



## ORIGINAL ARTICLE

# Behavioural responses of eel (*Anguilla anguilla*) approaching a large pumping station with trash rack using an acoustic camera (DIDSON)

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Email: Olvin.vanKeeken@wur.nl**Abstract**

European eel, *Anguilla anguilla* L., migrating to the sea encounter many man-made structures that can hamper and delay migration or induce mortality. Studying small-scale behavioural movements in front of these man-made structures could provide insight in further mitigating adverse effects. The behaviour of eel approaching a trash rack in front of a large pumping station was investigated using a dual-frequency identification sonar (DIDSON). Eels approaching the trash rack swam through the rack (40.5%) but also showed turning behaviour at (44.7%) or in front of the rack (14.7%). Eels approaching the rack had varying body positions, predominantly head or tail first, but also curled up into a ball or drifted sideways. After turning in front or at the trash rack, eels showed upstream and downwards swimming towards the canal bottom. The results suggest a stepwise response to potential cues, when firstly the body position is changed in such a way that secondly, later on, enhances eventual fast upstream escapement when perceived necessary. Implications for management of these behavioural observations are discussed.

**KEYWORDS**

conservation, fish behaviour, fish migration, imaging sonar, migration barriers

## 1 | INTRODUCTION

European eel, *Anguilla anguilla* L., is in strong decline since the 1970s (ICES, 2018) as a result of various factors, such as migration barriers, fisheries, habitat loss and deterioration, pollution, parasites and changes in oceanic conditions (Buysse, Mouton, Stevens, Neucker, & Coeck, 2014; Drouineau et al., 2018; Feunteun, 2002; Moriarty & Dekker, 1997; Palstra, Heppener, Ginneken, Székely, & Thillart, 2007; Westerberg et al., 2018). European eel migrates from inland waters to the sea during their adult stage (silver eel)

to head for their spawning area in the Sargasso Sea (Tesch, 2003). During the migration, they encounter man-made structures such as pumping stations, sluices, weirs and hydropower stations that obstruct their migration route. In the Netherlands, discharge sluices and large pumping stations have been built for water level control of the catchment areas, protection against the sea and to limit saltwater intrusion. Fish migration can be hampered by pumping stations by inducing additional mortality when the turbines are not designed in a fish-friendly manner (Buysse, Mouton, Baeyens, & Coeck, 2015; Fjeldstad, Pulg, & Forseth, 2018) or by delaying fish resulting in additional energy loss and potential mismatch in

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arrival time on spawning grounds affecting reproductive success and fitness (Fjeldstad et al., 2018; Travade, Larinier, Subra, Gomes, & De-Oliveira, 2010; Verhelst, Baeyens, et al., 2018). The delay in migration could also result in higher predation and fishing risk, higher risk of contracting diseases (Calles et al., 2010; Jansen, Winter, Bruijs, & Polman, 2007; Lennox, Økland, Mitamura, Cooke, & Thorstad, 2018; Verhelst, Buysse, et al., 2018) or eel could postpone their migration (Durif, Dufour, & Elie, 2005; Jansen et al., 2007; Winter, Jansen, & Bruijs, 2006).

The effects of man-made structures on silver eel migration are mostly studied to assess mortality after passage and overall migration routes using telemetry studies (e.g. Buysse et al., 2015; Calles et al., 2010; Trancart et al., 2018; Travade et al., 2010; Verhelst et al., 2018b, Buysse et al., 2018; Winter et al., 2006). Downstream migrating eels are considered to follow the main flow of water (Breteler et al., 2007; Jansen et al., 2007; Verhelst, Buysse, et al., 2018), swimming or drifting semi-passively with the current (Porcher, 2010; Tesch, 2003). However, eels can alter their normal migration behaviour and routes when encountering disturbing factors (Piper et al., 2017), for example, alter their position in the water column (Bruijs & Durif, 2009; Piper et al., 2015), hesitate before passing a trash rack in front of hydropower or pumping stations (Behrmann-Godel & Eckmann, 2003; Jansen et al., 2007; Bruijs & Durif, 2009; Travade et al., 2010) or show active escapement behaviour close to the structure (Bruijs & Durif, 2009; Russon, Kemp, & Calles, 2010; Travade et al., 2010). The reaction of an eel to changes in its environment is an effect of and response to visual, tactile and olfactory cues (Keefer, Caudill, Peery, & Moser, 2013). Trash racks are placed in front of pumping and hydropower stations to prevent large debris getting into the turbines and are the first physical obstacles fish encounter while approaching these structures. Most studies on the effects of pumping or hydropower stations with trash racks focus on the risk of entrainment, but more focus should be directed to behavioural responses of fish in the vicinity of these structures in relation to entrainment risk (Harrison et al., 2019). An eel approaching these structures perceives multiple cues that might trigger a change in its behaviour, for example, at larger distances underwater sound emitted by the stations (Behrmann-Godel & Eckmann, 2003) and near the trash rack and pumping stations water flows change in direction and increase in speed (Piper et al., 2015). Close to the structure, visual detection and eventually physical encounters could trigger eels to swim away from the structure, as has been shown in laboratory (Piper et al., 2015; Russon et al., 2010) and field experiments (Travade et al., 2010).

