival rate for Silver eel on the river Meuse between Ohé en Laak and the sea (315 km) was estimated at 31%.

Table 10 Results of models selection using all detection stations and no groups.

	Model	AICc	Delta AICc	No. of par.	Deviance
1	Phi(s) p(s)	981	0	17	946
2	Phi(.) p(s)	1007	26	10	987
3	Phi(.) p(.)	1026	45	2	1022

The survival rates per stretch are affected by several factors. Firstly, as indicated in Figure 21, on most stretches commercial fishery exist. Secondly, hydropower stations were present in the second and seventh river stretch. Unfortunately, as a result of the location of the detection stations, the presence of a hydropower station in a river stretch at both locations coincided with the presence of a commercial fishery. Thirdly, if natural mortality is more or less constant along the river, stretch survival rates should differ because of variable stretch lengths (0.5 to 75km). Finally, fish were caught and thereafter released several times at the outflow of Linne hydropower station (KEMA experiments at Linne). Among the five silver eels with operation wounds caught, only three still carried their transponder (all five had no injuries, see § 3.2.5.3). Apparently, tag loss had occurred and the problem may have been substantial (40% based on this very small sample size). Based on the length and weight of the two specimens that had lost their transponder, by excluding all downstream detected eel, only three eels released at Ohé en Laak remained to potentially match these specimens and none of these had been detected at Stevensweert. This implies that the transponders had already been lost in the first stretch and loss could not have been caused by turbine passage. No further information is available on the occurrence and importance of tag loss per stretch.

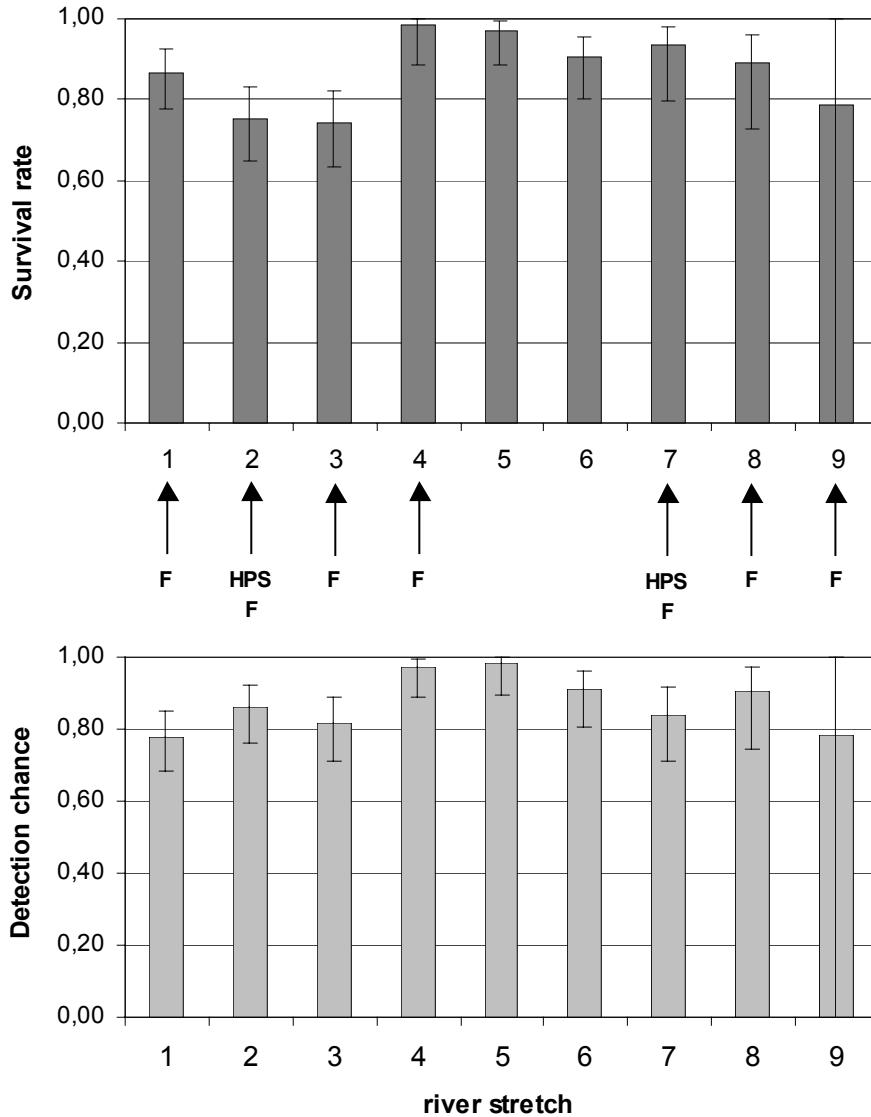


Figure 21 Survival rate (top panel) and detection chance (bottom panel) per river stretch. Errors bars indicate 95% confidence interval; HPS: stretches in which a hydropower station is located; F: stretches in which fisheries occur. Numbers on the x-axis refer to stretches between detection stations, see also Table 3.

To examine the contributions of length of river stretch, hydropower station presence and fishery to survival rate, the survival estimates were constrained as a linear function of those three parameters (model 1, Table 11). The length of river stretch was first accounted for as the most natural source of variation, since this may be associated with natural mortality and fisheries. The reduction in parameters (intercept + length of stretch versus nine stretches) did

not improve the fit of the model. The results can be inspected by plotting the initial stretch survival rates against stretch length (Figure 22).

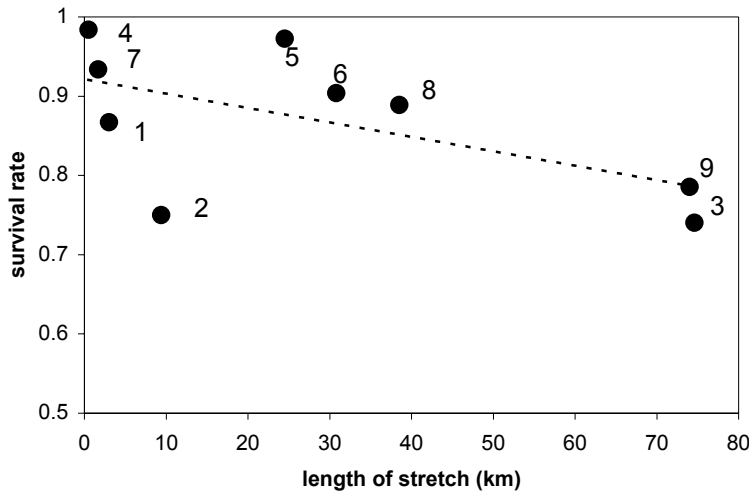


Figure 22 Survival rate per river stretch in relation to its length. The line represents a linear regression through all data points. No.'s refer to stretches between detection stations, see also Table 3.

The graph shows the expected overall trend of lower survival rates with increasing length of the stretch based on the data points. The first two stretches seem to represent negative outliers, which may be explained by tag loss (no tag, not detected or assumed dead). Tag loss was expected to be most prominent immediately after implantation, which was supported by the observations of 2 eels in the KEMA-experiments at Linne that had never been detected at Stevensweert, and to be reducing with increasing distance from the point of release. Tag loss was modelled in addition to river stretch length by adding a second constraint to the first two (three) stretches (model 2). This model had lower AICc and was preferred over the starting Phi(s)p(s) model. Adding the tag loss constraint to the first three stretches led to a worse fit than the previous model and the model was therefore rejected. Lacking quantitative information on the intensity of fisheries by stretch, model selection was continued by adding a constraint for presence/ absence (model 3). The model was slightly worse but virtually ($\Delta AICc < 2$) indistinguishable from the previous model. Adding a constraint for the presence of a hydropower station (combined with anchored stow net fishery presence/absence) to model 2 slightly improved the fit of the model (model 4). When the fishery-constraint was then added again (model 5), the model fitted the data less well than model 4. However, the predictions from model 5 to estimate the effects on survival of all contributing parameters were used, because the AICc were only slightly less than the preferred model 4.

Table 11 Results of models selection using all detection stations, no groups and various constraints on river stretch: length of stretch (km), presence/absence of tag loss, hydropower station and fisheries.

	Model	AICc	Delta AICc	No. of par.	Deviance
4	Phi(s-length, tag loss, HPS) p(s)	975	0.00	13	949
2	Phi(s-length, tag loss) p(s)	976	0.79	12	951
5	Phi(s-length, tag loss, HPS, fishing) p(s)	977	2.01	14	948
3	Phi(s-length, tag loss, fishing) p(s)	978	2.67	13	951
2a	Phi(s-length, tag loss (3)) p(s)	979	3.66	12	954
0	Phi(s) p(s)	981	5.71	17	946
1	Phi(stretch length) p(s)	1003	27.79	11	980
	Phi(.) p(s)	1007	31.72	10	986

Using model 5, the (negative) effects of the various factors on survival can be predicted. In each model, survival is expressed as a function of one or more variables (factors) following the general link function:

$$\text{logit}(\Phi) = \ln(\Phi/(1-\Phi)) = \alpha + \beta x \quad (a)$$

in which a is the intercept and b is the slope of the variable. Φ can then be estimated from:

$$\Phi = e^{\alpha + \beta x} / (1 + e^{\alpha + \beta x}) \quad (b)$$

The parameters α and β for each contributing factor are given in Table 12.

Table 12 Link function parameter estimates.

	Parameter	SE
Intercept	3.680	0.420
Stretch length	-0.034	0.008
Tag loss	-1.487	0.478
Hydropower station + fishery	-0.827	0.605
Fishery	-0.135	0.511

Because of the non-linear character of the link function, the main effects on survival cannot be estimated directly, but have to be calculated for each stretch separately. Estimated tag loss on the first two stretches accounted for a reduction in survival of 9.3% and 20.3% respectively. The presence of the hydropower stations at Linne and Alphen (including fishery) reduced survival by 13.7% and 3.6%, respectively. Fisheries on the other stretches accounted for estimated mortality rates of 0.4 to 2.5%.

3.1.5 Hydropower station induced delayed effects

One of the main aims of the project was to assess potential negative effects of hydropower stations on silver eel survival. However, as a result of the presence of a hydropower station combined with anchored stow net fishery in a river stretch at both locations, immediate effects of those two factors on survival rate could not be completely separated with the given experimental design. In Table 9, estimates for the maximum direct mortality for eels that probably passed the turbine are given. When including eels bypassing Linne hydropower station up to 6.7 % direct mortality due to hydropower was estimated by the Mark-model, whereas at Alphen hydropower station up to 3.2 % direct mortality was estimated. Besides direct effects also indirect effects might occur. By restricting the analysis to eels that had been detected at the first detection station after the first hydropower station (Linne-dorp) or later, we could test for delayed effects of hydropower station passage. It is hypothesised that – apart from known direct mortality effects – the passage of a hydropower station may incur physical but not immediately lethal damage, resulting in delayed mortality further downstream. To test this effect, eels were grouped according to whether or not they have been detected by the stations located at the intake of the hydropower station.

A total of 94 silver eels have been detected at detection station Linne-dorp or later. Of those, 76 eels had passed through the hydropower station, the other 18 eels went over the weir, through a fishway or (at extremely high water tables) outside the main river banks (as is reflected by the very low detection chance of the weir passing eels at Afferden, Figure 23). Survival rate for those two groups per river stretch after the first hydropower station passage is depicted in Figure 23. There appears to be a delayed effect, especially in the first stretch after the stretch with the Linne hydropower station. Disappearance rates were 26.0 % for the group through the hydropower station and 11.1 % for the group bypassing the hydropower station over the weir or fishway. The difference of 14.9 % might reflect a delayed hydropower station mortality, although the difference was not significantly different (G-test for independence: $p=0.13$; Sokal & Rohlf, 1995). In more downstream parts no differences between the groups was found. For the Alphen hydropower station, a similar analysis could not be performed because only two stretches were present downstream which is insufficient

to simultaneously model survival rate and detection chance. However, a direct calculation of the disappearance rate in stretch 8 showed no difference for the two groups.

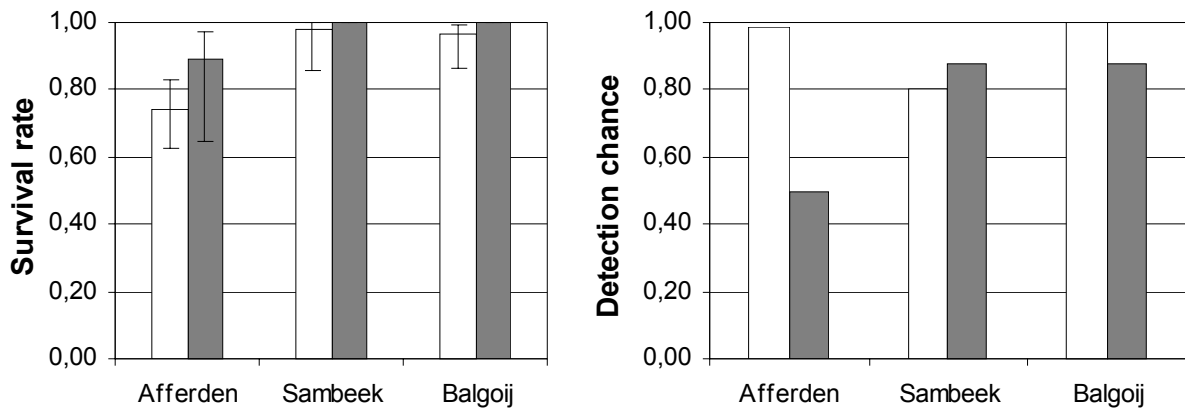


Figure 23 Survival rate (left panel) and detection chance (right panel) per river stretch for two groups of eel that have passed Linne hydropower station. White bars indicate survival of eels that were detected at the intake of Linne hydropower station (between detection stations Stevensweert and Linne-dorp, n = 76), grey bars indicate eels that went by the hydropower station over the weir or through the fishway (n = 18). For explanation of other features see Figure 21. Differences in survival rate between groups indicate a delayed effect of passing through the hydropower station.

3.1.6 Population estimates of downstream migrating silver eel in the river Meuse

At three locations, i.e. the turbine netting at Linne hydropower station and the two anchored stow net fisheries downstream Linne and Alphen hydropower stations, each 3 eels with transponders were recaptured in a known quantity of eels. This allowed for estimating the total population size of silver eel passing during the period since the first transpondered eels show up at these sites (Table 13): for Linne from September 8 until February 16 and for Alphen from October 21 until February 16. From the estimates per period an extrapolation over the entire silver eel migration period was made (M = numbers marked, C = numbers caught, R = numbers recaptured. In brackets are the extrapolated total numbers when assuming that five eels were recaptured per location, i.e. including two recaptures that remained undetected, which is the maximum recaptured number possible at Alphen.

Table 13 Estimated population size of silver eel based on mark-recapture data at three catch locations, where at Alphen both the population size through the hydropower station (HPS) and in total could be estimated (see text above).

Location		M	C	R	Estimated population size \pm S.D.	Extrapolation over total period (assuming R = 5)
Linne	turbine netting HPS	104	1,104	3	29,006 \pm 12,699	-
	Anchored stow net	104	1,922	3	50,479 \pm 22,118	94,000 (62,000)
Alphen	Anchored stow net (HPS)	36	6,708	3	62,058 \pm 26,202	182,000 (121,000)
	Anchored stow net (total)	62	6,708	3	105,667 \pm 45,717	225,000 (150,000)

Based on the turbine catches, an estimated 29,000 silver eels have passed the Linne weir / hydropower station after 8 September 2002 (Table 13). When assuming the catches for one turbine per night representative for three months September-November, taking on average 2.2 turbines active, correcting for an underreporting of 30 % for eel passing during the day (Figure 19) and including the same fraction of eels bypassing the hydropower station as found in the transponder experiment (20,9 % extra), this alternative estimate yields 24,000 silver eels passing the location Linne during September-November. This is likely to be an underestimation, because at least one sampling with likely very high number of eels was lost due to a torn net (see § 3.2.4).

Population size as estimated from mark-recapture in the anchored stow net fishery downstream Linne yields 50,000 since September. Extrapolating the estimate for the entire silver eel migration period, by assuming that the fishery catches the same fraction of eels passing before 8 September as thereafter results in a total population passing Linne of 94,000. However, it is not sure that all transpondered eels that were recaptured were reported. If for example two eels with transponders were not reported, this results in an estimate of 62,000 passing Linne (or 33,000 during September onwards). Compared with the Linne turbine estimates for the same period this indicates that it is likely that some underreporting of recaptured eel might indeed have occurred. At the Lith-Alphen fishery location 3 eels were recaptured resulting in a population estimate of 62,000 passing the Alphen hydropower station since 21 October, and 106,000 when including the bypassing eels. When extrapolating for the entire silver eel period it is assumed that the fishery catches the same fraction of eels coming from the hydropower station as thereafter and that given the low discharge no eels went over the weir before September, which presumably slightly underestimates total numbers. In total 225,000 were estimated to have passed the Alphen

weir / hydropower station during autumn 2002 – winter 2003. As at maximum 5 eels could be recaptured (Figure 17), an underreporting of two was calculated as well resulting in an estimate of 150,000 silver eels passing in the river Meuse at this location. This indicates that between probably 150,000 – 225,000 eels have passed Lith-Alphen.

3.1.7 Overall impact by hydropower-, fisheries- and unexplained mortality

By performing a Virtual Population Analysis, the contributions of the different factors to total mortality of the total silver eel population migrating downstream was assessed (Table 14). For the fisheries estimates, the number of transponders recaptured by fishermen were used. The total number that reached the sea (32) is corrected for the mean detection chance as assessed for the other detection stations, resulting in 38 specimens reaching the sea. After the closing date for the analyses, at least four more eels passed detection stations. Thus, the unexplained and overall mortality might be lower than presented.

Table 14 Estimated mortalities (on total silver eel population) by hydropower, anchored stow net fisheries, fykenet fisheries and unexplained mortality by means of Virtual Population Analysis. Estimated tag loss ‘mortality’ of 27% is excluded.

Factor	Estimated %
<i>HPS direct mortality</i>	6.3
<i>HPS delayed mortality</i>	9.5
HPS total mortality	15.8
<i>Anchored stow net fisheries</i>	5.1
<i>Fykenet fisheries (minimum)</i>	17.1
Fisheries total mortality	22.2
Unexplained mortality	25.3
Total mortality	63.3

The total mortality by the two hydropower stations is likely an overestimation, as of the eels that are considered to have passed the turbines and not being detected at downstream detection stations or are caught by fisheries, it is not sure if all are lethally injured. Furthermore, the fisheries mortality is likely an underestimation as there might be an underreporting of transponders by fisherman. Also, the unexplained mortality might be partially attributable to withdrawal by fisheries which has not been recognised so far.

