

Evidence

Understanding fish and eel behaviour
to improve protection and passage at
river structures

Extended summary – SC120061

We are the Environment Agency. We protect and improve the environment.

Acting to reduce the impacts of a changing climate on people and wildlife is at the heart of everything we do.

We reduce the risks to people, properties and businesses from flooding and coastal erosion.

We protect and improve the quality of water, making sure there is enough for people, businesses, agriculture and the environment. Our work helps to ensure people can enjoy the water environment through angling and navigation.

We look after land quality, promote sustainable land management and help protect and enhance wildlife habitats. And we work closely with businesses to help them comply with environmental regulations.

We can't do this alone. We work with government, local councils, businesses, civil society groups and communities to make our environment a better place for people and wildlife.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:

Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

<http://www.gov.uk/government/organisations/environment-agency>

© Environment Agency – June 2017

All rights reserved. This document may be reproduced with prior permission of the Environment Agency.

Further copies of this report are available from our publications catalogue:

<http://www.gov.uk/government/publications>

or our National Customer Contact Centre:
T: 03708 506506

Email: enquiries@environment-agency.gov.uk

Author(s):

Adam Piper and Ros Wright

Dissemination status:

Publicly available

Keywords:

Fish passage, eel migration, barriers, acoustic telemetry, hydrodynamics, habitat fragmentation

Research contractor:

International Centre for Ecohydraulics Research, Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ

Environment Agency's Project Manager:

Ros Wright

Collaborator(s):

Environment Agency, University of Southampton

Project number:

SC120061

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, and helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Research, Analysis and Evaluation group is an important ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment by:

- **Setting the agenda**, by providing the evidence for decisions.
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards.
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves.
- **Providing information, advice, tools and techniques**, by making appropriate products available.

Doug Wilson

Director of Research, Analysis and Evaluation

Executive summary

This project studied the behaviour of fish and eels to find better ways to protect them at flood control structures, weirs, hydropower sites and other intakes. The study showed significant impacts of some river structures on migrating eels, but also that understanding fish and eel behaviour at such structures and intakes in relation to flow could help improve their passage.

The findings show how designs and location of eel passes could be improved to increase the survival and passage of eels during their migration up and down rivers. This evidence will help to inform guidance for provision of eel passes and operational changes at river structures at critical times of the year for migrating fish and eels. The study also showed that trap and transport of mature eels from landlocked reservoirs is an option to increase numbers of eels undertaking their spawning migration.

Eel migration

The European eel is now classified as endangered. Its complex life cycle makes this species vulnerable to man-made river structures that hinder its migration. Mature adult eels (known as silver eels) migrate down rivers and travel 4,800km to spawn in the Sargasso Sea (an area of the Atlantic Ocean). The larvae return across the Atlantic Ocean to Europe to migrate up rivers as glass eels and elvers. The provision of eel passes at in river structures and the screening of intakes where water is abstracted is required under the Eels (England and Wales) Regulations 2009.

Results from field trials on rivers

Using sonar cameras and acoustic telemetry systems to track fish and eels, researchers monitored their movement past river structures and investigated the effects of changing flows on passage and the effects of a hydropower installation on coarse fish and eel behaviour and movements.

For upstream migration of eels, field trials showed that introducing a plunging flow at the entrance of eel passes improved passage by two-fold for immature life stages. Plunging flow is water cascaded to the entrance of the pass which assists eels in locating a pass. The position of the pass also influenced catches; smaller eels (<121mm) favoured bankside passes and larger eels mainly used passes in the centre of the river.

Tracking of silver eels on their spawning migration in one river showed that a single abstraction intake was the main cause of mortality, while several structures were associated with delays in movement of up to 68 days.

Detailed tracking of silver eels at a complex of 5 structures found that they rarely took a direct route and did not follow the expected route of greatest flow. Changes in water velocity at one of the structures revealed that at high velocities eels tended to swim rapidly back upstream away from the structure, whereas at low velocities the eels explored the structure.

Helping eels in landlocked waters to migrate

The research also looked at the problem of eels in landlocked still waters which may not be able to undertake their spawning migration. 'Trap and transport' has been suggested as a means to overcome this, but it was not known if eels transported from such water bodies would migrate successfully.