The behaviour of downstream migrating eels approaching a trash rack at the entrance of a large pumping station in IJmuiden, the Netherlands, was investigated using a dual-frequency identification sonar (DIDSON). The aim of this study was (a) to assess how eels were positioned in the water column while approaching the rack; (b) how the eels reacted in the vicinity of the trash rack and entrance of the pumping station; and (c) to use these observations to discuss management options.

## 2 | MATERIALS AND METHODS

The study site was a large pumping station at IJmuiden (52°28'N, 4°36'E), the Netherlands, that is part of a sluice complex that discharges fresh water from Lake Markermeer, the Amsterdam-Rhine canal and the North Sea canal towards the North Sea. The entire complex consists of six turbines, seven discharge sluices (combined maximum capacity 500 m<sup>3</sup>/s) and four ship locks. Both the pumping station and the "Noordersluis" ship lock are among the largest in Europe. Four turbines were installed in 1975 and have a capacity of 40 m<sup>3</sup>/s each. Two other turbines with a capacity of 50 m<sup>3</sup>/s each were installed in 2005 and were separated by a small pier from the other four turbines. Water coming from the North Sea canal flows through 20-m long supply channels to each turbine. In front of the entrance of the supply channels to turbines 1–4 and 5–6, there is a trash rack, positioned at a 15 degree angle, with a bar width of 1.6 cm and a bar spacing of 15.1 cm. The water depth at each turbine inlet is 8.2 m.

The behaviour of migrating eels near the trash rack was studied during the first hours after sunset when migrating eels are most active (e.g. Winter et al., 2006). Migrating eels were observed for two periods: five evenings in November–December 2009 and five evenings in November–December 2010. In both periods, the turbines were in operation.

To study migrating eel behaviour in front of a trash rack at small scale, a DIDSON "dual-frequency identification sonar" was used (Sound Metrics). The DIDSON functioned at a frequency of 1.1 and 1.8 Mhz. At the high frequency of 1.8 Mhz, the sonar emits 96 acoustic beams, the field of view is 28° horizontal and 14° vertical and the maximum range is 15 m. The DIDSON was mounted on a frame and secured in a submerged position at an angle facing the trash rack in front of turbine five and six. Approximately, a quarter of the rack in front of turbine five was covered by the DIDSON field of view. DIDSON software (Sound Metrics, 2009) was used for sonar survey analyses. Eel behaviour was categorised as: (a) direction the eels were swimming in relation to the trash rack; (b) body position of the eels while approaching the trash rack; and (c) behaviour of the eels during the encounter with the trash rack. After passing the trash rack, the eels enter the supply channel between the rack and the turbine. Here, they continue towards the turbine and eventually passing it or they turn around and swim against the water current, passing the trash rack again in an opposite direction.

Observations of eels derived from the DIDSON software files were carried out separately by two observers to validate the categorisation of eel movements. When lacking consensus between both observers, a third observer was consulted and the movement was discussed. When no consensus could be reached, the eel movement was scored as unknown. Distance of an eel to the canal bottom was measured using the DIDSON software measuring tool.

Differences in behaviour were tested using a two-sided *t* test, and changes in swimming depth before and after the approach were tested using a two-sided paired *t* test (SAS version 9.3: SAS Institute Inc, 2011).