3.2 Monitoring eel passage and mortality rate at Linne hydropower station

3.2.1 Discharge of the river Meuse

An oversight of the average daily river discharge of the river Meuse at Linne during the sampling period is shown in Figure 24. During the sampling period, until half October the river discharge is relatively low and usually below $50 \text{ m}^3 \cdot \text{s}^{-1}$. A first strong increase of the river discharge, showing a peak of $397 \text{ m}^3 \cdot \text{s}^{-1}$, occurred at October 28, decreasing to $173 \text{ m}^3 \cdot \text{s}^{-1}$ again until November 1. Because of heavy rainfall, hereafter the river discharge shows a strong continuing increase during the first half of November, starting from at November 1, showing a first peak at November 4 ($712 \text{ m}^3 \cdot \text{s}^{-1}$), up to $1491 \text{ m}^3 \cdot \text{s}^{-1}$ at November 12. Hereafter the river discharge decreases again until December 20. The highest peak of $2547 \text{ m}^3 \cdot \text{s}^{-1}$ was found at January 4, 2003 (not shown in figure 24).

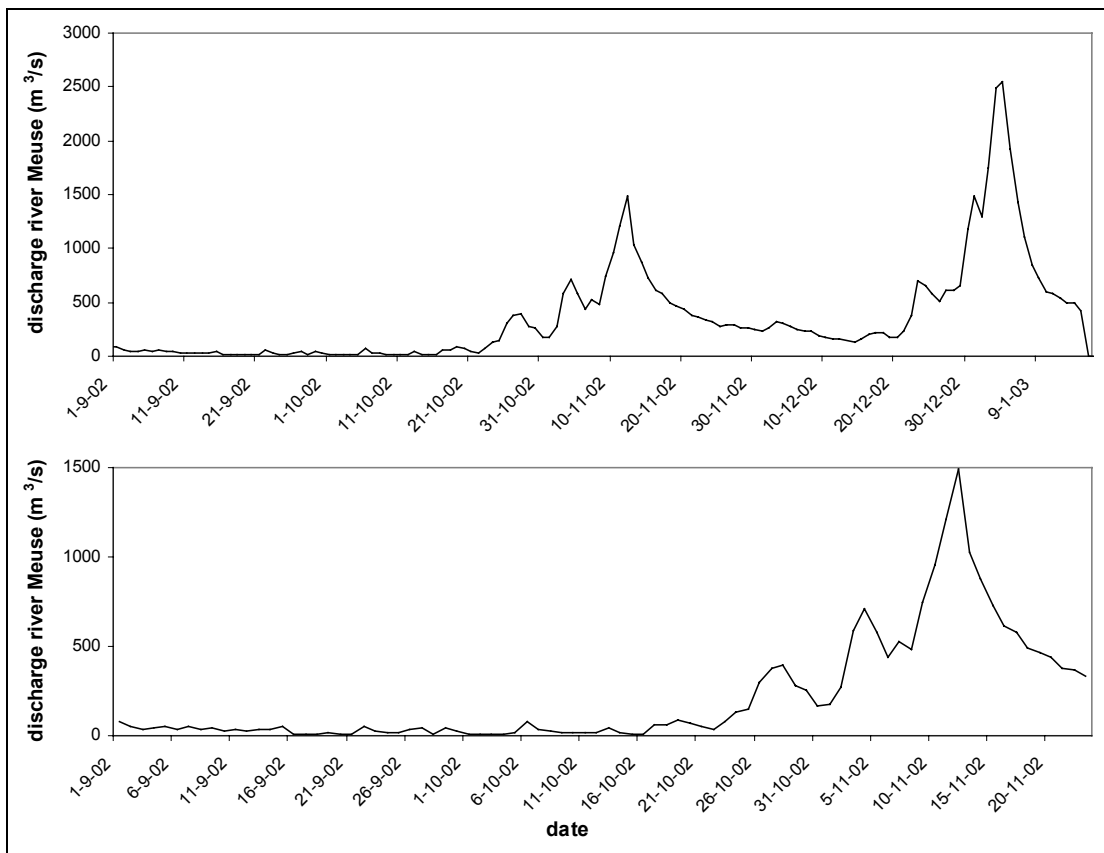


Figure 24 Discharge of the river Meuse (daily averages in $\text{m}^3 \cdot \text{s}^{-1}$) from September 1 – January 16 2003 (upper panel) and from September 1 – November 23 2002 (lower panel), measured at location Borgharen-Dorp (river km 16).

3.2.2 Turbine flows

The average flows of the weir and the four turbines during the samplings are shown in Table 15. The averages are calculated from the start till the end of each sampling. The minimum and maximum flows of the sampled turbine 4 are given, as well as the average flow over the weir and the flow through Linne hydropower station (LHPS_{Tot}). The average flows varied from 0 – 125 m³·s⁻¹ for the weir and 32 – 337 m³·s⁻¹ for Linne hydropower station (in total). The average flow through turbine 4 varied from 30 – 126 m³·s⁻¹.

Table 15 Average weir and turbine flows (Q in m³·s⁻¹) of Linne hydropower station during the samplings.

Nr.	Sampling night (date)	Q _{average} weir	Q _{average} turbines				Q turbine 4		Q _{average} LHPS _{Tot}
			1	2	3	4	Q _{min}	Q _{max}	
	September								
1	2 – 3	0	24	0	0	30	27	31	53
2	5 – 6	0	14	7	0	30	29	31	50
3	8 – 9	0	11	0	0	30	28	30	40
4	11 – 12	0	16	0	0	31	30	31	47
5	14 – 15	0	3	0	0	30	29	31	33
6	23 – 24	0	1	0	0	31	30	31	32
7	26 – 27	0	16	0	0	31	30	53	47
	October								
8	7 – 8	0	12	0	0	30	29	31	42
9	11 – 12	0	3	0	0	30	29	31	33
10	13 – 14	0	0	0	0	49	37	61	49
11	17 – 18	0	0	0	50	30	29	31	80
12	20 – 21	0	14	0	0	49	48	50	62
13	23 – 24	0	32	0	7	50	49	51	88
14	26 – 27	12	107	0	115	115	86	126	337
	November								
15	2	0	87	0	87	50	49	51	224
16	7	124	115	0	114	96	92	99	305
17	19	110	124	0	108	69	28	90	301
18	22	125	126	0	116	85	82	91	321

3.2.3 Water temperature and turbidity

The water temperature decreased from 22.2 °C at the beginning of September to 11.2 °C at the end of November 2002 (Table 16). Within this temperature range the downstream migration of eel is very well possible. Eel migration stops at a temperature of about 4 – 6 °C. The turbidity varied between 40 and 185 cm (Secchi). The lowest value of 40 cm was measured in the rise of the first river discharge peak occurring during the sampling at 26 and 27 October, respectively 299 and 379 m³·s⁻¹, by which the river became highly turbid. Highest value was measured during the sampling at 13 and 14 October, when the river was very calm and the discharge was decreasing from 43 to about 13 m³·s⁻¹.

Table 16 Water temperature, turbidity and average discharge* of the river Meuse during the sampling period at Linne hydropower station in 2002.

Sample nr.	Secchi-depth (cm)	Temperature (°C)	Average flow Meuse (m ³ /s)
1	100	22.2	46
2	110	21.5	47
3	98	21.2	41
4	150	21.2	27
5	140	20.4	43
6	150	18	19
7	160	16.6	38
8	160	16	29
9	130	14.2	17
10	185	14.6	28
11	120	13	58
12	140	13	60
13**	-	-	103
14	40	14.2	340
15	95	13.4	271
16	60	12.6	523
17	60	11.4	462
18	75	11.2	369

* The average discharge of the river Meuse during the sampling is calculated as the average of the two days of the night during which each sample took place, except for samplings 15 – 18.

** No measurements were taken during this sampling.

3.2.4 Sampling eel passage at Linne hydropower station

Details of the separate samplings at Linne hydropower station are shown in Table 17.

Table 17 Overview of the samplings: dates, sample duration and additional comments.

nr.	Sampling				Duration (hr)	Comments
	Net in date	Net in time	Net out date	Net out time		
1	2-sep	17:00	3-sep	9:00	16:00	
2	5-sep	15:45	6-sep	9:30	17:45	
3	8-sep	15:30	9-sep	8:30	17:00	
4	11-sep	14:45	12-sep	8:30	17:45	Hole in the net due to a sharp projection of the sheet piling
5	14-sep	15:00	15-sep	8:45	16:45	
6	23-sep	15:15	24-sep	8:30	16:45	
7	26-sep	15:30	27-sep	8:30	17:00	
8	7-okt	15:30	8-okt	8:30	17:00	
9	11-okt	15:30	12-okt	8:00	16:30	
10	13-okt	15:30	14-okt	4:30	13:00	Protective cover net along the sheet piling repaired
11	17-okt	15:45	18-okt	9:00	17:15	Two transpondered eels
12	20-okt	16:00	21-okt	8:30	16:30	One transpondered eel, but no transponder inside
13	23-okt	15:15	24-okt	8:00	16:15	Nocturnal sampling (see §3.2.5.1); One transpondered eel (13B); One transpondered eel, but no transponder inside (13D)
14	26-okt	15:40	27-okt	8:45	17:05	Breakage of net, no eels were captured
15	2-nov	16:00	2-nov	23:30	7:30	
16	7-nov	16:20	7-nov	20:20	4:00	
17	19-nov	17:00	19-nov	20:00	3:00	
18	22-nov	16:00	22-nov	20:00	3:30	Breakage of net during last sub-sampling, no eels were captured: final stop of samplings.

In total 17 effective samplings have been carried out. A number of nights it was not able to sample because the river discharge was too low or too high for the power station to operate. During the sampling night of 26 – 27 October the net became severely damaged because of the very high turbine flow (daily averages for the turbine flow of turbine 4 at 26 and 27

October were respectively 87 and > 120 m³·s⁻¹). The excess of water provided an considerable amount of energy on the net which was heavily fouled by debris (mainly leaves), by which the left side of the net was completely torn away. The total duration of the samplings was in September – October about 16 – 17.5 hours. In November the sampling duration was kept shorter, about 3 – 7.5 hours, to prevent breakage of the net due to the high amounts of debris in the net during high river discharge.

3.2.5 Results fish sampling

An overview of the separate eel catches at Linne hydropower station is shown in Table 18. In total 1196 eel were captured during the 17 samplings. The number of yellow eel passing the turbines is very low, counting 16 specimens, which is 1.34 % of the total catch.

Table 18 Overview of the eel catches at Linne hydropower station, autumn 2002.

Nr.	Date	Number of eels	Average length (cm)	Average weight (g)
September				
1	2 – 3	37	62,65	557,78
2	5 – 6	55	64,29	625,15
3	8 – 9	54	62,17	547,89
4	11 – 12	50	65,48	637,32
5	14 – 15	51	61,57	535,67
6	23 – 24	96	63,77	589,18
7	26 – 27	122	64,32	593,66
October				
8	7 – 8	163	61,63	517,07
9	11 – 12	30	65,27	652,90
10	13 – 14	21	63,43	565,50
11	17 – 18	65	64,22	598,52
12	20 – 21	220	66,14	637,25
13	23 – 24	207	65,50	622,39
14	26 – 27	-	-	-
November				
15	2	16	72,25	832,19
16	7	7	75,29	871,71
17	19	1	86,00	1463,00
18	22	1	73,00	875,00

The proceeding of the number of eels in time sampled at Linne hydropower station and the river flow are shown in Figure 25. In the lower panel, the data is presented in a restricted time scale from the beginning of September until the end of October.

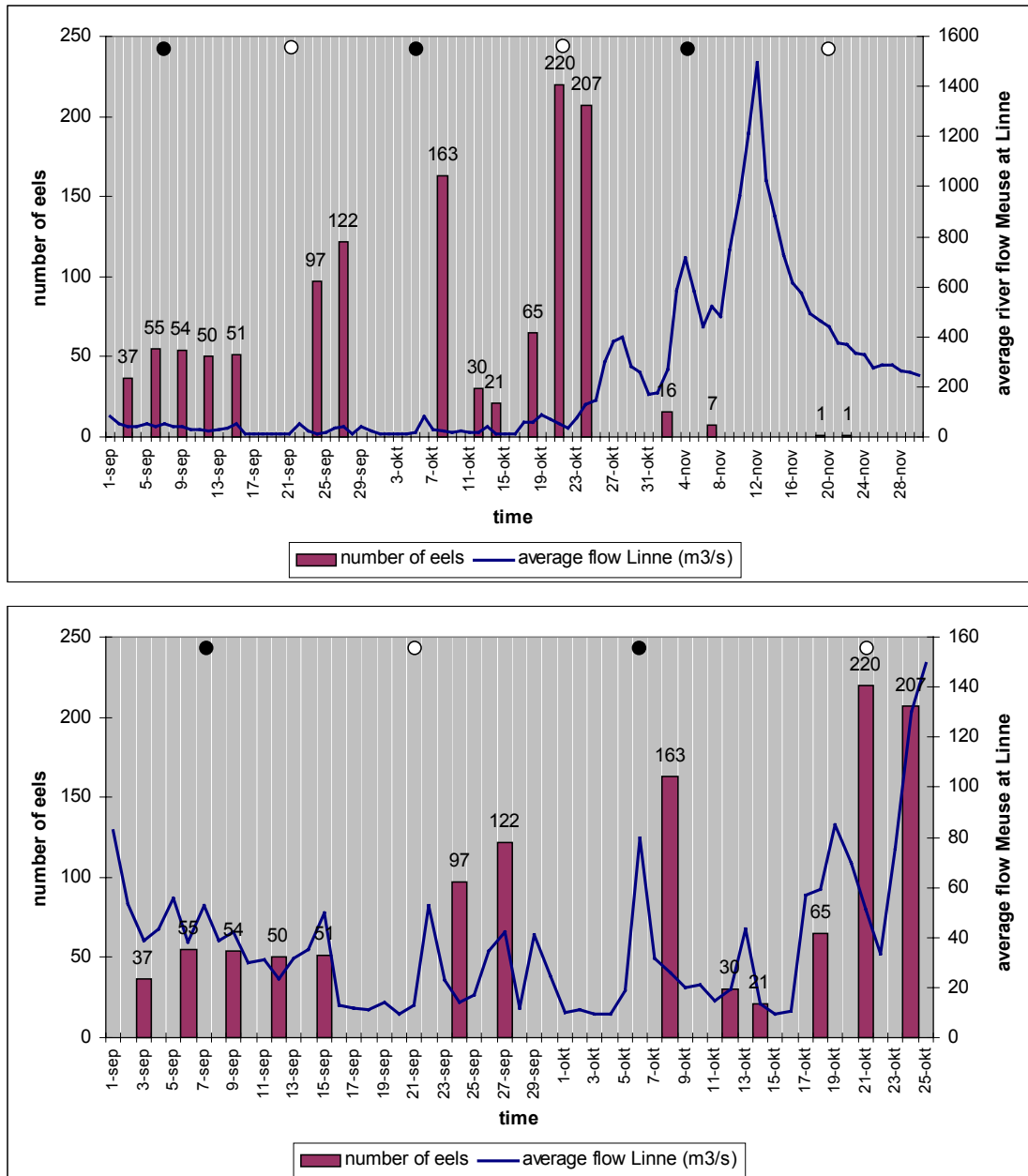


Figure 25 Proceeding of eel numbers (silver eel + yellow eel) at Linne hydropower station, the river Meuse flow and the lunar (● = new moon; ○ = full moon). Upper panel: data throughout entire sampling period. Lower panel, data from the beginning of September until the end of October.

The increase of the number of eels passing the turbine starts late September and correspond to an increase of the river flow. The increase in river flow, although not always the case, provides an impulse for downstream migration events and is a known phenomenon (Scheuring, 1930; Schiemenz, 1960; Jonsson, 1991). The timing of the first increase in eel numbers occurs also 1 week after full moon (September 21). The largest catch of 220 eels took place during the night of 20 – 21 October. During this sampling it was difficult to empty and clean the net because the amount of debris, i.e. leaves, mussel shells, branches, increased heavily due to the increasing river discharge.

3.2.5.1 Nocturnal partitioning of eel passage at Linne hydropower station

During the nocturnal sub-samplings in the night of 23 – 24 October (sampling 13), the net was emptied each 2 hours and only silver eel were captured. The number of eels for each sub-sample are shown in Table 19.

Table 19 Number of eels captured during the sub-samplings at October 23 – 24 2002.

Timing (CET) of sub-samplings		Number of eels
Start time	End time	
23 October (average discharge river Meuse = 75.32 m ³ ·s ⁻¹)		
15:15	18:30	4
19:30	20:30	47
20:30	22:00	52
22:00	0:00	39
24 October (average discharge river Meuse = 130.14 m ³ ·s ⁻¹)		
0:00	2:00	17
2:00	4:00	21
4:00	6:00	19
6:00	8:00	8
Total		207

From these data it is found that the migratory activity of eel started between 19:00 and 20:00 in the evening, after the darkness fell (sunset at 18:28 p.m. CET). It is also observed that >> 50% of the migrating eel pass the turbines before midnight. After midnight the number of eel per sub-sample decreased again (sunrise at 08:19 a.m. CET). These results fully correspond to the observations made by the transponder experiment, which shows that the activity of

migrating eels, foremost in front of the hydropower station, starts between 18:00 – 19:00 p.m. and lasts until 23:00 p.m.

The daily average river Meuse discharge at 23 and 24 October were respectively 75.32 and $130.14 \text{ m}^3\cdot\text{s}^{-1}$, showing an increase during the night. The flow of turbine 4 was the whole night $50 \text{ m}^3\cdot\text{s}^{-1}$. At 0:45 the total turbine flow of Linne hydropower station increased to $100 \text{ m}^3\cdot\text{s}^{-1}$ and increased again at 5:30 to $140 \text{ m}^3\cdot\text{s}^{-1}$ (Figure 26).