The project captured 80 reservoir eels which were acoustically tagged, released into a river and tracked, alongside 30 migrating silver eels from the same river. The results

showed that 88% of the reservoir eels and 90% of the river eels migrated through the 25km study reach and into the sea, suggesting that trap and transport could be a way of boosting the number of silver eels able to migrate.

Acknowledgements

This study was jointly funded by the Environment Agency, the University of Southampton and the Interreg IVB Living North Sea project, which aims to improve access to migratory fish in the North Sea Region.

The authors thank all the participants in the various elements of this study and acknowledge organisations and individuals in peer-reviewed publications.

Contents

1	Introduction	1
1.1	Background	1
1.2	Legislation	1
1.3	About this report	1
2	Seaward migration of silver eels and entrainment at water offtakes	3
2.1	Background	3
2.2	Study outline	3
2.3	Key findings	4
2.4	Management implications	4
3	Silver eel behaviour and hydrodynamics	6
3.1	Background	6
3.2	Study outline	6
3.3	Key findings	7
3.4	Management implications	8
4	Eel and fish behaviour and passage at an Archimedes screw hydropower turbine	9
4.1	Background	9
4.2	Study outline	9
4.3	Key findings	10
4.4	Management implications	10
5	Trap and transport of landlocked eels	12
5.1	Background	12
5.2	Study outline	12
5.3	Key findings	12
5.4	Management implications	13
6	Understanding juvenile eel responses to hydrodynamics to enhance upstream passage	15
6.1	Background	15
6.2	Study outline	15
6.3	Key findings	15
6.4	Management implications	16
7	Flow gauging weirs and riverine connectivity	19
7.1	Background	19
7.2	Study outline	19
7.3	Key findings	20
7.4	Management implications	20
	List of abbreviations	22

List of figures

Figure 2.1	Study reach in the lower River Stour, Suffolk, indicating key locations of silver eel loss and delay	4
Figure 3.1	Example of trajectories of downstream migrating adult eel through the forebay of a redundant hydropower facility	7
Figure 4.1	Operation pattern of hydropower facility over the study period	11
Figure 4.2	Woody debris and vegetation causing partial blockage in the lower section of the Larinier pass	11
Figure 5.1	Fyke netting for silver eels in Alton Water, Suffolk	13
Figure 5.2	Time taken to escape to the estuary after release by eels originating from the Alton Water and Hanningfield reservoirs and the River Stour	14
Figure 5.3	Time at which tagged and released eels originating from Alton Water and Hanningfield reservoirs and the River Stour escaped the freshwater Stour catchment	14
Figure 6.1	Schematic of the eel trap configuration used within the study	16
Figure 6.2	Total numbers of eel of 5 length classes captured in 4 traps (right bank, centre right, centre left and left bank) across Judas Gap weir, River Stour, June–August 2010	17
Figure 6.3	Plunging attraction flow delivered to the base of an eel pass	17
Figure 6.4	Recently constructed elver pass at Nieuwe Statenzijl, Netherlands, employing multiple plunging flow outlets at the downstream end of the pass to enhance attraction and passage	18
Figure 7.1	PIT telemetry configurations installed at 2 flow gauging weirs to track eel passage	20
Figure 7.2	Yellow eel (~300mm total length) attempting to ascend flow gauging weir after recent rainfall	21
Figure 7.3	Juvenile eel emerging from within the algal growth during the ascent of a flow gauging weir	21

1 Introduction

1.1 Background

Stocks of the European eel (*Anguilla anguilla*) have declined markedly, with estimated recruitment reduced to between 4 and 12% of 1980s levels in many rivers. As a result, the European eel is designated as 'critically endangered' and the stock considered outside safe biological limits.

As a facultative catadromous species, *A. anguilla* typically requires access to both marine and freshwater habitats to complete its life cycle. Barriers to migration such as weirs, dams and hydropower facilities, which prevent eels accessing suitable habitats, are thought to be a contributing factor in the decline. Furthermore, their elongated body shape and relatively poor swimming burst abilities means that eels are particularly vulnerable to damage and mortality at screens, water pumps and turbines.