### 3 | RESULTS

A total of 376 eel movements were recorded during 35.5 hr spread over five nights in 2009. In 2010, 88 eel movements were recorded during 7.36 hr spread over five nights. Eels could have been recorded more than once, because they could swim in and out of the DIDSON field of view as it did not cover the entire trash rack. Out of the 464 eel movements recorded by the DIDSON, 46.7% ( $n = 217$ ) were within the DIDSON field of view when approaching the trash rack from upstream moving with the water current towards the turbine. In 22.8% ( $n = 106$ ) of the movements, eels were observed while passing the trash rack in an upstream direction (Table 1). In 30.3% ( $n = 141$ ) of the movements, eels were observed in a sideways direction in front of the trash rack, not passing it, coming into the field of the DIDSON from the side, with no clear approach of the trash rack from upstream.

The observed eels displayed different body positions while approaching the trash rack with the water current, coming from the trash rack and pumping station (Figure 1). Of the 217 detected, 118 eels swam "with the current" and head first (negative rheotaxis), 42 swam actively "against the current" and tail first (positive rheotaxis), 27 swam "sideways," and 27 were "curled up" into a small ball and passively floating with the current. The exact body position for three eels was not clear from the DIDSON observations.

Eels approaching the trash rack from the canal side showed three behaviours near the trash rack: 40.5% of the eels swam through the trash rack towards the turbine, 14.7% showed turning behaviour in front of the trash rack and 44.7% at the trash rack, thereby swimming away from the trash rack in an upstream direction. The number of eels turning in front of or at the trash rack was significantly more than eels swimming through the trash rack ( $t = 2.750$ ,  $p < 0.01$ ,  $n = 217$ );

Of the eels that swam with the current and against the current during their approach to the trash rack, 47% and 45%, respectively, swam through the rack, while 53% and 55% turned either in front of or at the rack (Figure 2). Both were not significantly different ( $t = 0.542$ ,  $i < 0.59$ ,  $n = 118$  and  $t = 0.851$ ,  $p < 0.56$ ,  $n = 42$ ). With eels swimming sideways, the percentage of eels swimming through the trash rack declined to 37% ( $1.308$ ,  $p < 0.20$ ,  $n = 27$ ), while for curled

up eels, this percentage was only 11% ( $t = 3.192$ ,  $p < 0.01$ ,  $n = 27$ ), with most eels (81%) that approached the trash rack curled up turning at the trash rack. For eels approaching sideways and going through the rack ( $n = 10$ ), it could not be assessed if the eels eventually went head first, tail first or body first through the rack from the DIDSON images as the reflection of the trash rack dominated in the images.

Differences in swimming depth of the eels when entering the DIDSON field of view, at or near the trash rack and leaving the field of view (Figure 3), showed no significant change in swimming depth for eels going through the trash rack towards the turbine or eels approaching the trash rack before turning near or at the trash rack (Table 2). However, eels turning both at ( $p < 0.001$ ) and in front ( $p = 0.02$ ) of the trash rack showed a significant change in swimming depth after turning with eels swimming deeper towards the bottom. Also eels passing the trash rack in an upstream direction showed a significant ( $p < 0.001$ ) change in swimming depth, swimming deeper towards the bottom after passage through the rack.