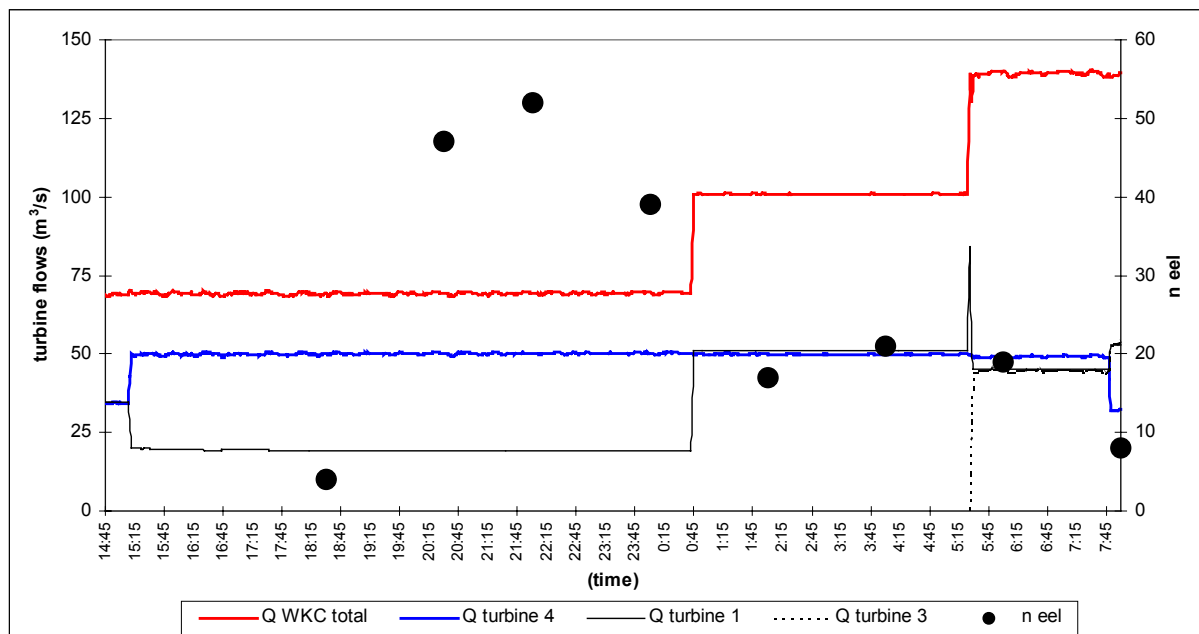


Figure 26 Turbine flows during the nocturnal sub-samplings at 23 – 24 October 2002 and the number of eel caught (●). Sunset occurred at 18:28 p.m..

3.2.5.2 Catches of transpondered eel

During the samplings 3 transpondered eels have been captured at Linne hydropower station. Two more eels were caught, showing the typical surgical wounds, but no transponders were found (Table 20). It is found that of the three transpondered eel, the detections of these eel took place during the dark period after sunset and before sunrise. All the transpondered / operated eel captured in the net were undamaged and returned to the river Meuse.

Table 20 Oversight of the detection of transpondered silver eel which were captured during the samplings at Linne hydropower station (HPS). Underlined hours is the last detection after which the eels passed the turbine.

Sampling	Tag number	Length (cm)	Weight (g)	Detections at Linne HPS (timing)	Comments
11 (Oct 18)	5075	66	758	Oct 18 <u>00:57</u>	
11 (Oct 18)	5113	72	831	Oct 5 20:21 Oct 5 20:27 Oct 5 20:29 Oct 7 04:31 Oct 15 03:40 Oct 15 03:42 Oct 15 03:44 Oct 15 03:47 Oct 17 06:29 Oct 17 06:33 Oct 17 18:40 Oct 17 <u>18:42</u>	Recurrence behaviour (see also § 3.1.3.4)
12 (Oct 21)	?*	68	617	- -	Visible wound of surgery, but no transponder inside
13B (Oct 23)	5005	78	930	Oct 23 <u>19:13</u>	Caught between 19:30 and 20:30
13D (Oct 24)	?*	70	699	- -	Visible wound of surgery, but no transponder inside. Caught between 22:00 and 24:00

* The two eel with no transponders have been identified according to their length and weight. It is assumed that these eels must have lost the transponders soon after its implantation, as these were not detected upstream at Stevensweert as well.

3.2.5.3 Length frequency

The length frequency distribution of the yellow and silver eel sampled at Linne hydroelectric power station are shown in Figure 27 and Table 21. From the length frequency distribution of the eel (n = 1196) it is found that the length ranges from 31 to 95 cm. The total and average weight (yellow eel + silver eel) measure respectively 717 kg and 600.5 g. The average length of all captured eel (yellow eel + silver eel) measures 64.42 cm. The average length of the yellow eel is 40.56 cm (n = 16), showing lengths between 32 and 59 cm. It is clear that the

yellow eel is smaller than the silver eel and that little overlap exists between both groups. The major part of the captured eel concern downstream migrating silver eel, showing an average length of 64.74 cm (n = 1180). Most silver eels occur in the length class 60 – 69 cm.

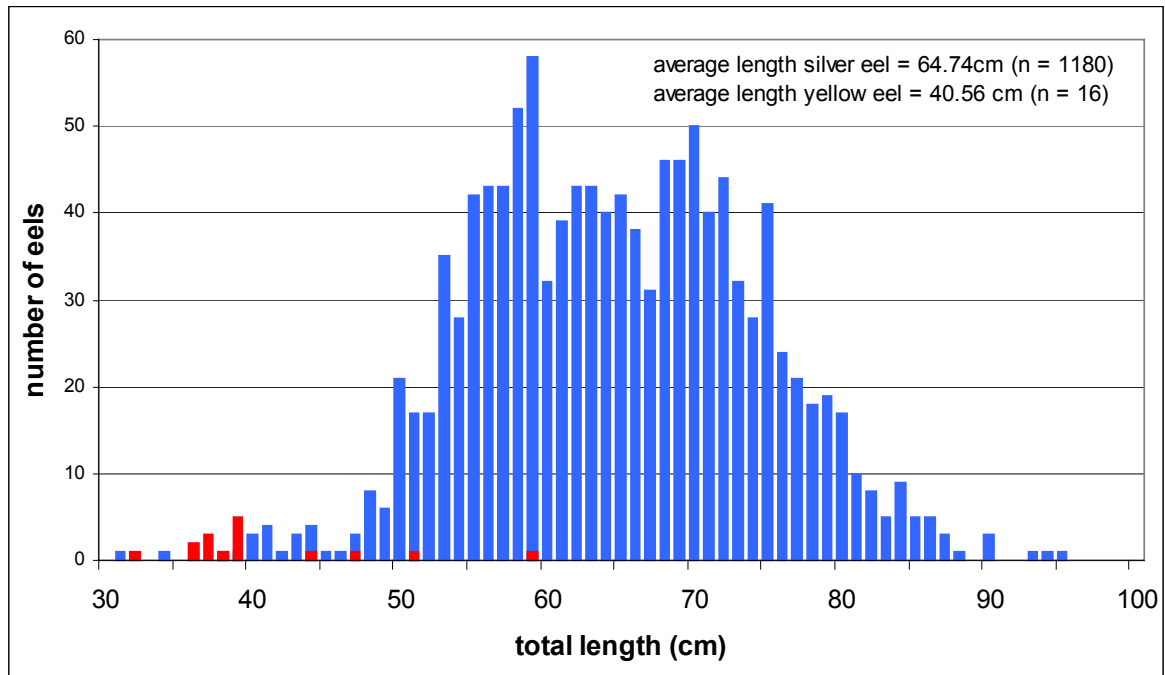


Figure 27 Length frequency distribution of 1196 eels (■ silver eel + ■ yellow eel) that were sampled at turbine 4, September 2 until October 22 in 2002.

Table 21 Length distribution per length class (silver eel + yellow eel).

Length class (cm)	Number		
	Silver eel	Yellow eel	Total
20-29	0	0	0
30-39	4	12	16
40-49	34	2	36
50-59	356	2	358
60-69	400	0	400
70-79	317	0	317
80-89	63	0	63
90-99	6	0	6
Total	1180	16	1196

3.2.6 Turbine related injuries

The assessment of injuries and mortality was established directly after collection of the eel from the net. The mortality found is based on the amount of eels that certainly have died or are thought to die eventually due to injuries by passage of the turbine. As there might be a certain degree of eels that might survive and overcome their injury, the mortality percentage presented is a maximum. Further delayed mortality of non-lethal injured eels, for example mortality after 24 hours, cannot be excluded but was not investigated. Given the little catch of yellow eel (only 1% of the total catch) the results apply to silver eel. The following aspects on turbine related injuries and mortality have examined: oversight of mortality, influence of turbine flow on mortality and influence of eel length on mortality. An oversight of the eel damage is provided Table 22. The deployment of the turbines during the samplings and the actual turbine flows are comparable to the turbine management during normal operation (without investigation). The percentages of injury mentioned are therefore also applicable for the period in 2002, in case no investigation had been performed.

Table 22 Oversight of the percentage of turbine related injuries and mortality of eel at Linne hydropower station in the period September 2 until October 22, 2002.

Eel	Total number	Not injured	Injured					
			Total		Lethal		Non-lethal	
			n	%	n	%	n	%
Silver eel	1180	776	404	34.24	287	24.32	117	9.92
Yellow eel	16	13	3	18.75	0	0	3	18.75
Total	1196	789	407	34.0	287	24	120	10

Of the total catch of 1196 eels during the entire sampling period, 407 specimens (34.0 %) have been injured (non-lethal + lethal damage). The percentage of total injury (non-lethal + lethal) for silver eel (34.24 % of the total of silver eel) shows to be notably higher than that of yellow eel (18.75 % of the total of yellow eel), however, due to the small sample size the percentage of injury for yellow eel not reliable. Nevertheless, this indicative difference might be a consequence of the difference in likelihood for damage, which is higher for the larger silver eel than for the smaller yellow eel, as is shown in earlier studies (Haddingh & Bakker, 1998, Montén, 1985). The relative lethal damage for silver eel (24.32 %) is substantially higher than that of yellow eel (0 %). When calculated for the total eel catch, the overall percentage of total injured eels amounts 34.0% and the overall lethal damage amounts maximal 24% of the eel passing the turbine.

3.2.7 Relation between mortality and turbine flow

Several investigations have already demonstrated that the tuning of the turbine affects the percentage of mortality of fish (Calderwood, 1945; Muir, 1959; Schoeneman *et al.*, 1961; Cramer & Oligher, 1964; Collins, 1984; Montén, 1985; Berg, 1986). Two important causes are mentioned. Firstly the turbine flow, which determines the water velocity and thus the speed at which the fish pass the runners (the faster, the smaller the likelihood of being hit). This also determines the extent in which cavitation and turbulence occur (the most at minimum and maximum flows). Secondly the variable position of the runner blades. By changing the angle of the runner blades, the relative opening distance between these blades is changed. The smaller the angle and opening, the larger the likelihood of injury. These two aspects are connected, because the turbine flow is tuned by changing the position of the guide vanes, which control the flow of water to the runner, and the runner blades. At minimum flows both the flow and the position of the blades will have an increasing effect on injury. At maximum flows, the injury-effect of the blades is the smallest, however, the injury by turbulence and cavitation increases. This may have the consequence that at maximum flow, more injuries occur than at average flows. This is among others observed by Montén (1985), Travade *et al.* (1987) en Oligher & Donaldson (1966). The effect of turbine flow on injury has been investigated earlier at Linne in 1990/91 and 1999 (Hadderingh & Bakker, 1998; Hadderingh & Bruijs, 2002). During these investigations, a clear relation was found between the mortality and turbine flow, showing the highest mortality at low turbine flows. The percentages of mortality in 1990, 1999 and 2002 (Table 23) have been plotted in a graph (Figure 28). The relation between mortality and turbine flow has only been investigated in situations with constant turbine flows. During all three years, the level of mortality is found to be highest at low turbine flows and lowest at high turbine flows.

Table 23 Percentage of mortality (based on lethal injuries) in relation to turbine flow ($m^3 \cdot s^{-1}$) 1990, 1999 and 2002 at Linne hydropower station.

Turbine flow ($m^3 \cdot s^{-1}$)	Total number of eels			Average length (cm)			Mortality (%)		
	1990	1999	2002	1990	1999	2002	1990	1999	2002
30	268	110	723	48.9	60.8	63.3	23.7	25	26.97
50	355	85	464	59.1	62.8	65.9	11	16	18.97
95	-	-	7	-	-	75.3	-	-	42.9*
100	941	127	-	59.8	64.7	-	5.8	9	-

* the mortality rate in 2002 at $95 m^3 \cdot s^{-1}$ (n = 7 eels) is not a reliable estimate because of the very small sample size.

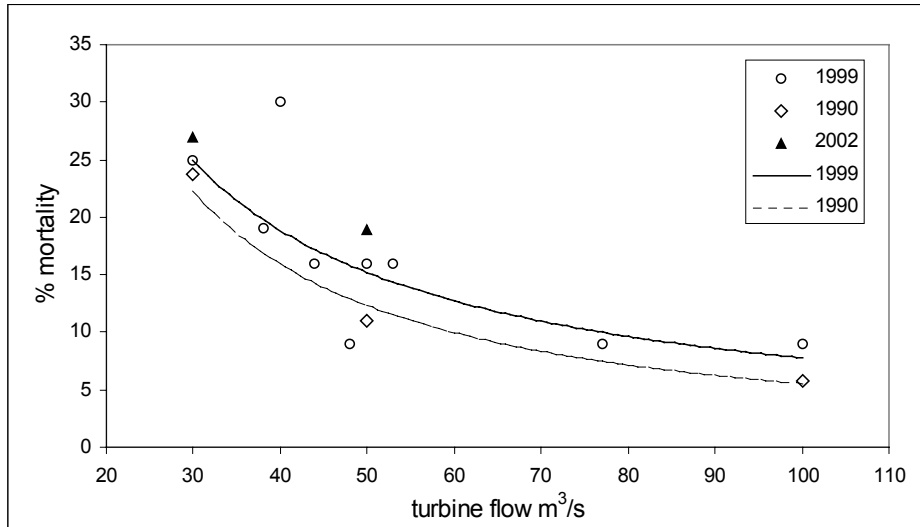


Figure 28 Percentage of mortality of 1990, 1999 and 2002 at different turbine flows at Linne hydropower station.

It is observed that the coherence between the mortality and turbine flow for all three years runs parallel. In 1990 and 1999 the average mortalities decrease from an average of respectively 23.7 and 25% at $30 \text{ m}^3 \cdot \text{s}^{-1}$ to an average of 5.8 and 9% at $100 \text{ m}^3 \cdot \text{s}^{-1}$. In 2002 the average mortality level is higher at both $30 \text{ m}^3 \cdot \text{s}^{-1}$ and $50 \text{ m}^3 \cdot \text{s}^{-1}$, respectively 26.97% and 18.97%, which may be caused by the larger average length of the eels in this year.

Another explanation could be the head, the difference in water level upstream and downstream the hydropower station. The position of the guide vanes and runner blades depend on the head. With increasing head, the opening between the blades is smaller and the likelihood for injury larger. A relative high head occurs at lower turbine flows. During 2002 the total flow through the station at $50 \text{ m}^3 \cdot \text{s}^{-1}$ turns out to be lower than during the former years, although not the case at $30 \text{ m}^3 \cdot \text{s}^{-1}$, which may implicate that in this case the eels' length has more effect than turbine flow. Differences, however, are little and the ranges between the years show overlap. However, the data indicate that the likelihood of injury in 2002 has been higher than in 1990 and 1999, which can be explained by both higher head but foremost the larger length of the eel.

3.2.8 Relation between mortality and eel length

The eel are relatively large individuals and >> 90% of the eels caught are silver eels migrating downstream. In principle eels of large size can easily resist the water current in front of the turbine intakes. Due to their behaviour, however, downstream migrating silver eels pass the turbines, because they follow the main river flow through the turbines. The length frequencies of the injured and undamaged eels have been plotted separately in Figure 29. It is visible that for the undamaged eels the frequency distribution tends towards the smaller length classes and for the injured eels towards larger length classes. However, for both the injured and undamaged groups, the frequency distribution show the same partitioning in three distinct peaks for length classes 50 – 59; 60 – 69 and 70 – 79.

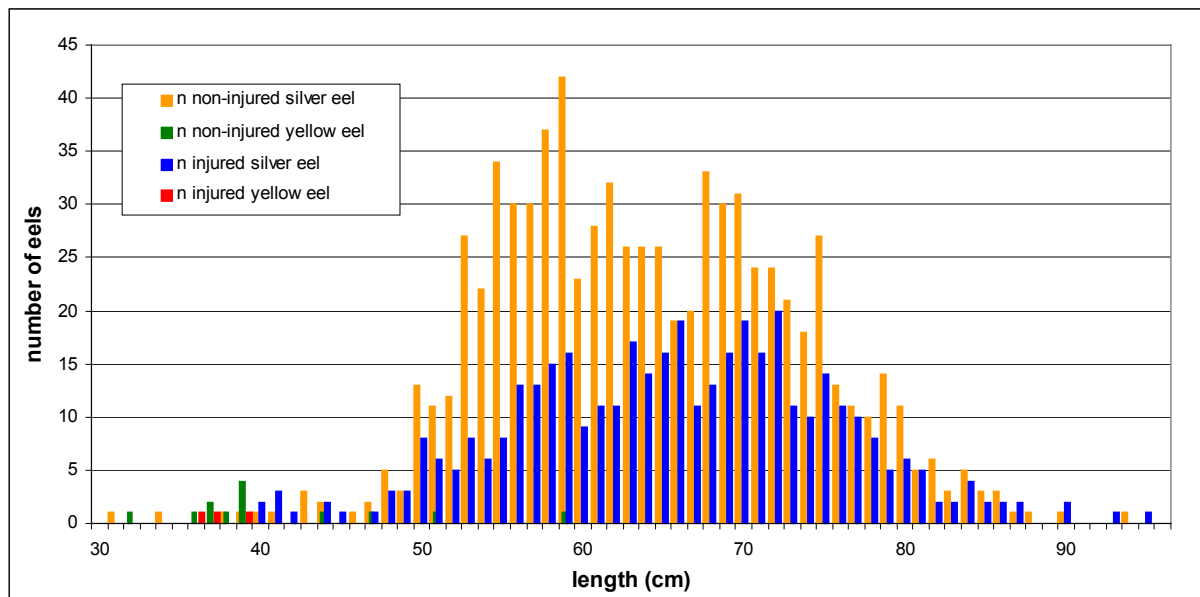


Figure 29 Length frequency of undamaged and injured eels at Linne hydropower station, autumn 2002.

Table 24 shows the injury percentage of the eel viewed for 8 length classes between 20 and 99 cm. It should be noticed that the number of specimens for the smallest and largest length classes is low, making the accompanying mortality percentages unreliable. The data is also shown in Figure 30. The highest percentage of mortality is found in the length class 70–79 cm. The percentages found for the length classes 50 – 59 : 70 – 79 are the most important because of the large amount of eel.

Table 24 Overall mortality percentage of eel due to passage of turbine 4 at Linne hydropower station in relation to the eels' length, autumn 2002.

length class (cm)	Undamaged		Injured				Total	mortality (%)
	silver eel	yellow eel	silver eel		yellow eel			
			lethal	non-lethal	lethal	non-lethal		
20-29	0	0	0	0	0	0	0	0
30-39	4	9	0	0	0	3	16	0
40-49	18	2	8	8	0	0	36	22,22
50-59	258	2	69	29	0	0	358	19,27
60-69	263	0	99	38	0	0	400	24,75
70-79	193	0	93	31	0	0	317	29,34
80-89	38	0	14	11	0	0	63	22,22
90-99	2	0	4	0	0	0	6	66,67
Total	776	13	287	117	0	3	1196	24,00

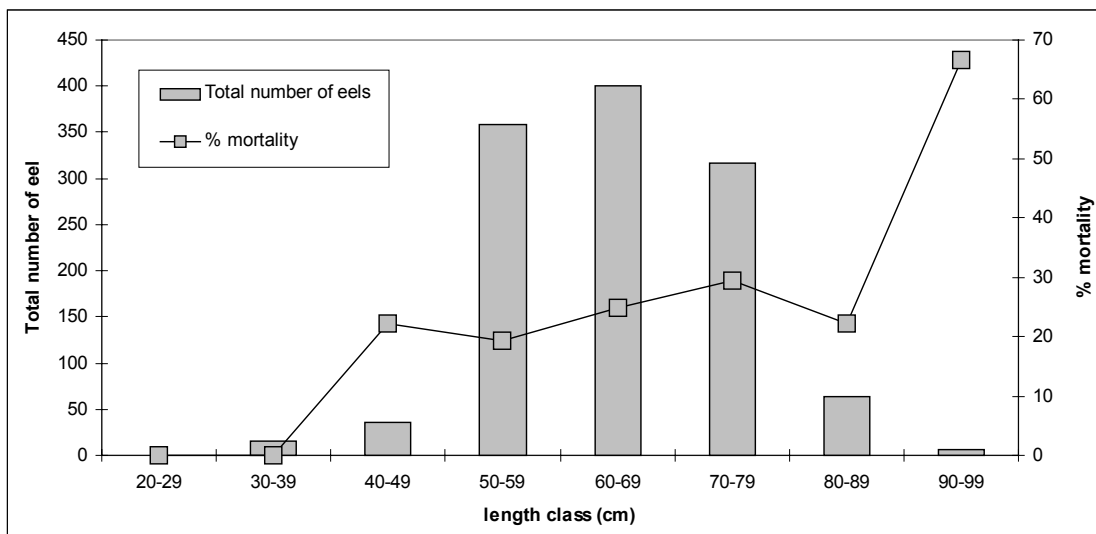


Figure 30 Mortality percentage per length class at Linne hydropower station, autumn 2002.

The mortality percentages per length class for different turbine flows are compared in Table 25. In earlier investigation at Linne, clear relation was found between the mortality and the length of the eel at $30 \text{ m}^3 \cdot \text{s}^{-1}$: the larger eel showing higher mortality than smaller eel. At turbine flows of 50 and $100 \text{ m}^3 \cdot \text{s}^{-1}$ only a small length-effect was found and highest mortalities were found in the $70 - 79 \text{ cm}$ length class (Haddingh & Bakker, 1998). In 2002

the overall mortality percentage is also highest for the 70 – 79 cm length class. However, when checked for different turbine flows, it is found that this length shows to be stronger at 50 m³·s⁻¹ than at 30 m³·s⁻¹ (Figure 31). For turbines flows > 70 m³·s⁻¹ too little specimens were caught.

Table 25 Percentage mortality of eel due to turbine passage of the of Linne hydropower station in relation to the length at different turbine flows, autumn 2002.

Length class (cm)	Turbine flow (m ³ ·s ⁻¹)										
	All flows		30			50			> 70		
	n eel	%	n eel	n lethal	%	n eel	n lethal	%	n eel	n lethal	%
20-29	0	0	0	0	-	0	0	-	0	0	-
30-39	16	0	14	0	-	2	0	-	0	0	-
40-49	36	22.2	20	5	25	16	3	18.8	0	0	-
50-59	358	19.3	246	57	23.2	112	12	10.7	0	0	-
60-69	400	24.8	244	72	29.5	154	27	17.5	2	0	-
70-79	317	29.3	165	49	29.7	147	42	28.6	5	2	40
80-89	63	22.2	29	9	31.0	33	4	12.1	1	1	100
90-99	6	66.7	5	3	60	0	0	-	1	1	100

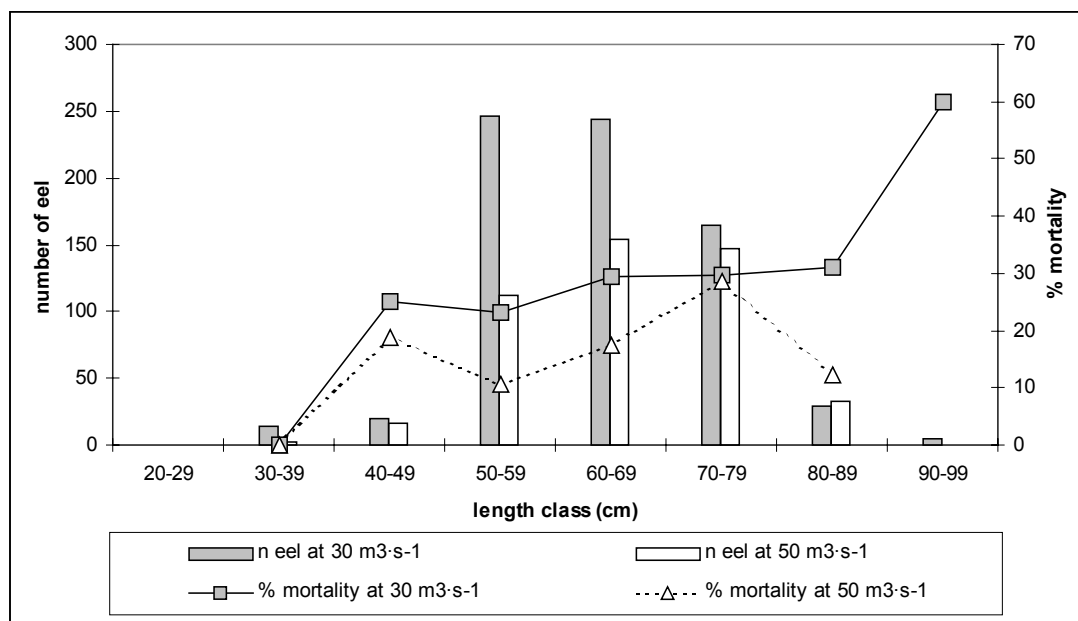


Figure 31 Mortality percentage of eel per length class at 30 and 50 m³·s⁻¹ at Linne hydropower station, autumn 2002.

3.3 Monitoring downstream migration activity by means of the Migromat[®] system

3.3.1 Design, construction and operational experience of the Migromat[®]

After survey of the two sites locations for the Migromats[®] (MM), the hydropower stations at Alphen and Linne, the MM's had been assigned in April 2001. The first period (pilot) lasted from September 20 – December 20 2001. In June 2002, both Migromat[®] systems (MM) at Linne and Alphen hydropower stations were prepared for the second monitoring period, which was started at the beginning of July 2002. For this period several technical and operational changes have been applied to the MM according to the operational experiences during the first period. The operational experiences as well as the technical measures taken with respect to the design, construction and operation of the MM in the second period are described in this paragraph.

3.3.1.1 Operational experiences

In spite of protecting screens mounted in front of the water inlet openings, the phenomenon of eel wandering between the two containers remained. In order to prevent this displacement of eels in the MM tanks, the gaps had to be reduced a second time.

Unlike in 2001, in the second monitoring period the upstream water level upstream the weir at Alphen was lowered heavily due to flood control measures by the RWS. As this fact was unknown to the service staff, the control was overrun manually assuming a sensor problem, resulting in a pump damage by overheating. The construction of the fresh water intake is now mainly reliable. Additional measures have to be taken, where necessary, to cope with varying water level at the intake, as continuous fresh water supply is a basic need for the function of a MM system. The use of a flow control sensor in the intake pipe affords some experience, but finally showed to be a reliable means of control of the fresh water supply.

During the first period, the MM installation at Alphen already turned out not to be safe with respect to flood conditions. Therefore, for the design the possibility of a fast "removal" without consequences for the experiment had to be taken into account. This event took place at the end of the second period at January 3 2003, when as a consequence of a great flood the MM at Alphen had to be removed. The location of the MM at Linne was safe with respect flood conditions. However, as this MM was to be set up at a place accessible by the public, the possibility of vandalism and fish robbery required additional measures, like a fence (see

Figure 9). As the MM at Alphen had been opened by thieves, soon after the experiment was started for the first period, the covers of the MM's were equipped with sensors sending automatically alarm messages when the covers were opened.

An unexpected problem for the functioning of the MM at Linne appeared to be the fast growth of the mussel *Dreissena polymorpha*. The outlet was blocked by a thick layer of the mussels covering the screens in front of the tank outlet (Figure 33). Hence the screens had to be cleaned 2 times during the summer. In comparison to Linne, the growth of Zebra mussels at Alphen was much less intense.



Figure 33 *Dreissena polymorpha* covering the outlet screens of the MM in Linne (left) and the deposition of mud inside of the tanks (right).

Inside of the tanks of the MM at Linne and Alphen a lot of mud deposited. During the 6 months of operation the level of the muddy sediments reached up to 20 cm (Figure 33). This situation seemed to be very comfortable for the eels, because they build caves in the substratum in which they find shelter. Moreover, the fully oxygenated mud contained a lot of prey organisms for the eels like gammaridae and asselidae.

3.3.1.2 Changes in Hardware

As the originally used fresh water pumps were not suitable due to heavy corrosion problems, a new type of pumps completely manufactured out of stainless steel had to be integrated. This made minor changes necessary with regard to the intake screens and electric equipment.

3.3.1.3 Software, computer equipment and data acquisition

The software monitoring the data from the MM turned out to be very time critical and would not run on a modern operating system. Therefore the original idea of using one central server was left. Data acquisition and hardware control therefore remained completely separated. The separation of hardware control and data acquisition shows advantages in comparison to an integrated system with regard to reliability and remote control offering the possibility of remote resets on several levels. In order to avoid daily manual remote control of the systems, new sophisticated modems were acquired and programmed, allowing, together with the PLC, automatic alarms and regular real-time-messages.

With respect to data acquisition, only between September 2 and 11 2002 the telephone line at Linne was temporarily interrupted, but the data were reliably recorded by the computer. After solving the technical problem the data transfer could be continued without loss of data.

3.3.1.4 Overall performance of the Migromats®

Overall, the MM's at Linne and Alphen worked without any problems during the second period in 2002/03. The current technical standard achieved allows now an unattended service of a Migromat® system for a complete monitoring period of up to 2 months, covering the migration period of downstream migrating silver eel.

3.3.2 Capturing and mortality of eels used for stocking the Migromats®

At the beginning of phase I of the project (2001) the MM at Linne was stocked with 60 healthy and vital eels. Due to the additional dummy experiments in 2001, the MM at Alphen was stocked in 2001 with 80 and in 2002/03 with 60 PIT-tagged specimens. Figure 34 shows the total length of all eels caught for the MM during phase I (2001) and II (2002/03).

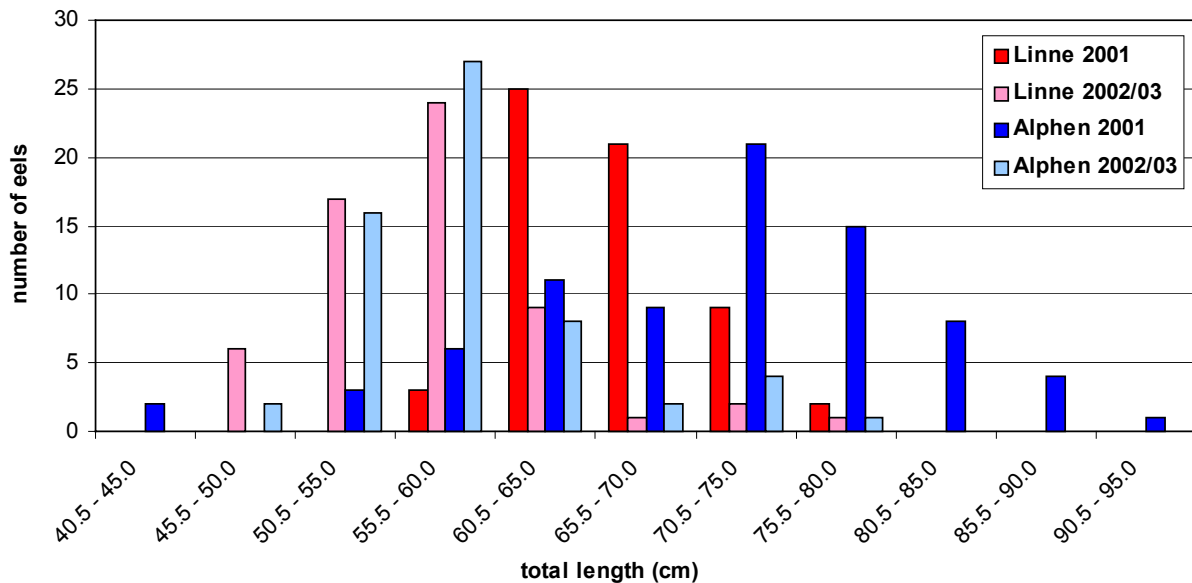


Figure 34 Total length of the PIT-tagged eels at Linne and Alphen.

The eels used in 2001 were acquired from professional fisherman and showed an evident larger size than the specimen of the season 2002/03, which have been obtained by electrofishing without any size specific selection.

Unfortunately, during phase I (2001) the eels showed a very high mortality rate: after the first month 50% of the specimens at Linne died; in the Alphen experiment the mortality reached 14%. The reason for this high mortality rates is not known, but might be attributable to relative rough catching methods by fykenets, handling of the eels by the fisherman or period of keeping them in collection corf prior of being used to stock the MM.

In order to minimise the risk of damage and to reduce the mortality of the eels, for phase II (2002/03) the eels were caught by means of electrofishing and handled very carefully by the IFÖ-biologists. In consequence of this strategy, the mortality during phase II was successfully reduced (Table 26). However, a relatively high level of losses at Alphen occurred, which cannot be explained.

Table 26 Comparison of the mortality of the eels in phase I and II of the project.

Location	2001				2002/03			
	Catch method	total	mortality		Catch method	total	mortality	
		n	n	%		n	n	%
Linne	net captures	60	30	50	electrofishing	60	2	3
Alphen	net captures	80	11	14	electrofishing	60	7	11

Furthermore, it has been observed during phase I (2001) that the registered activity of the eels was very high at the beginning after stocking the MM, until it sunk constant and rapidly to reach a plateau after four weeks (Figure 35a). In opposite to this, and obviously as a result of careful handling of the specimens to avoid effects of stress, this period of adaption could be shortened in phase II (2002/03) to less than two weeks (Figure 35b).

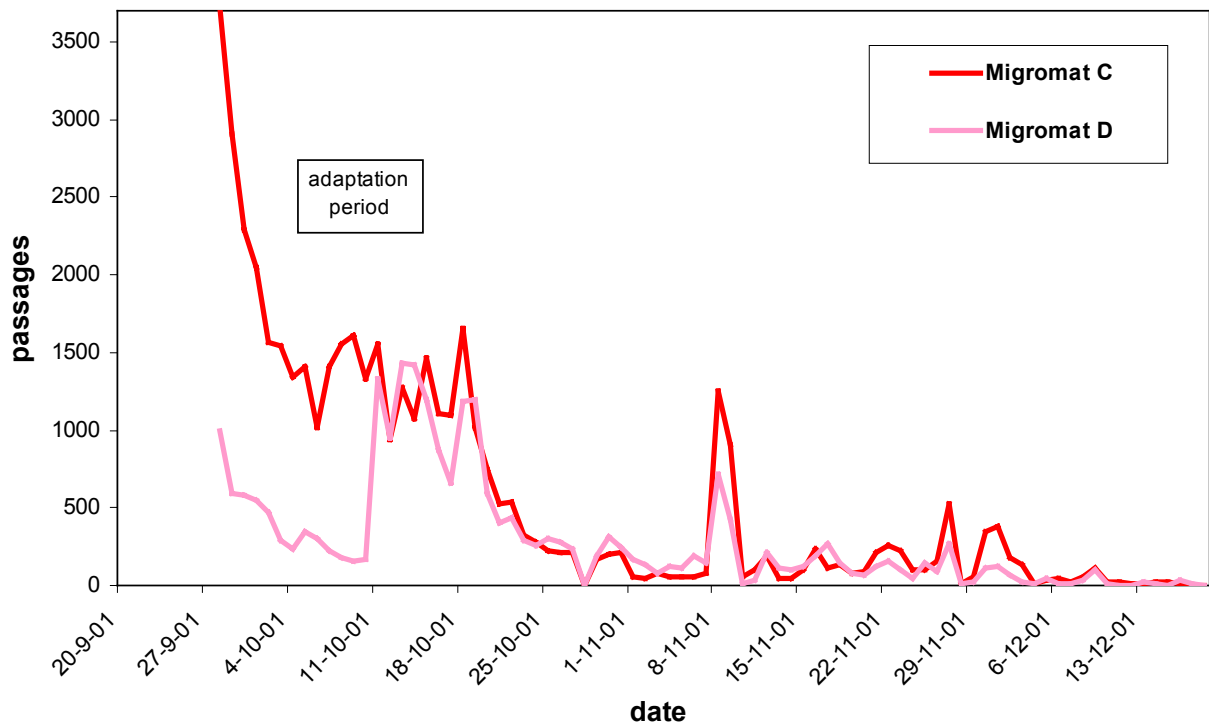


Figure 35a Duration of the adaptation period of the eels inside the MM at Linne during phase I (2001) of the project.