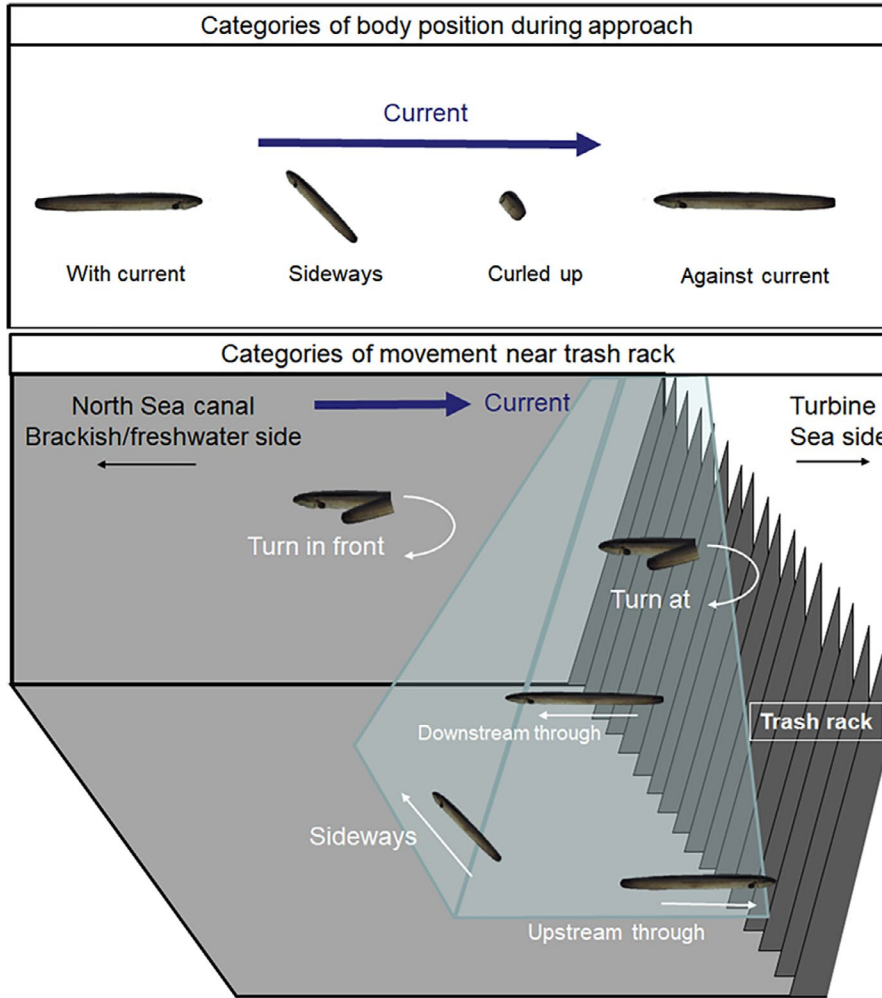
### 4 | DISCUSSION

There were clear behavioural responses and patterns in eel approaching and swimming near the trash rack and pumping station. Near the trash rack, migrating eels showed different behaviour with significantly more eels turning near the trash rack or after direct contact with the trash rack than going through the rack, indicating trash rack avoidance behaviour. During the approach of the trash rack, eels turned at and in front of the trash rack and eels were also seen swimming alongside the trash rack and out of the trash rack after having turned closer to the entrance of the turbine.

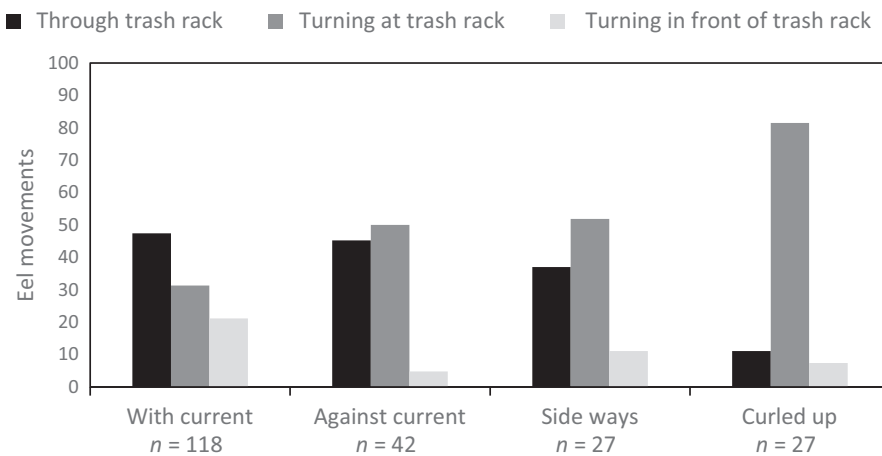
The results suggest a stepwise response to different cues when approaching the trash rack and pumping station. Firstly changing their body position to curled up, sideways drifting or swimming tail first and secondly showing avoidance or countercurrent swimming away from the structures. It might well be that a perceived cue triggers the eel to a more wary state, and a second or stronger cue triggers an avoidance or flee response. Eels that are curled up, sideways drifting or swimming tail first can change quicker to upstream sprinting than downstream swimming eel. A similar stepwise