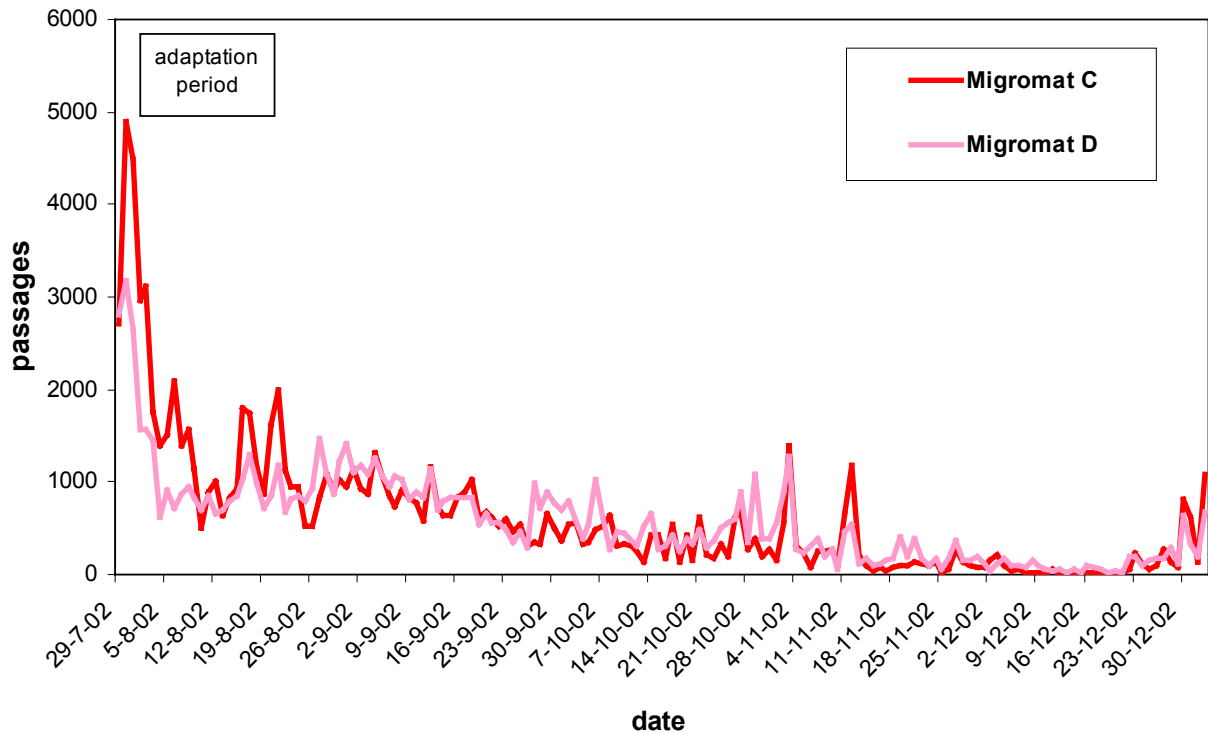


Figure 35b Duration of the adaptation period of the eels inside the MM at Linne during phase II (2002/03) of the project.

3.3.3 Monitoring downstream migration by means of the Migromat® system

At the sites at Linne and Alphen, the MM's periodically registered an increase of eel activity during both phases of the project (Figures 36 and 37). In phase II of the project (2002/03) the eels inside the MM's at both Linne and Alphen produced a relative high basis level of activity from July to September. During this period, the activity oversteps its average in Linne at 8 days and in Alphen at 2 days. In comparison to this situation in summer, the number of activity peaks accumulated in autumn, when each of the MM's recorded 15 events from October to December.

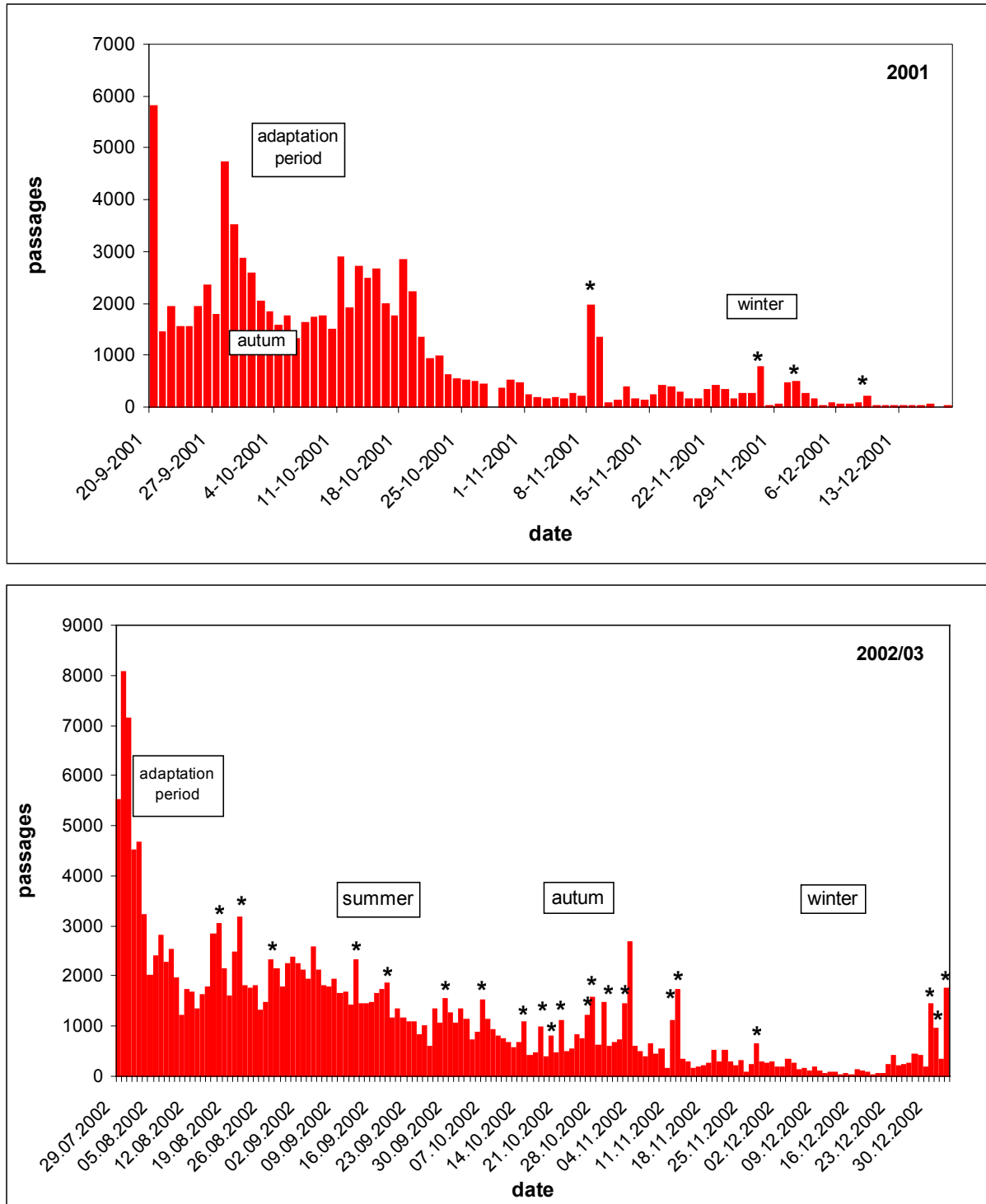


Figure 36 Development of activity in the MM at Linne during phase I in 2001 (upper panel) and phase II in 2002/03 (lower panel). Days of high activity are marked by (*).

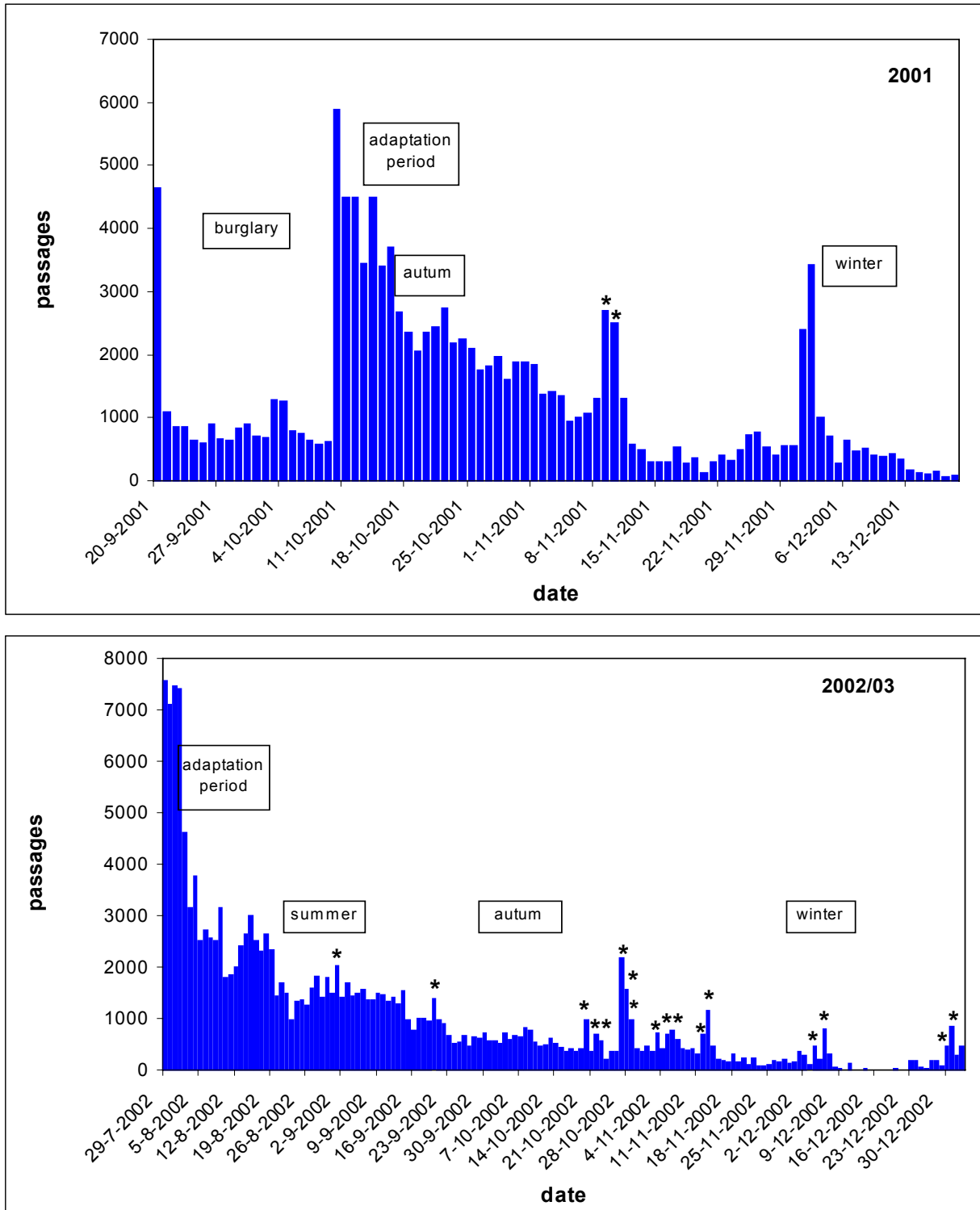


Figure 37 Development of activity in the MM at Alphen during phase I in 2001 (upper panel) and phase II in 2002/03 (lower panel). Days of high activity are marked by (*).

The prediction of eel migration by the MM is based upon the observation of hourly development of eel activity considering their circadian rhythm. Accordingly, the eels show a minimum of activity at 11:00 a.m. and a maximum activity around midnight. Among other biological criteria, it is characteristic for the beginning of a downstream migration event that the daily routine of the eels changes. They show a significant pre-migratory restlessness during dawn, prior to the night they start to migrate. This mechanism is shown representatively in Figure 38. Not only at October 26, but also at October 27 2002 a high increase of activity was registered by the MM, which was twice as intense as the eel activity during the previous days.

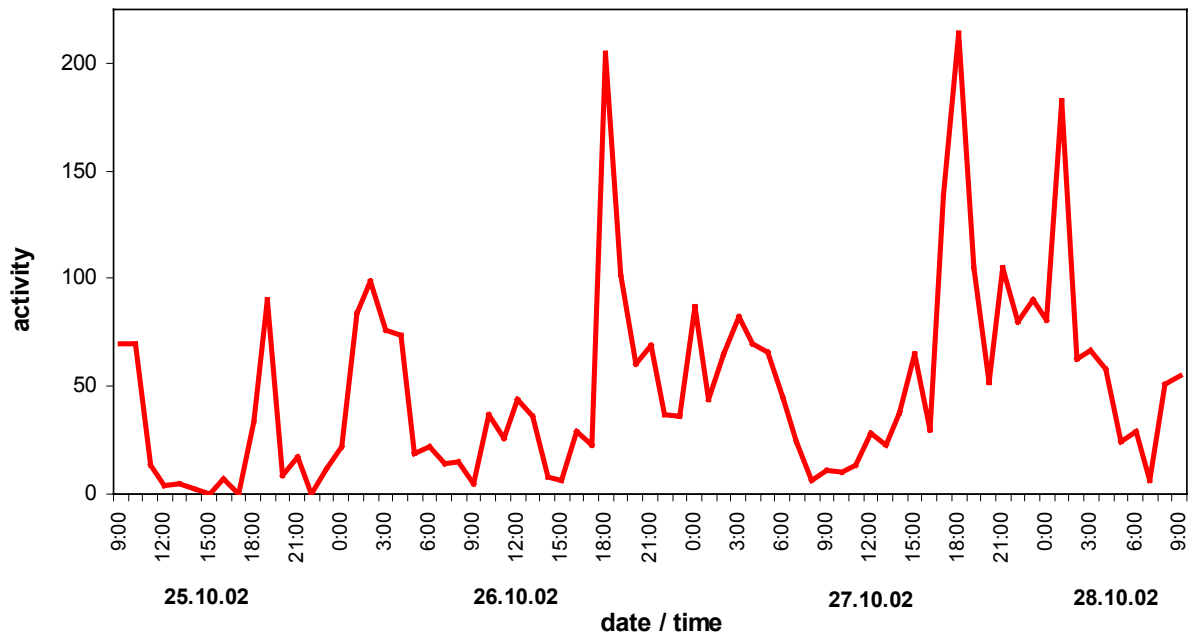


Figure 38 Development of the activity level of eels from October 25 – 28 2002 in the MM at Linne.

Likewise, by means of a MM set-up at the river Lahn (Germany), the activity of eels in this river was registered. In this case the activity peaks predicted an actual downstream migration event the following night. This correlation has to be evaluated for the migration situation at the river Meuse. For this proof, the results of fishery monitoring, the transponder experiments and monitoring eel passages at Linne hydropower station have been compared with the peaks of eel activity, that had been documented by the MM's.

3.3.4 Comparison results from Migromat® with the monitored downstream migration

First of all it has to be stated, that the three available monitoring data-sets, i.e. fishery monitoring, the transponder experiments and monitoring eel passages at Linne hydropower station, considerably differ in quality:

- The sampling catches at Linne hydropower station in order to estimate the mortality (in total 17 days) were executed at irregular intervals, caused by the irregular operation of Linne hydropower station. However, consequently the reliability of the MM's forecasts can not be exclusively supported by the data of these samplings.
- The data of the eel catches of commercial fishermen at Linne and Alphen appeared to be rather indistinct and fragmentary, which makes their correlation with MM's data output more difficult. Predominantly, the number of catches is dependent on the efficiency of the fishing equipment used and furthermore on the frequency of exposure and the exposure time of the equipment. For example, at Linne there are no reports of eel catches over a long period between September 8 – October 20 (Figure 39), because the local fishermen concentrated his catching activity on times, when he expected most successful catches according to his experiences in former years.

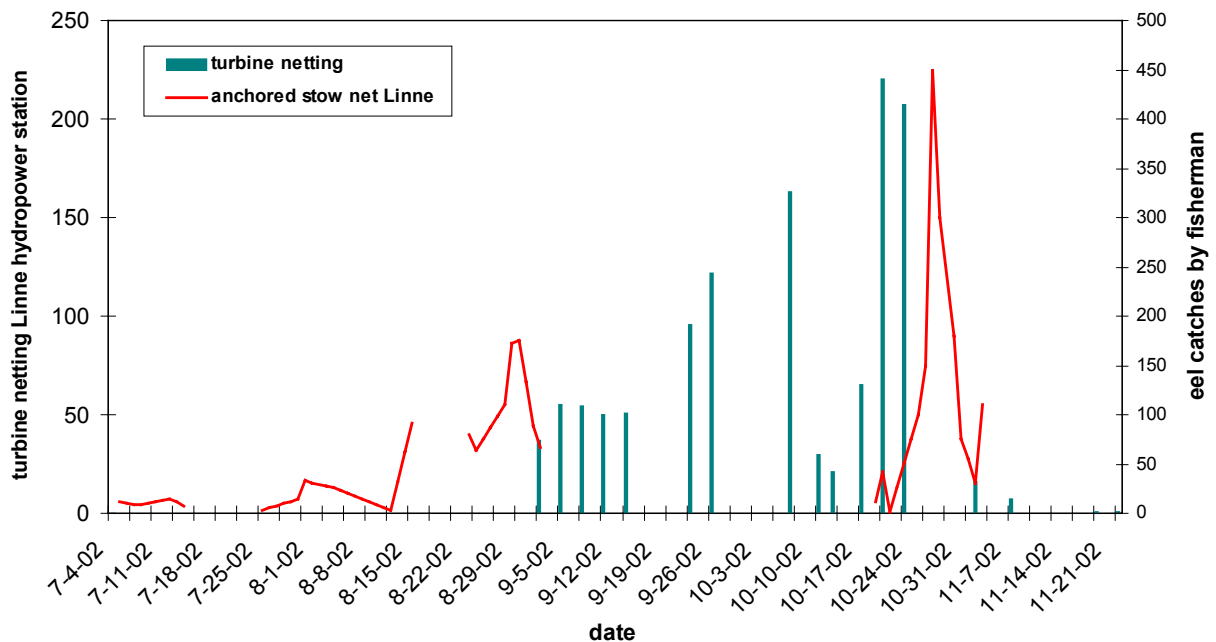


Figure 39 Fragmentary data of the eel catches by fisherman at Linne. Furthermore, no correlation has been found between these catches and the KEMA samplings.

However, the fisherman at Alphen provided numbers of eel catches for the entire operational period of the MM, but obviously not all of the caught eels were actually migrating downstream, because the course of his eel catches did neither correspond to the monitored eel activity of the MM, nor to the downstream migration times of registered transpondered eels (Figure 40).

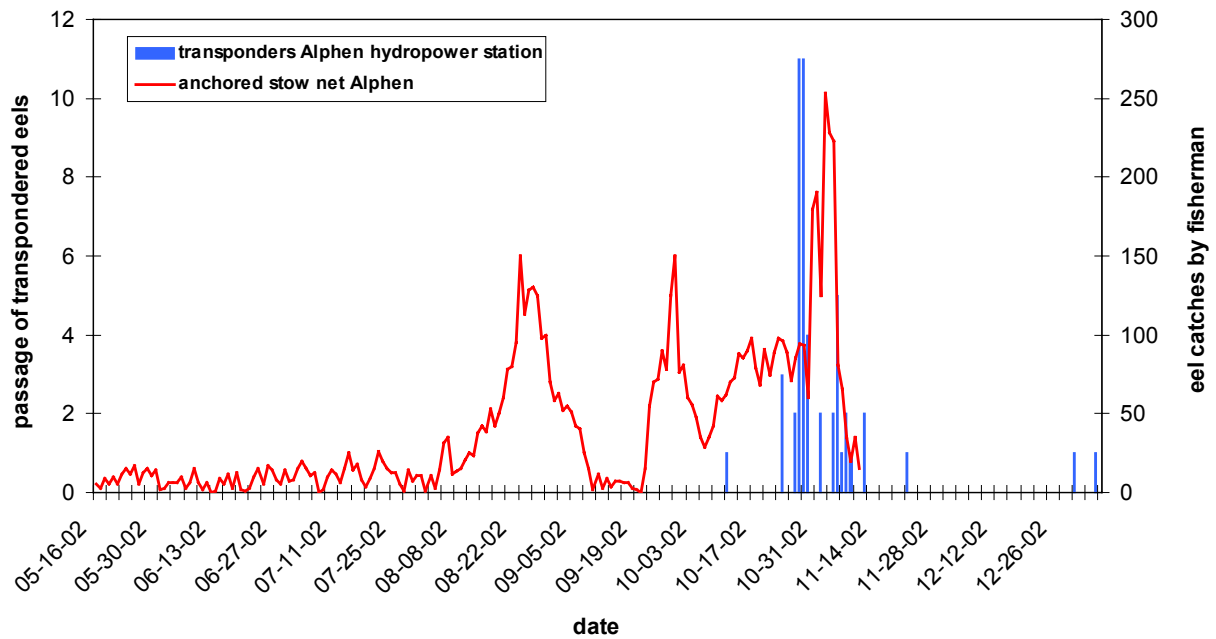


Figure 40 Eel catches by fisherman at Alphen and times of downstream migrating eels as monitored by transponders. No significant correlation has been found between both methods to monitor the eel migrating events in the river Meuse.

Only the transponder monitoring experiment independently and continuously supplied information about the downstream migration events of silver eels in the river Meuse. These data records merged easy with the monitoring results the MM's. The detection stations punctually registered downstream migration activity, when 83 of the 150 transpondered eels passed the hydropower stations at Linne and Alphen. Days of passage of transpondered specimens are presented in Table 27.

Table 27 Days that individual transpondered eels passed the detection stations at the intakes of the hydropower stations at Linne and Alphen.

Transp. Nr.	date of passage		Transp. Nr.	date of passage		Transp. Nr.	date of passage	
	Linne	Alphen		Linne	Alphen		Linne	Alphen
5002	27.10.02	-	5055	26.10.02	28.10.02	5110	27.10.02	-
5003	27.10.02	29.10.02	5056	-	27.10.02	5112	-	05.11.02
5006	27.10.02	30.12.02	5060	26.10.02	29.10.02	5113	18.10.02	-
5008	27.10.02	28.10.02	5061	27.10.02	-	5114	21.10.02	-
5010	30.10.02	-	5062	08.11.02	21.11.02	5115	30.09.02	27.10.02
5014	22.10.02	05.11.02	5068	27.10.02	28.10.02	5117	27.10.02	-
5015	26.10.02	-	5069	29.10.02	-	5118	17.10.02	-
5017	20.10.02	-	5070	23.09.02	-	5119	29.09.02	27.10.02
5018	25.10.02	-	5072	27.10.02	28.10.02	5120	27.10.02	-
5021	06.11.02	08.11.02	5075	18.10.02	23.10.02	5121	26.10.02	-
5025	26.10.02	27.10.02	5076	-	23.10.02	5123	-	23.10.02
5027	26.10.02	-	5077	-	07.11.02	5124	04.11.02	06.11.02
5029	27.10.02	-	5078	26.10.02	28.10.02	5125	30.09.02	05.11.02
5030	26.10.02	01.11.02	5080	27.10.02	-	5126	06.10.02	27.10.02
5032	10.09.02	-	5081	25.10.02	27.10.02	5127	26.10.02	28.10.02
5033	27.10.02	01.11.02	5083	27.10.02	28.10.02	5130	24.10.02	27.10.02
5034	25.10.02	-	5085	29.10.02	-	5132	30.10.02	04.11.02
5035	08.09.02	-	5086	28.10.02	04.11.02	5133	-	28.10.02
5036	17.09.02	27.10.02	5088	30.09.02	27.10.02	5134	29.09.02	29.10.02
5038	26.10.02	27.10.02	5090	30.09.02	28.10.02	5136	26.10.02	28.10.02
5040	03.01.03	-	5092	-	07.11.02	5141	29.09.02	26.10.02
5042	03.01.03	04.01.03	5095	27.10.02	-	5142	06.10.02	-
5045	09.09.02	-	5100	30.09.02	-	5143	27.10.02	-
5046	27.10.02	05.11.02	5101	26.10.02	28.10.02	5146	28.09.02	-
5047	26.10.02	-	5102	27.10.02	11.11.02	5147	24.10.02	-
5048	17.10.02	-	5107	26.10.02	-	5149	23.10.02	26.10.02
5050	19.10.02	27.10.02	5108	07.10.02	28.10.02	5150	03.01.02	05.01.02
5053	29.10.02	11.11.02	5109	30.09.02	-			

Whereas passage of 1 to 2 transpondered eels can be considered as usual basic activity level, days with occurrence of distinctively more frequent eel passages have been regarded as downstream migration events. The days of maximum migration activity of transpondered eels during phase II (2002/03) are shown in Table 28. Number and temporal distribution of the downstream migrating eel via Linne and Alphen are shown in Figure 41, including the

river discharge at both locations. Highest amount of transpondered eel detections are observed at October 27 at Linne (n = 18) and at October 28 at Alphen (n = 12).

Table 28 Main downstream migrating events, identified by transpondered eels.

Linne		Alphen	
date	number	date	number
30.09.2002	6	23.10.2002	3
25.10.2002	3	27.10.2002	11
26.10.2002	15	28.10.2002	12
27.10.2002	18	29.10.2002	3
29.10.2002	3	05.01.2003	5
03.01.2003	3		

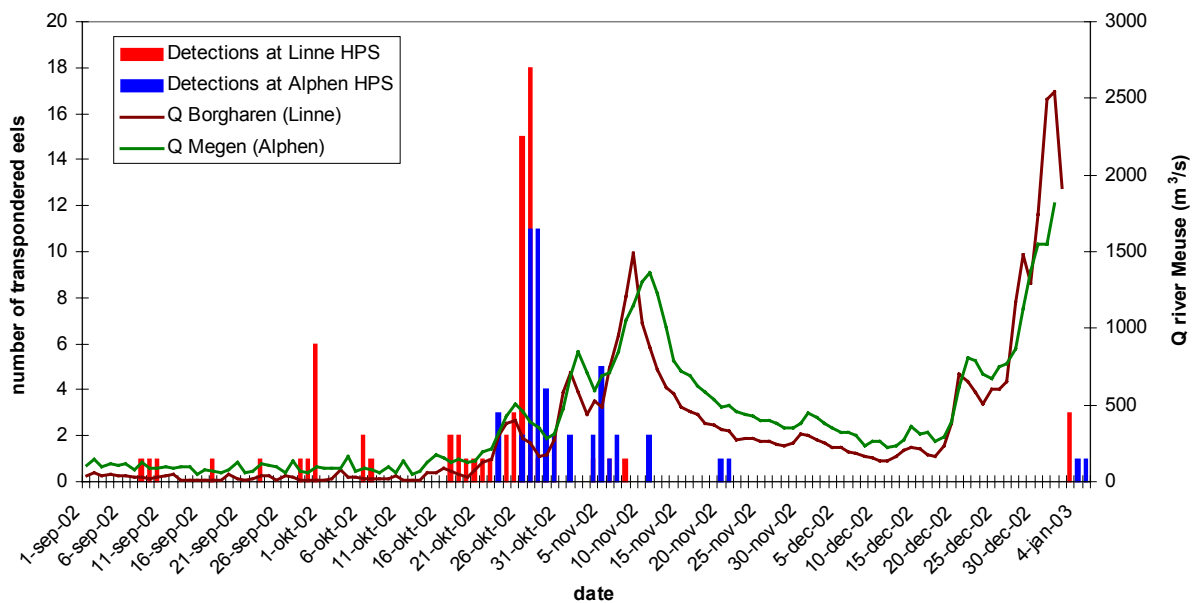


Figure 41 Detections of transpondered eels passing Linne and Alphen

To answer the question if an increase of activity in the MM corresponds to downstream migration of eel in the river Meuse and if the registered activity peaks can be used to predict migration event, the results of the different monitorings have been compared with the data of the MM (Table 29). For this evaluation, the quality of the monitoring investigations and the range of the monitored migration waves has not been considered.

Table 29 Comparison of increased activity levels (warning of migration event) in the Migromat® (MM) with migration events observed by monitorings (m) of (1) fisheries catches, (2) transpondered eels and (3) turbine passage at Linne hydropower station. Dates when no complementary simultaneous datasets on downstream migration are available are marked by ▲.

Year and period	2001				2002/03			
	September 20 – December 18		Alphen (90)		Linne (160)		Alphen (160)	
Location (n eels)	Linne (90)		Alphen (90)		Linne (160)		Alphen (160)	
Comparison of MM with m	MM	m	MM	m	MM	m	MM	m
	08.11	2	09.11	2	17.08	▲	01.09	▲
	09.11	2	10.11	2	21.08	▲	20.09	▲
	27.11	▲	01.12	2	27.08	1	20.10	▲
	01.12	2	02.12	2	04.09	▲	22.10	▲
					12.09	▲	23.10	2
					18.09	▲	27.10	2
					29.09	2	28.10	2
					30.09	2	29.10	1,2
					06.10	2	03.11	1
					14.10	▲	05.11	2
					17.10	2,3	06.11	▲
					19.10	▲	11.11	2
					21.10	▲	12.11	▲
					26.10	1,2	04.12	▲
					27.10	1,2,3	06.12	▲
					29.10	2	30.12	▲
					02.11	3	31.12	▲
					03.11	1		
					11.11	▲		
					12.11	▲		
					27.11	▲		
					30.12	▲		
					31.12	▲		
					02.01	▲		
n days of high MM-activity	4		4		24		17	
n days with coincidence of MM-activity and monitoring	3		4		10		7	

Phase I (2001) of the project originally dealt with methodical development for the transponder monitoring experiment, but initiated first recognition of correlation of downstream migration events in the river Meuse with activity peaks registered by the MM: despite the fact that only 10 transpondered eels were released in the river Meuse, 3 of 4 activity peaks detected by the MM at Linne occurred at nights when transpondered eels passed the location as well. At Alphen the MM eel activity peaks correspond to downstream migration of transpondered eels in even 4 out of 4 cases. In phase II of the project (2002/03) activity peaks of the MM's could be compared to much more extensive downstream migration monitoring data: the report of fisheries catches and registration of 150 transpondered eels at 14 detection stations in the river Meuse (including the 4 detection stations at the hydropower stations) and monitoring of eel passage through the turbines of Linne hydropower station.

During the time period from the beginning of August to the beginning of October, primarily isolated downstream migration events occurred. The main downstream migration wave occurred at the end of October 2002: at Linne it can be assigned to October 26 – 27 due to the registration of a great number of transpondered eels. Two days later, transpondered eels also reached Alphen and were detected from October 27 – 29. Likewise, reports of numerous eel fisheries catches clearly documented this main downstream migration event.

The activity of the eels kept in the MM showed a good consistency with the registered actual downstream migration events by means of the transpondered eel experiment. Not only the occasional downstream migration events of August to the middle of October 2002, but primarily the main migration time corresponds exactly to a high increase of eel activity in the MM's. Altogether, at Linne and Alphen, the MM's documented respectively 10 and 7 downstream migration waves by detection of an increasing eel activity. The only downstream migration event not being predicted by the MM, but by the commercial fisheries monitoring and transponder experiment, occurred at Linne at October 25. Conversely, the concerning MM's recorded 14 increases of activity at Linne and 10 increases at Alphen, which could not be supported by the other monitoring data. Nevertheless, the monitoring by the fishermen and registration of transpondered eels and monitoring eel passage of Linne hydropower station are inconsistent, as discussed before. For that reason the missing monitoring data does not allow the conclusion that there was in fact no downstream migration event.

Due to the peaks of eel activity in the MM tanks it was possible to identify 24 days in Linne, and 17 days in Alphen during which downstream migration events have been predicted. This represents respectively 10 and 15% of the total period of investigation, i.e the migration period of silver eel in the Dutch section of the river Meuse. During these few days 66% of the transpondered eels passed through Linne, and even 73% passed Alphen.

4 DISCUSSION & CONCLUSION

4.1 Characteristics of silver eel migration in the river Meuse

4.1.1 Commercial eel fisheries

When the cumulative fraction of silver eel catches at Lith-Alphen fisheries, calculated per day for each year during 1997-2002, is ranked in decreasing order, in most years about 20 days yield 50 % of the total silver eel catches, and in one year just 10 days yielded more than 60 % of total catch. However, as the anchored stow net fishery is located directly in the tailrace of Alphen hydropower station, it will miss migration peaks during periods that the hydropower station is out of operation due to high discharge of the river Meuse. Therefore, it is likely that > 50% of the total eel passing this location occurs in less than 20 days, i.e. the migrating silver eel population in one season passes during < 20 downstream migration events.

Investigations described by Oberwahrenbrock (1999) in the river Mosel at the Fankel hydropower station (Germany), brought up that during three months of nightly samplings (by means of 1 anchored stow net (10 x 5 m) in the tailrace of the hydropower station, alike Alphen), a migration peak was observed during 1 night (during waning of the moon + increase of river discharge) in which 67% of all migrating eel passes and 90% of all eel passed during the 10 days of largest catches (i.e. 10 days of highest migration activity). So it seems that the majority of downstream migrating silver eel migrate during a limited number of nights.

4.1.2 Telemetry experiments

During the tank experiments with dummy transponders, none of the remaining 17 eels with the dummy transponders had lost these and all individuals had closed wounds varying from fat tissue incorporated in the closed wound to a complete closing of the skin. When analysing the activity patterns between the two groups, a higher level of activity was observed for the control group (without transponder) during most of the period. A clear diurnal pattern was observed for both groups. During night time, especially between 17:00 and 20:00 hours, activity was higher. In contrast to activity level, timing of activity is very similar in both groups during the different periods as well as during the day. Implanting transponder might reduce the activity of silver eel to an extent, which might have an effect on timing, but probably not on mortality rates. It is concluded that telemetry provides a good and accurate method to monitor downstream movement of silver eels.

In the pilot study of 2001, of the 10 silver eels that were implanted with a transponder and released in the river Meuse, 8 started migration and passed the first detection station Stevensweert and finally 2 have reached the sea, which is 25%. Of the 150 silver eels that were released in the full scale field experiment in 2002/03, 125 individuals have passed the first detection station at Stevensweert and at least 32, but most probably 38 silver eels reached the sea which is at least 25.6% and most probably 30.4% of the eels reaching the sea. Thus, the disappearance rates found in both studies are similar. This indicates that the mortalities found in the river Meuse ranges between minimal 44.3% and maximal 74.4%, when assuming that the eels contributing to the unexplained mortality (25.3%; Table 14) are still alive.

In the last week of October 2002 and end of December / early January, many eels started to migrate downstream as show by transponders. This migratory activity coincided with the increased catches by commercial fisheries during this week. High migration activity appears to be associated with an increase of the water discharge, rather than with lunar phase. Thus, in this study no indication has been found that migration events can be prognosed based on moon phase. Furthermore, the timing of migration activity at 24 hours scale, shows a higher activity during the night than during the daytime. The diurnal differences shows to be stronger at the detection station in front of the hydropower stations intakes, indicating a hesitation of the eels to pass the hydropower station.

4.1.3 **Survival rate estimation by MARK and VPA modeling**

In the first two stretches tag loss occurred, which caused a reduction in 'survival' of 9.3% and 20.3%. The presence of Linne hydropower station and anchored stow net fishery, in combination reduced survival with 13.7%, whereas Alphen hydropower station and anchored stow net fishery, in combination reduced survival with 3.6%. Other fisheries show mortality rates of 0.4 to 2.5% per stretch between two detection stations. The estimation by MARK-model showed for Linne hydropower station up to 6.7 % direct mortality and for Alphen hydropower station up to 3.2 % direct mortality, based on the transponder experiment.

As estimated by Virtual Population Analysis (on total silver eel population) a total mortality of 63.3% was found. To this, hydropower contributes 15.8% (6.3% direct and 9.5% delayed mortality), fisheries contribute in total 22.2% (anchored stow net 5.1% and fykenet fisheries 17.1%) and unexplained mortality contributes 25.3%. The total mortality by the two hydropower stations is likely an overestimation, as of the eels that are considered to have passed the turbines and not being detected at downstream detection stations or are caught by fisheries, it is not sure if all are lethally injured. Fisheries mortality is likely an

underestimation as there might be an underreporting of transponders by fisherman. Also, the unexplained mortality might be partially attributable to withdrawal by fisheries which has not been recognised so far.

4.1.4 **Population estimation of downstream migrating silver eel in the river Meuse**

Based on the turbine catches, the total number of silver passing the location Linne after September 8 amounts 29.000 specimens, and at location Alphen since October 62.000 specimens. Based the mark-recapture data, the total population passing Linne since September amounts 94.000 and at Alphen between autumn and December in total 225.000 (minimum 150.000). The population estimates at the different locations appear accurate since independable methods and data yield very similar estimates. To what extent the lower section of the river Meuse downstream from Alphen contributes to the total population is unknown.

4.2 **Turbine passage of silver eel and related mortality at hydropower stations**

In the turbine netting experiments, a total 1196 eel were captured during 17 samplings, most of the silver eel occurred in the length class of 60 – 69 cm. The number of yellow eel passing the turbines is very low, counting 16 individuals (1.34 % of total catch). The increase of the number of silver eels passing the turbine starts late September and correspond to an increase of the river discharge. However, not each increase of river discharge implicated a migration event. The migratory activity of eel, as shown by checking the nocturnal partitioning of turbine passage, started between 19:00 and 20:00, just after the darkness fell and > 50% of the migrating silver eels passed the turbines before midnight. After midnight the number of eel per sub-sample decreased again. These results fully correspond to the observations made by the telemetry experiment. It is expected that during the night of October 26 – 27, when breakage of the net occurred due to an excess of turbine flow, the amount of eel through Linne hydropower station has been the largest, considering both the detection rate of transpondered eels and the result of the Migromat®.