**TABLE 1** Number of eels per approaching direction (upstream coming from canal side and downstream coming from the turbine side), movement near the trash rack and body position of the eels

Approaching from	Movement	With current	Sideways	Curled up	Against current	Not determined	Total
Upstream	Turning in front of trash rack	25	3	2	2		32
	Turning at trash rack	37	14	22	21	3	97
	Through trash rack	56	10	3	19		88
Side	Passing in front of trash rack	5	20		116		141
Downstream	Through trash rack				106		106
	Total	123	48	27	263	3	464



**FIGURE 1** Categories of body position during approach of the trash rack and movement response of eel near the trash rack with the beam covered by DIDSON in transparent grey

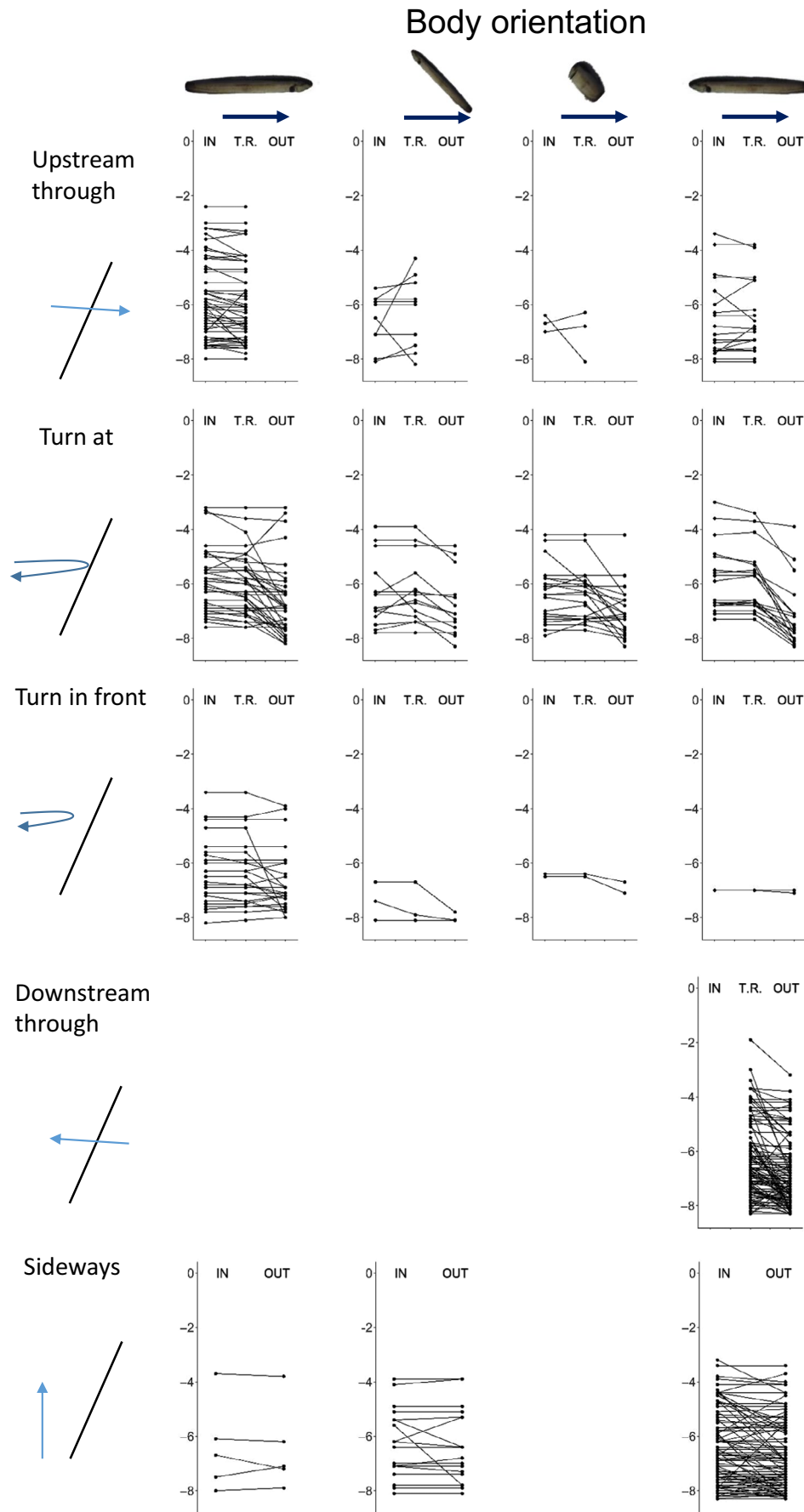


**FIGURE 2** Body position of the eels approaching the trash rack by behaviour near the trash rack in percentage

change in behavioural response, first a change body position to tail first drifting eventually followed by fleeing by swimming or sprinting against the water current, was found for salmon smolts approaching unnatural structures (Kemp & Williams, 2009).

In a laboratory experiment of eels approaching a trash rack, the majority of eels released in front of a trash rack tended to maintain regular contact with the channel floor (91.7%) and walls (95%)

(Russon et al., 2010) indicating positive thigmotaxis. These eels did not avoid abrupt changes in the hydrodynamic environment created as a result of fluid–structure interactions. They only rejected trash racks after direct contact with them, indicating negative thigmotaxis. In the present study, eels also turned after physical contact with the trash rack. However, in contrast to Russon et al. (2010), most eels approached the trash rack in mid-water and the majority



**FIGURE 3** Changes in depth of eels entering the DIDSON field of view (IN), recorded at the trash rack (TR) and leaving the DIDSON field of view (OUT). Observations of the same individual are connected

Direction	Difference	df	t	p
Upstream through trash rack	Depth_in - Depth_rack	87	1.02	0.3097
Upstream turning at trash rack	Depth_in - Depth_rack	96	1.58	0.1163
Upstream turning at trash rack	Depth_rack - Depth_out	96	9.38	<0.0001
Upstream turning in front of trash rack	Depth_in - Depth_rack	31	1.43	0.1632
Upstream turning in front of trash rack	Depth_rack - Depth_out	31	2.36	0.0248
Downstream through trash rack	Depth_rack - Depth_out	105	5.55	<0.0001
Passing in front of trash rack	Depth_in - Depth_out	140	2.81	0.0057