The total of injured eels (non-lethal + lethal) is 34.0 % of the total of eel that passed the turbine. The total of lethal injuries amounts 24% of the total of eel that passed the turbine, however, this is likely to be an overestimation as part of the injured eels that have been defined as lethally injured still were alive and might survive the injury. The non-lethally injured

eels correspond to 10% of the total of eel that passed the turbine. These specimens are likely to be able to, although with an unknown delay, continue their migration.

The mortality is clearly related to turbine flow and the mortality rates found at 30 and 50 m³·s⁻¹ correspond to the results of earlier investigations at Linne hydropower station (Hadderingh & Bakker, 1998; Hadderingh & Bruijs, 2002). A clear relation was also found between the mortality and the length of the eel at 30 m³·s⁻¹: larger eel showing higher mortality than smaller eel. At turbine flows of 50 and 100 m³·s⁻¹ only a small length-effect was found. Overall, highest mortality rates are found for the 70 – 79 cm length class.

4.2.1 Silver eel behaviour in front of hydropower station intake

A clear hesitation of eel to pass the trash racks was found, as observed by the transponder experiment showing that silver eels in front of the hydropower stations may remain in a stationary position or show recurrence behaviour, i.e. some eels wait for longer periods or even return in upstream direction. Therefore, it is uncertain if they went downstream through the hydropower station or went back upstream and bypassed through the weir or the fishway, or even remained upstream for longer periods. It can be concluded that eels show a clear hesitation to pass the hydropower station as well as an upstream orientated escaping movement in front of trash racks. This typical behaviour corresponds to earlier investigations by Adam (1998 and 1999), Holzner (2000) and Haro *et al* (2000).

The upstream orientated escaping movements of eels in front trash racks were first observed in flume tank experiments, documented on video and published by Adam (1998) and Adam *et al* (1999). Because this behavioural pattern of eels in front passable and impassable trash racks up to an approach velocity of 0.5 m/s is characteristic for eels, this has led to the development of the so-called Bottom Gallery, by Floecksmühle and IFÖ. This is a bottom oriented bypass system crossing the inlet of a hydropower station. However, it has not been tested yet under real conditions in front of a hydropower station.

The observations of the upstream orientated escaping movements of eels in front of trash racks are confirmed by investigations of Holzner (Technische Universität München). During the autumn of 1999 the Technische Universität München (Weihenstephan, Germany) investigated the migration of eel at the hydropower station of Dettelbach in the Main in Germany (Holzner, 2000). Using sonar (Simrad) it has been shown that eel turns back to upstream direction at the trash rack, before it has made physical contact with the rack. At a water temperature of about 12 °C the number of turn-registrations is 4 – 6 times higher than the number of passages through the turbine, as indicated by the proportion of sonar

registrations and catches by nets behind the turbines. The extent of turns decreases with temperature and is much lower at 6 °C, as at this temperature the eels have less swimming capacity. In this investigation it is shown that at an average river flow the silver eel migrate at the bottom region, up to 1 m above the bottom at a total water depth of 5.5 m. Eels that turn at the trash rack swims even closer to the bottom in upstream direction.

Haro *et al.* (2000) investigated the behaviour of silver eel equipped with radio or acoustic transmitters at a hydropower station at the river Connecticut (USA). The eels were released at 0.4 to 1.5 km upstream the station. Of the 25 transmitted eel, at least 50% swam into the inlet channel of the station. A number of eels lost the transmitters, probably because they were fixed external. The eel remained in the inlet channel for an average period of 32 minutes. The eel mostly stayed at depths between 6.6 and 10 m (maximum depth inlet channel 10.5 m), although it had also been observed that the eel in front of the trash rack swam to the surface but immediately went downwards hereafter. It has also been observed that the eels entered the inlet channel for several times, but returning in upstream direction again, indicating that eels hesitate to pass the trash rack. The eels moved very little during the day and downstream movement started several hours after sunset.

The above described findings regarding the hesitation reaction of eel in front of a hydropower facilities, combined with the observations in this project, indicate that there are good possibilities to divert eels from trash racks and inlet channels of hydropower facilities.

4.3 **Monitoring downstream migration by means of the Migromat[®]**

4.3.1 **Design, construction and operational experience of the Migromat[®]**

An unexpected problem for the functioning of the MM at Linne was the fast growth of the Zebra mussel (*Dreissena polymorpha*). The sedimentation of mud seemed to be very comfortable for the eels, because they build tunnel-like structures in the substratum in which they find shelter. Moreover, the fully oxygenated mud contained a lot of prey-organisms. Overall, the MM's at Linne and Alphen functioned without any problems during the second period in 2002/03.

The way of capturing eels used for stocking the MM may be important, as of the eels caught by electrofishing and carefully handled before stocking, the mortality was reduced and the adaptation period of eel in the MM's was shortened.

4.3.2 Identification of migration events by means of the Migromat®

During the monitoring downstream migration by means of the MM system, eels show a minimum of activity at 11:00 a.m. and a maximum activity around midnight. The daily routine of the eels changes in periods of migration, showing a significant pre-migratory restlessness during dawn, prior to the night a migration event occurs in the river at which the MM is situated. Comparison of the results from Migromat® with the monitored downstream migration by means of telemetry, turbine netting and fisheries catches, during phase I (2001) at Linne 3 of 4 peaks and at Alphen:4 of 4 peaks of MM corresponded with downstream migration of transpondered eels. During phase II (2002/03), at Linne 24 days with high activity correlation with 10 monitored downstream migration events and at Alphen 17 days with high activity correlating with 7 monitored downstream migration events. The missing monitoring data does not allow the conclusion that there were in fact no downstream migration events. Furthermore, by the MM at Linne one migration event has not been predicted, which was observed by commercial fisheries monitoring and telemetry experiment (Linne, October 25). However, the main migration events during 2002, appearing a day later, have significantly been detected by the MM.

Due to the peaks of eel activity in the MM tanks it was possible to identify 24 days in Linne, and 17 days in Alphen during which downstream migration events have been predicted. This represents respectively 10 and 15% of the total period of investigation, i.e. the migration period of silver eel. During these few days 66% of the transpondered eels passed through Linne, and even 73% passed Alphen.

4.4 Human impact on downstream migrating silver eel in the river Meuse

It can be concluded that the combined mortality by the two hydropower stations is smaller than the combined mortality by the commercial fisheries. Fykenet fishing is more intensive than the anchored stow net fisheries. Furthermore, fisheries mortalities based on recaptures are minimum estimates, and it is likely that the real mortalities are up to a factor 2 higher, when presuming an underreporting of recaptured tags, as indicated by the population estimates at Linne. In table 31 the results of the different monitorings and models, attributable to similar mortality factors are presented. Table 32 presents a tentative approximation which solely holds for the disappearance and survival of eels that start migrating from upstream Linne.. The approximation is based on estimated population number at Linne, using the combined results and several assumptions to calculate the number of eel that hypothetically have reached the North sea during the silver eel migration season of 2002.

Table 31 Results of the monitorings and models performed for similar mortality factors.

Locations	Mortality factors on silver eel mortality in a stretch	Number of transpondered eels left *	Best guess of n eels that disappeared		Fisheries (%)	Turbine netting (%)	VPA Model (%)
			n (%)	n **			
North Sea		38 (30.4%)					
	<i>Rest</i>						
Capelse veer	<i>Fykenets</i>						
		50 (40%)					
Alphen HPS	<i>Rest</i>		12 (-5?)	11.3 (0.0 – 29.0)	-	-	16.1
	<i>Fykenets</i>		7 (+5?)	19.4 (11.3 – 40.3)	-	-	18.0
	<i>Anchored stow</i>		3 (+1?)	6.5 (4.8 – 8.1)	5.8	-	4.7
	<i>HPS direct</i>		2 (-1?)	1.6 (0.0 – 4.8)	-	-	3.1
	<i>HPS delayed</i>		0	0.0 (0.0 – 29.0)	-	-	-
		62 (49.6%)					
	<i>Rest</i>		11	10.6 (0.0 – 28.8)	-	-	18.4
Linne HPS	<i>Fykenets</i>		2 (+2?)	3.8 (1.9 – 30.8)	-	-	4.5
	<i>Anchored stow</i>		3 (+1?)	3.8 (2.9 – 9.6)	1.7	-	2.8
	<i>(HPS direct)</i>		(7 (-1?))	5.8 (0.0 – 6.7)	-	-	6.6
	<i>(HPS delayed)</i>		(11)	10.6 (0.0 – 28.8)	-	-	14.1
	<i>HPS total</i>		17	16.3	-	15.7***	20.7
Stevensweert Ohé en Laak		104 (83.2%)					
	<i>Rest</i>		20 (-1?)	15.2 (0.0 – 16.0)	-	-	-
	<i>Fykenets</i>		1 (+1?)	1.6 (0.8 – 16.8)	-	-	-
		125 (100%)					
		150					

* Number of transponders left (percentage of total of 125 that started downstream migration)

** Best guess for number of eels that disappeared from the experiment by hydropower stations, fisheries or other causes. Between brackets are the number of eel that could be added up (+) or subtracted (-) at most. (%) represent the chance of each specimen to disappear from a stretch.

*** Percentage of 24% mortality of the eel passing the turbine, corrected for the total number of eel passing the location (n eel passing the turbine + the weir/fishway).

Table 32 Tentative approximation of the number of silver eel reaching the North sea.

	Station	n out	n left
a	Population at Linne From the modelling by RIVO the yearly population passing the location at Linne amounts about 94,000 silver eels. Of these, at least 25 % is estimated to pass by the weir/fishway. At maximum 75% pass the turbines = 70,500.		94,000
b	Linne hydropower station At Linne hydropower station, a mortality rate of maximum 24% was found found, which are 16,920 lethally damage of the turbine passing silver eels.	16,920	77,080
c	Anchored stow net fishery Linne In total 1,639 specimens have been caught by the anchored stow net at Linne.	1,639	
<i>n eels that hypothetically passed Linne weir / hydropower station alive:</i>			75,441
d	Disappearance between Linne and Alphen Based on the transponder data, 34% of the eel that passes Linne have disappeared in this stretch = 25,650 specimens.	25,650	
<i>n eels from Linne that hypothetically have reached Alphen:</i>			49,791
	Population at Alphen From the modelling by RIVO the yearly population passing the location at Linne amounts 225,000 silver eels, of which 49,791 (22.1 %) are from Linne. Of these, at least 42% are estimated to pass by the weir/fishway. At maximum 58% passes the turbines = 28,879		
f	Alphen hydropower station For Alphen no investigation on mortality took place. Assuming the eels at Alphen pass the turbine at higher turbine flows (figure 28), a lower mortality is estimated. This corresponds to lower mortality found at Alphen, as found by the transponder results. Therefore, for Alphen a mortality rate of 12% is used.	3,465	46,326
g	Anchored stow net Alphen The anchored stow net at Alphen caught 4,316 eels in one net, and in three nets 12,948, of which 22% = 2,849 are from Linne.	2,849	43,477
h	Disappearance between Alphen and Capelse veer Based on the transponder data, 9% of the eel that passed Linne have disappeared in this stretch = 3,913 specimens.	3,913	
<i>n eels that hypothetically reach Capelse veer</i>			39,564
j	Disappearance between Capelse veer and Haringvliet Downstream Capelse veer an intensive fykenet fishery takes place, and as shown by the transponder experiment, 36% do not reach the Haringvliet dam. Of the total of 39,564 specimens left, 14,243 disappear.	14,243	
<i>n eels from upstream Linne that tentatively reached the North sea</i>			25,321

In the following paragraphs, the tentative approximation is hypothesised further, taking into account the impact at Alphen and effect of application of the Migromat® as well.

For the river Meuse section from upstream Linne to the North sea, an approximate maximum mortality of about 73% is calculated (on a total of 94,000 eels), i.e. a total of 25,321 specimens (about 27%) that tentatively reached the sea (see table 32). Of the mortality, hydropower contributes about 21.7% (n = 20,385; for both Linne and Alphen), anchored stow net fisheries contributes 4.8% (n = 4,488) and fykenet fisheries + other cause contribute 46.6% (n = 43,806). This mortality solely holds for the eel population that started migration upstream Linne.

When approximated for the river Meuse section from upstream Alphen to the North sea (not shown in table 32), an approximate maximum mortality of about 49% can be calculated (on a total of 225,000 eels starting from upstream Alphen, including the eels that successfully passed Linne), i.e. a total of 114,379 specimens (about 51%) that hypothetically reached the sea. Of this mortality, hydropower contributes 7% (n = 15,660), anchored stow net fisheries contributes 5.8% (n = 12,948) and fykenet fisheries + other cause contribute 36.5% (n = 82,013).

To answer the question how many eels migrating downstream in the river Meuse, starting in the river section from upstream Linne to upstream Alphen, have hypothetically reached the North sea during the migration season of 2002, the approximate number of eels surviving from Alphen has to be used, as these also include the eels that have successfully passed Linne. Tentatively a survival rate of 51% is calculated of the total population starting from upstream Alphen of 225,000 specimens, which includes the number of eel that successively passed Linne. The total number of downstream migrating silver eels that tentatively have reached the North sea amounts approximated 114,379 specimens. To what extent the lower section of the river Meuse downstream Alphen contributes to the total population is unknown.

4.5 Silver eel management in European rivers

There is a large number of rivers with damages on eels at hydropower stations in Europe. Well known examples are the rivers Mosel, Main, Lahn (Germany), the river Meuse (Belgium and the Netherland) and the rivers Dordogne and Loire (France). The Migromat® system provides a solution with economic benefits compared to installation of expensive specific fish screen systems in front of hydropower facilities. Besides that, till now there are no screen systems for midsize and large turbines available. As the impact by commercial fisheries in

the river Meuse has been found to have an even larger impact on downstream migrating silver eel, it is clear that measures reducing their catch should be taken. However, fisheries intensity in the Netherlands is relatively high compared to other countries. Hydropower is relatively low in other countries. Thus, the impact by hydropower in other European countries is likely much higher, and the effect by using the Migromat is likely higher as well.

4.5.1 **The Migromat[®]: eel-friendly turbine management of hydropower facilities**

During the investigation period of the EU Silver eel project, by identification of peaks of eel activity in the MM tanks and registration of subsequent warnings, it was possible to identify 24 days in Linne, and 17 days in Alphen during which downstream migration events have been predicted. This represents respectively 10 and 15% of the total period of investigation, i.e. the migration period of silver eel in the Dutch section of the river Meuse. During these few days 66% of the transpondered eels passed through Linne, and even 73% passed Alphen.

As approximated, in total 32,580 silver eels have died due to hydropower (at Linne 16,920 eels and at Alphen 15,660). By means of the warnings provided by Migromat[®] during the migration season of 2002, the mortality would have been reduced to in total 9,981 specimens, i.e. 5,753 specimens at Linne (66% reduction) and to 4,228 specimens at Alphen (73% reduction). This implies a total reduction of the hydropower mortality by 69.4%, based on the assumption that all eels that normally would have passed the hydropower station will pass the weir or fishway. Using the Migromat[®], the total number of eels successfully passing Linne weir / hydropower station and reaching Alphen would have been 57,161 specimens (including impact by anchored stow net and fykenet fisheries + other causes). The number of eels successfully passing Alphen weir / hydropower station would have been 126,013 specimens (including impact by anchored stow net and fykenet fisheries + other causes).

4.5.2 **Implications for commercial eel fisheries**

As the impact by fisheries in the Dutch of the river Meuse is relatively high, a reduction of catches immediately results in a elevated number of silver eels reaching the sea. Also, the number of eel that can be saved by using the Migromat[®] will be reduced by fisheries as the number of eel passing these fisheries will increase. In order to achieve the best overall effect of applying the Migromat[®], this implicates that the withdrawal by fisheries should be reduced by the fraction it catches of the eel saved by the Migromat[®].

4.6 **General conclusions**

The Nedap Trail System[®] has been shown to be a appropriate system to monitor downstream migration of silver eel.

Currently, within the Dutch section of the river Meuse from upstream Linne to the North sea, each individual downstream migrating silver eel has a chance of at least 30% and probably about 40% to reach the North sea.

The impact of the combined mortality by the two hydropower stations is smaller than the combined mortality by the commercial fisheries. Fisheries mortality is up to a factor 2 higher than hydropower mortality. The mortality by hydropower is likely an overestimation and the fisheries mortality is likely an underestimation. Reducing the catches by fisheries in Dutch section the river Meuse results directly in a higher number of eel reaching the North sea.

The results of the monitoring experiments verify that the Migromat[®] system accurately registers the pre-migratory restlessness of eels, thereby predicting the downstream migration events of silver eels.

A high percentage of turbine passing eels can be saved. Hence, the prediction of this early warning system, enables an eel-friendly turbine operating management of hydropower facilities. Application of the Migromat[®] during the migration season of 2002, the mortality by hydropower would have been reduced with maximal 69.4%.

5 EXPLOITATION AND DISSEMINATION OF RESULTS

No scientific publications have been prepared yet. At the beginning of the project, on the KEMA web-site, to be found at 'www.kema-water.com', a specific page has been created for the project. A description of the project can be found under 'projects'. More specific information on the Migromat[®] system the IFÖ provides more information at their web-site www.schwevers.de.

Several actions have been taken towards the effective communication of project's objectives to the targeted audience. The project has been, brought to attention through several media and symposia, which are listed in the table below:

Partner	Type	Media / symposia
KEMA	Notification	Global Contact, KEMA's worldwide quarterly magazine (March 2002, issue no. 1).
KEMA	Lecture	Symposium: Monitoring Behaviour; 27 – 30 August 2002, VU Amsterdam, The Netherlands.
KEMA	Announcement	Eel Symposium, 20 March 2002, Harderwijk, The Netherlands
KEMA	Article + lecture	International Cebedeau Conference, 29/31 Oct. 2002, Liege, Belgium.
KEMA	Live radio broadcast	Radio show 'Vara's Vroege Vogels', an informative radio-show on environmental topics (interview with Rolf Haddingh and Maarten Bruijs during sampling at Linne hydropower station).
KEMA	Announcement	newspaper 'Volkskrant', a short message as a result of the 'Vara's Vroege Vogels' radio show.
KEMA	Article	'Duurzame Energie': trade journal for sustainable energy, a short interview with Maarten Bruijs about the application of the Migromat [®] .
KEMA	Announcement	The project's objectives have been brought to the attention of the attendants of a brainstorm meeting on 'Het Aalplan' (the national eelplan) organised by the Ministry of Agriculture, Nature Management and Fisheries in The Hague, which concerns habitat & migration and commercial fisheries of eel (December 11, 2002).
KEMA	Notification	KEMA-report: 'Knowledge update cooling water 2002': annual report for the electricity production companies on surface water topics concerning research and legislation with respect to electricity production.
KEMA	Presentation	Presentation of the project overall objectives and material and methods at the yearly meeting of Hydroécologie Appliquée at Strasbourg, May 22 – 23 2003. The theme of this meeting is the implications of the European Water Framework Directive for electricity companies.

- table continued -

Partner	Type	Media / symposia
KEMA/ RIVO	Notification	Both KEMA and RIVO participate in a commission, consisting in scientist, fisheries bodies and legislative bodies, that deals with research performed at the river Meuse, with respect to fish migration. The project has been described and explained during the last meeting at May 8.
KEMA / IFÖ / FM	Posters	1 st International Scientific Maassymposium by the ICBM, November 27 & 28 2002 (Maastricht, the Netherlands). Two posters were presented: one on the overall objectives and activities of the project and one on the Migromat [®] . The co-financiers had been invited to visit the symposium.
IFÖ / FM	Poster	3 th International AFS Eel Symposium, August 10 - 14, 2003 (Quebec, Canada). Presentation of the poster: Protection of downstream migrating silver eels with the early warning system Migromat [®] .
KEMA		Proceedings of the 3 th International AFS Eel Symposium, August 10 - 14, 2003 (Quebec, Canada). An introduction to the project goals and outcomes (to be published in 2004).
IFÖ / FM	Installation of a Migromat [®]	2002 - 2004 Installation and full operation of a Migromat [®] as tool (early warning system) for an eel friendly operation management of the Wahnhausen hydropower station at the river Fulda (Germany) by order of E.ON.
RIVO	Article	'Onze Zoetwatervisserij': trade journal for commercial fisheries (official paper of Dutch professional fisherman) they took over integrally the article on the project in general by Erwin Winter which was published in the 'Jaarkrant 2001-2002' of RIVO.
RIVO	Announcement	EIFAC Eel Working Group, 2002, Kopenhagen, Denmark.
RIVO	Article	'Jaarkrant 2001-2002': the annual paper of RIVO.
RIVO	Announcement	The project's objectives have been brought tot the attention of the attendants of a workshop organised by Rijkswaterstaat at Elsloo, on fish migration in the river Meuse, September 30, 2002.
RIVO	Presentation article	Presentation of the tank-experiment at the 5 th Conference on Fish Telemetry Palermo-Ustica, Italy. 9 – 13 June, 2003.

6 POLICY RELATED BENEFITS

6.1 Community added value and contribution to EU policies

The eel is the target species of a relative small-scale fishing industry scattered throughout all coastal countries of Europe, which comprises both fisheries and aquaculture. The reproduction of the eel is not yet fully known, despite the general acceptance of Schmidt's (1922) hypothesis that spawning would occur in the Sargasso Sea. Since the early eighties, the recruitment of young eels is failing throughout Europe. This recruitment failure has now become a serious threat to the eel fishing industry. The Commission of the European Community has expressed their concerns and has addressed the need to manage the European eel fisheries under the Common Fisheries Policy. A major stumbling stone is the inadequate knowledge on basic biology of the eel, crippling the attempt to set up rational management. Furthermore it is well known that substantial mortality appears with downstream migrating eel passing the turbines of hydropower stations. Hydropower stations are widespread in many European rivers and might have detrimental effects on the population level of the European eel.

Adequate management measures can only be taken at a European scale. This project provides clear guidelines whether commercial fisheries and hydropower stations are of crucial importance for the escapement of silver eel out of river systems. The results of this project contributes to the reduction of the environmental impact of the use and production of hydropower energy as well a fisheries. The project addresses the activity Energy, Environment and Sustainable Development under the Fifth Framework Programme.

6.2 Contribution to Community social objectives

Although the European annual production of eel in weight is rather limited (15 k tonnes in fisheries and 10 k tonnes in aquaculture), the profit (180 M. ECU, primary value only) and labour (500 full time jobs, but 25,000 part time) is of great importance for rural communities.

Hydropower stations are a spin-off of a demand for environmentally friendly energy sources. The dilemma between detrimental damage on migratory fish populations on one hand and "clean" energy on the other is difficult and might hamper the introduction of new hydropower stations. By clarifying the role of hydropower stations on the silver eel, this project provides guidelines how these conflicting issues can be managed adequately.

6.3 Economic development and scientific & technological prospects – Exploitation

Under economical aspects an important objective of the project is to demonstrate the Migromat[®] as a successful forecast (Early Warning) system for migration peaks of silver eels in rivers. This system will help to reduce damages on eels by managing operation of turbines according to their migration behaviour. This prospect might lead to a more healthy eel population, which (on the long-term) guarantees a valuable commercial eel fishery.

A successful turbine management system also means a positive contribution to a sustainable exploitation of hydropower stations and the compliance of environmental requirements of the governments.

The consortium is well established in the field of hydropower and river ecology. They participated at a number of conferences giving lectures on their experience and results of scientific work. By this, the consortium was able to manage this project well. As a first step, the result of the project will help to show all European electricity companies operating hydropower stations the new forecast device and its advantage for starting a "turbine-management" during periods of eel migration.

6.4 Exploitation and dissemination plan

The functioning of the Migromat[®] and the Nedap Trail System[®] used for monitoring eel migration have been shown at the two hydropower stations at Linne and Alphen at the river Meuse. The functioning of the Migromat[®] has been presented by a poster at the 1st International Scientific Maassymposium by the ICBM, November 27 & 28 2002 (Maastricht, the Netherlands). Two posters were presented: one on the overall objectives and activities of the project and one on the Migromat[®]. The co-financiers have been invited to visit the symposium. At August 10 - 14 2003, the poster entitled 'Protection of downstream migrating silver eels with the early warning system Migromat[®]', will be presented at the 3th International AFS Eel Symposium, (Quebec, Canada). Furthermore, installation and full operation of a Migromat[®] as tool (early warning system) for an eel friendly operation management took place at the Wahnhausen hydropower station at the river Fulda (Germany) by the order of Electricity company E.ON for the period 2002 – 2004.

As the project was successful, FM and IFÖ will establish a marketing program for the Migromat[®] system. When establishing an ecological turbine management with the Migromat[®] system, it will be necessary to install a number of such device a long a river or river system.

The project provided information about reliability of the migration forecast for a certain length of a river. Using these results it will be possible to implement the forecast system correctly at rivers. The Migromat[®] devices will be rented. IFÖ will operate them and will get all information about eel behaviour inside the tanks via phone network or via internet. IFÖ will be able to detect future migration peaks and to provide an automated message to the operators of the hydropower installations. IFÖ will control operation of the Migromat[®] system scientifically. KEMA will be asked to participate in further evaluation of the Migromat[®] system. FM will produce all equipment for the Migromat[®] system including tanks, pumps, electric and electronic devices. Installation and maintenance will also be done by FM.

6.4.1 Patents

European Patents have been asked for the Migromat[®] system by FM and IFÖ in 1998. The paper was published by the European Patent Office in September 1999.

6.4.2 Public Interests

European policy is aiming at growing use of renewable energy. Hydro energy will remain the most important renewable energy for a long time and any effort to reduce CO₂ in the atmosphere has to take in account. But societies will focus on environmental problems of this electricity production technique too. During the last years damages on eels by passage turbine have been investigated scientifically at different rivers in Europe. On one hand these damages are violating laws, on the other hand public opinion is changing: people are no longer willing accept "clean" energy with ethic problems. In result, damages on fish, especially on eels must be reduced. The results of the project show that the Migromat[®] system can be applied to achieve this reduction for eel.

ACKNOWLEDGEMENTS

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LITERATURE CITED

ADAM, B., 1998. Aalabwanderung - Ergebnisse von Versuchen in Modellgerinnen. - Arbeiten Dt. Fischereiverband 70 (Durchgängigkeit von Fließgewässern für stromabwärts wandernde Fische), 37 - 68.

ADAM, B., SCHWEVERS U. & DUMONT U., 1999. Beiträge zum Schutz abwandernder Fische - Verhaltensbeobachtungen in einem Modellgerinne. - Solingen (Verlag Natur & Wissenschaft), Bibliothek Natur & Wissenschaft 16, 63 S.

ADAM, B., 2000. Migromat[®] - ein Frühwarnsystem zur Erkennung der Aalabwanderung. Wasser & Boden, 52/4, 16 – 19.

AKAIKE, H. 1985. Prediction and entropy. Pages 1-24 in A. C. Atkinson and S.E. Fienberg, (eds.) A Celebration of Statistics: the ISI Centenary Volume, Springer-Verlag, New York, New York, USA.

ANONYMOUS, 2000. World Atlas & Industry Guide, 2000. The International Journal on Hydropower & Dams. Aqua-Media, Sutton, UK.

ATV-DVWK, 2002. Merkblatt ATV-DVWK-M 501. Fischschuts- und Fischabstiegsanlagen – Bemessung, Gestaltung, Funktinskontrolle (Entwurf) November 2002.

BARAS, E. & JEANDRAIN, D., 1998. Evaluation of surgery procedures for tagging eel *Anguilla anguilla* (L.) with biotelemetry transmitters. *Hydrobiologia* 371/372: 107-111.

BARTIN, S., BERNOCCHI, G. & GERZELI, G., 1985. Morphohistochemical changes during the life cycle of the European eel. *Tissue & Cell*, 17: 97-109.

BERG, R., 1985. Turbinenbedingte Schäden an Fischen. Bericht über Versuche am Laufkraftwerk Neckarzimmern, Landesanstalt für Seenforschung und Fischereiwesen.

BERG, R., 1986. Fish passage through Kaplan turbines at a power plant on the River Neckar and subsequent eel injuries. *Vie Milieu* 36:307-310.

BERG, R., 1987. Gutachtliche Stellungname zu Fischschäden durch den Betrieb der Wasserkraftanlage 'Am letzten Heller'. Intern rapport Landesanstalt für Umweltschutz Baden Württemberg, Institut für Seenforschung und Fischereiwesen.

BEVERTON R.J.H., AND HOLT S.J., 1957. On the dynamics of exploited fish populations. Fisheries Investigations London, 19.

BIJ DE VAATE, A. & BREUKELAAR, A.W., 2001. De migratie van zeeforel in Nederland. Rijksinstituut voor Integraal Zoetwaterbeheer & Afvalwaterbehandeling, rapport nr. 2001.046.

BOETIUS, J., 1967. Experimental indication of lunar activity in European silver-eels, *Anguilla anguilla* (L.). - Medd. Dan. Fisk.- og Havunders. 6, 1 - 6.

BREUKELAAR, A.W., BIJ DE VAATE, A. & FOCKENS, K.T.W., 1998. Inland migration study of sea trout (*Salmo trutta*) into the rivers Rhine and Meuse (Netherlands), based on inductive coupling radio telemetry. *Hydrobiologia* 371/372: 29-33.

CALDERWOOD, W.L., 1945. Passage of smolts through turbines: effects of high pressures. Salmon Trout Mag. 115, pp. 214-221.

CRAMER, F.K., OLIGHER, R.G., 1964. Passing fish through hydraulic turbines, Trans. Am. Fish. Soc., 93: 243-259

COLLINS, N.H., RUGGLES, C.P., 1982. Fish mortality in Francis turbines, Research report G 261, Can. Electr. Assoc.

DAVIES, J.K., 1988. A review of information relating to fish passage through turbines: implications to tidal power schemes. Journal of Fish Biology, 33 (Supplement A): 111-126.

DAVE, G., JOHANSSON, M.L., LARSSON, A., LEWANDER, K. & LIDMAN, U. 1974. Metabolic and haematological studies on the yellow and silver phases of the European eel, *Anguilla anguilla* L.-11. Fatty acid composition. Comp. Biochem. Physiol. 74B: 583-591.

DEKKER, W. 2000. Impact of yellow eel exploitation on spawner production in Lake IJsselmeer, the Netherlands. Dana 2000 vol. 12, pp.17-32.

DEKKER, W. 2002. Status of the European Eel Stock and Fisheries. Proceedings International Symposium Advances in Eel Biology, Tokyo, Japan, September 2001.

EICHER ASSOCIATES INC., 1987. Turbine related fish mortality: review and evaluation of studies. Final report EPRI, Palo Alto.

EPRI (Electric Power Research Institute), 2000. Eel 2000: Symposium Pre-Prints. - 1st International Catadromous Eel Symposium in association with the 130th Annual Meeting of the American Fisheries Society, St. Louis, Missouri, USA, August 20-24 2000.

GULLAND, J.A., 1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report (meeting in Hamburg, January 1965). ICES C.M. 1965, Doc. No 3.

HADDERINGH, R.H. & BAKKER, H.D., 1998. Fish mortality due to passage through hydroelectric power stations on the Meuse and Vecht rivers. In: Jungwirth, M., Schmutz, S. & Weiss, S. (eds.) Fish migration and fish bypasses. Fishing News Books, Oxford. 315-328.

HADDERINGH, R.H. & BRUIJS M.C.M., 2002. Hydroelectric power stations and fish migration. Tribune de l'eau, Vol. 55, nrs. 619-620/5-6: 79 – 87.

HARO, A., CASTRO-SANTOS, T. & BOUBÉE, J., 2000. Behavior and passage of silver-phase American eels, *Anguilla rostrata* (LeSueur) at a small hydroelectric facility. Dana 12:33 – 42.

HOLZNER, M., 1999. Untersuchungen zur Vermeidung von Fischschäden im Kraftwerksbereich dargestellt am Kraftwerk Dettelbach am Main/Unterfranken. Landesfischereiverband Bayern e.V.

HOLZNER, M., 2000. Neue Versuche zur Schaden minimierung bei der Aalabwanderung. Voordracht SVK Fischereitagung, Künzell, 1 en 2 maart 2000. pp 8.

JONSSON, N., 1991. Influence of water flow, water temperature and light on fish migration in rivers. - Nordic J. Freshwater Res. 66, 20 - 35.

LARINIER, M. & DARTIGUELONGUE, J., 1989. La circulation des poissons migrateurs: le transit a travers les turbines des installations hydroélectrique. Bull. Fr. Pêche Piscic. 312-313, pp.90.

LEBRETON, J.D., BURNHAM, K. P., CLOBERT, J. & ANDERSON, D.R., 1992. Modeling survival and testing biological hypotheses using marked animals: case studies and recent advances. Ecol. Monogr. 62:67-118.

LEWANDER, K., DAVE, G., JOHANSSON, M.L., LARSSON, A. & LIDMAN, U., 1974. Metabolic and haematological studies on the yellow and silver phases of the European eel,

Anguilla anguilla L.-1 Carbohydrate, lipid, protein and inorganic ion metabolism. Comp. Biochem. Physiol., 47B: 571-581.

LOBON-CERVIA, J., 1999. The decline of eel *Anguilla anguilla* (L.) in a river catchment of northern Spain 1986-1997. Further evidence for a critical status of eel in Iberian waters. Archiv für Hydrobiologie, 144(2): 245-253.

LOWE, R. H., 1952. The influence of light and other factors on the seaward migration of silver eel. - J. Anim. Ecol. 21, 275 - 309.

MONTÉN, E., 1985. Fish and turbines. Stockholm, Vattenfall, pp. 111.

MUIR, J.F. 1959. Passage of young fish through turbines. Proc. Am. Soc. Civil Engng, J. Power Div., 23 – 46.

OBERWAHRENBROCK, G.K., 1999. Aalschutzinitiative Rheinland Pfalz/RWE-Energie AG. Projektfortschrittsbericht 1: Stand der Arbeiten an den Projektzielen a, b und c zum Januar 1999.

OLIGHER, R.C. & DONALDSON, I.J. 1966. Fingerling mortality versus turbine efficiency at Big Cliff dam. U.S. Army Corps. of Engineers, Walla Walla district.

POLLOCK, K.H., NICHOLS, J.D., BROWNIE, C. & HINES, J.E.. 1990. Statistical interference for mark-recapture experiments. Wildlife Monographs 107: 1-97.

PRIGNON, C., LAFFINEUR, B. & MICHA J.C., 2001. Convention d'études pour le suivi scientifique de la réhabilitation du saumon atlantique dans le bassin de la Meuse, Projet Meuse Saumon 2000. Rapport annuel (partie FUND) période février 2000 - janvier 2001. Ministère de la Région Wallone.

RABEN, K. VON, 1955. Kaplan-turbinen und Fische. Wasserwirtschaft 45:196-200 (in German).

RABEN, K. VON, 1957. Über Turbinen und ihre schädliche Wirkung auf Fische. Zeitschrift für Fischerei und deren Hilfswissenschaften, Band VI N.F. Heft 1-8:171-182 (in German)

RICKER, W.E., 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 1991. 382 p.

SCHEURING, L., 1930. Die Wanderungen der Fische II. - Ergebnisse der Biologie 6, 4 - 326.

SCHIEMENZ, F., 1960. Unterschied der Wanderungen der Fische, insbesondere der Aale verschiedenen Reifegrades, im unkanalisierten Strom und im kanalisierten Strom. - Z. Fischerei NF. 9, 133 - 154.

SCHOENEMAN, D.E., PRESSEY, R.T. & JUNGE, C.O.Jr., 1961. Mortalities of downstream migrant salmon at McNary dam. Trans. Am. Fish. Soc. 90, pp. 58-72.

SEBER, G. A. F., 1982. The estimation of animal abundance and related parameters. 2nd ed. Macmillan, New York, USA. 654pp.

SOKAL, R. R. & ROHLF F. J., 1995. Biometry: the principles and practice of statistics in biological research. 3rd edition. W.H. Freeman and Company, New York. 887 p.

TESCH, F. W., WESTERBERG H. & KARLSSON L., 1990. Tracking studies on migrating silver eels in the central Baltic. - Int. Revue ges. Hydrobiol. 75, 866.

TRAVADE, F., DARTIGUELONGUE, J. & LARINIER, M., 1987. Dévalaison et franchissement des turbines et ouvrages énergétiques: expériences E.D.F. La Houille Blanche, nr. 1/2, pp. 125-133.

WHITE, G.C. & BURNHAM, K. P., 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.