**TABLE 2** Paired t test of depth at entering the DIDSON files of view (depth\_in) to depth at either turning at or near the trash rack (depth\_trash rack) or leaving the field of view (depth\_out), and depth at or near the trash rack (depth trash rack) to depth when leaving the field of view (depth\_out)

of the observed turning behaviour already occurred in front of the trash rack without physical contact. Piper et al. (2015) also showed that eels changed behaviour when approaching an obstacle. It is likely that the differences between laboratory and field studies were linked to cues that are related to the presence of pumping and hydropower stations, since these were lacking in the laboratory studies. At present, there is little insight into the behavioural responses to different potential cues when approaching pumping and hydro-power stations with trash racks. For the first responses at some distance upstream from the structures, underwater sound emitted by the stations is a likely important candidate, since there are not many other cues to travel against the current. Further research on this could focus on measuring eel behaviour simultaneously with measuring the strength of potential parameters that can serve as cues in the field, combined with laboratory experiments to disentangle individual cues.

Identification sonars such as the DIDSON and ARIS (Adaptive Resolution Imaging Sonar) are useful tools to investigate fish movement and behaviour in water. They have been used in multiple studies of European eel migration, but mostly for estimating silver eel production (e.g. Bilotta, Sibley, Hateley, & Don, 2011; Egg, Mueller, Pander, Knott, & Geist, 2017; MacNamara & McCarthy, 2014; McCarthy et al., 2014). Identification sonars have also been used to assess fish abundance and distribution of fish near a trash rack of a hydropower plant in Germany (Schmidt, Tuhtan, & Schletterer, 2018).

DIDSON underwater recordings can detect small-scale fish behaviour in front of the trash rack, showing body position and how fish react in detail to the trash rack in dark and turbid conditions. Because only part of the entire trash rack was observed, eels could enter the rack at another position and appear out of the trash rack within the field of the DIDSON. Further, eels were recorded swimming along the trash rack, indicating some searching behaviour, while the original position of approach and how these eels reacted was not detected. Furthermore, eels approaching the trash rack could already have turned at greater distance from the trash rack outside

the field of view of the DIDSON. Given the observed back and forward swimming of eels at and through the trash rack, it cannot be excluded that individuals were seen more than once. To assess individual movements at a larger scale, but without the high resolution of body position and detailed responses yielded by DIDSON, could be determined using positioning telemetry.

## 5 | IMPLICATIONS FOR MANAGEMENT

Eels seen in the DIDSON field of view showed a lot of recurrence behaviour in front of or at the trash rack and also showed exploratory behaviour by swimming in and out of the trash rack and along the trash rack. In other studies, recurrence behaviour of eels near large turbines has been reported thereby increasing their migration time (e.g. Behrmann-Godel & Eckmann, 2003; Calles et al., 2010; Jansen et al., 2007). Calles et al. (2010), using radio-tagged eels, found eels only showed recurrence behaviour near hydroelectric plants and not at other locations in the study area. The delay in migration could deplete energy resources and could reduce the probability of reaching the spawning grounds. The eels showing recurrence behaviour, 10% returned upstream, cancelling their migration. Despite the installation of more fish-friendly turbines for mitigating downstream eel migration, avoidance behaviour of these turbines by eels could result in a behavioural bottleneck for part of the eel population.

When there are no alternative routes other than migrating through the pumping station, there is a higher chance of these eels eventually going through the turbines. Mortality rates then depend on how "fish friendly" the type of turbine is, the size of the fish and also on the position of the eel. An elongated species like eel has a higher chance of being struck by one of the blades than an eel that is curled up into a small ball or drifting sideward, and an eel that is swimming slowly against the current has a higher expected mortality rate than eel swimming with the current due to a shorter presence in the striking zone. Mortality rates can be



reduced when eels are able to use alternative downstream passage routes. Searching and recurrence behaviour and upstream swimming enhance the chance of finding these alternative routes if they are in the vicinity and have sufficient attraction by cues. Mortality rates can also be reduced when eels are hindered from entering the turbines, for example covering the entrance with racks with narrow bar spacings and at the same time supplying safe bypass routes (Dainys, Stakenas, Gorfine, & Lozys, 2018; Økland et al., 2019; Travade et al., 2010). A large, fine-mesh trash rack, however, is technically challenging to construct and operate, and could result in fish mortality due to impingement (Calles et al., 2010; Fjeldstad et al., 2018).

After turning in front or at the trash rack, eels showed a downward movement towards the bottom. Eels that passed the trash rack from the turbine also showed a downwards swimming direction against the water current. This is probably because water velocities are slower at the bottom than in the water column, and it is therefore easier to use for upstream escapement. Providing alternative migration routes or fishways near the bottom near objects such as a trash rack could enhance the redirection of eels away from the pumping station, thereby contributing to eel migration survival. Bottom bypasses have been suggested over surface bypasses for eel (Dumont & Hermens, 2012; Gosset, Travade, Durif, Rives, & Elie, 2005; Klopries, Deng, Lachmann, Schüttrumpf, & Trumbo, 2018); however, surface bypasses have also been reported to benefit eel migration (Travade et al., 2010). Redirection would, however, only work if there are other possibilities to migrate and it should be taken into account that eels follow migration routes with the largest portion of water flow (Jansen et al., 2007; Økland et al., 2019; Trancart et al., 2018; Travade et al., 2010). Only 5%–9% of the eels migrating through a river power station in Germany (Økland et al., 2019) entered a specially built side bottom bypass and 1% a side bypass. Most eels, however, passed over a spillway gate (59%–49% in two study years) or continued the migration towards the turbines (24%–27%), where they were redirected to a flushing channel. Of the eels migrating downstream through a hydropower plant in Lithuania with fish passage for upstream migrating salmon (Dainys et al., 2018), 34% of eels used the fish passage to migrate past the plant. Eels migrating through a hydropower station in Germany (Egg et al., 2017) did not use an eel bypass system, but used an opening of an undershot sluice gate to pass the complex. Higher current velocities in front of this sluice gate were identified as the most important trigger to use this gate instead of the bypass. Giving alternative fish passages next to the rack, especially in combination with effective screening and higher velocities at the bypass, may be an effective measure to reduce mortality rates substantially among migrating eels (Calles et al., 2010; Egg et al., 2017; Travade et al., 2010).

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