1.2 Legislation

In response to the population decline, the European Union adopted Council Regulation 1100/2007/EC in 2007, establishing measures for the recovery of stocks of European eel. The Regulation required all Member States to produce Eel Management Plans (EMPs) detailing actions to meet the target to permit with high probability the escape to sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had affected the stock.

The Eels (England and Wales) Regulations 2009 (Statutory Instrument 2009 No. 3344) requires that:

- no new infrastructure be constructed, or existing structures modified, without provision for eel
- appropriate physical exclusion or alternative measures be provided at all potentially harmful water abstraction or flow points (>20m³ per day)

In addition, the Water Framework Directive (2000/ 60/EC) requires that water bodies meet good ecological status, of which unobstructed passage for fish is an important component. The presence of eel, where expected, contributes to the classification of fisheries when assessing ecological status.

1.3 About this report

This document provides a summary of a programme of research conducted between October 2009 to March 2015 to quantify the movement and behaviour of coarse fish and European eel in relation to the conditions encountered at riverine structures. The focus of the research was on the eel life stages most likely to encounter such structures, that is, immigrating juveniles and emigrating adults.

The main project partners and funders were the Environment Agency and the University of Southampton. Other collaborators included Cefas, Sembcorp, Essex and Suffolk Water, Anglian Water and partners within the Living North Sea project.

The project involved separate studies at different locations in East Anglia and Dorset. The topics covered were:

- the seaward migration of silver eels and their entrainment at water offtakes
- silver eel behaviour and hydrodynamics
- eel and fish behaviour and passage at an Archimedes screw hydropower turbine
- trap and transport of landlocked eels
- understanding juvenile eel responses to hydrodynamics to enhance upstream passage
- flow gauging weirs and riverine connectivity

Each of the next 6 sections gives the background to a particular study, an outline of the work, a list of key findings, a summary of the management implications, and details of any peer-reviewed papers or reports resulting from the work.

The findings have implications for wider catchment management and highlight the potential to reduce barrier impacts through the manipulation of structures and abstraction regimes. Quantifying eel behavioural response to physical and hydrodynamic environments at biologically relevant scales provides potential to aid the development of attraction, guidance and passage technologies for the species.

2 Seaward migration of silver eels and entrainment at water offtakes

2.1 Background

To meet EMP eel escapement targets, it is important to identify key locations of silver eel loss and delay during freshwater migration.

Silver eel migration typically occurs over short periods or 'runs' induced by environmental cues including increased river discharge, a fall in water temperature and the lunar phase. Barrier mitigation (for example, by opening spill gates) during these key periods is effective in increasing escapement.

The operation of sluices can influence route choice and the rate of eel migration. There is strong evidence that eels tend to make route selection choices based on those localities with the highest flow.

Knowledge of the physical and environmental conditions at structures that prevent or delay eel passage is crucial to identify and reduce restrictions to migration. In particular, there is limited understanding of the individual and cumulative effect of low-head structures that may be barriers for only some of the time.

2.2 Study outline

A study was conducted during 2009 and 2010 on the River Stour in Suffolk, a highly regulated lowland river. A total of 69 silver eels were captured, tagged with passive integrated transponder (PIT) and acoustic tags, and released. Their movements were tracked through a 9.2km reach that included:

- 12 cross-channel structures for water level management and navigation (weirs and locks)
- 2 water abstraction offtakes
- several points where the main channel bifurcates

The results were used to quantify:

- successful migration from the study reach to the sea
- time taken to escape
- barrier delay
- migration velocity
- entrainment loss
- route choice

2.3 Key findings

- Overall, 76% (in 2009) and 65% (in 2010) of tagged eels successfully migrated, taking between 5 and 113 days to reach the sea.
- The main cause of eel loss was entrainment at a water offtake (12% and 26% entrainment rate in 2009 and 2010, respectively). There was a positive correlation between loss and rapid increases in abstraction while eels were in the vicinity of the offtake.
- Migration speed was lower in obstructed reaches and eels were delayed at some structures for several days.
- The choice of route into the estuary depended on the height of spill over an intertidal weir combined with the opening regimes of a tidal gate at the termination of the alternative channel, and the abstraction rate at a nearby water offtake (Figure 2.1).

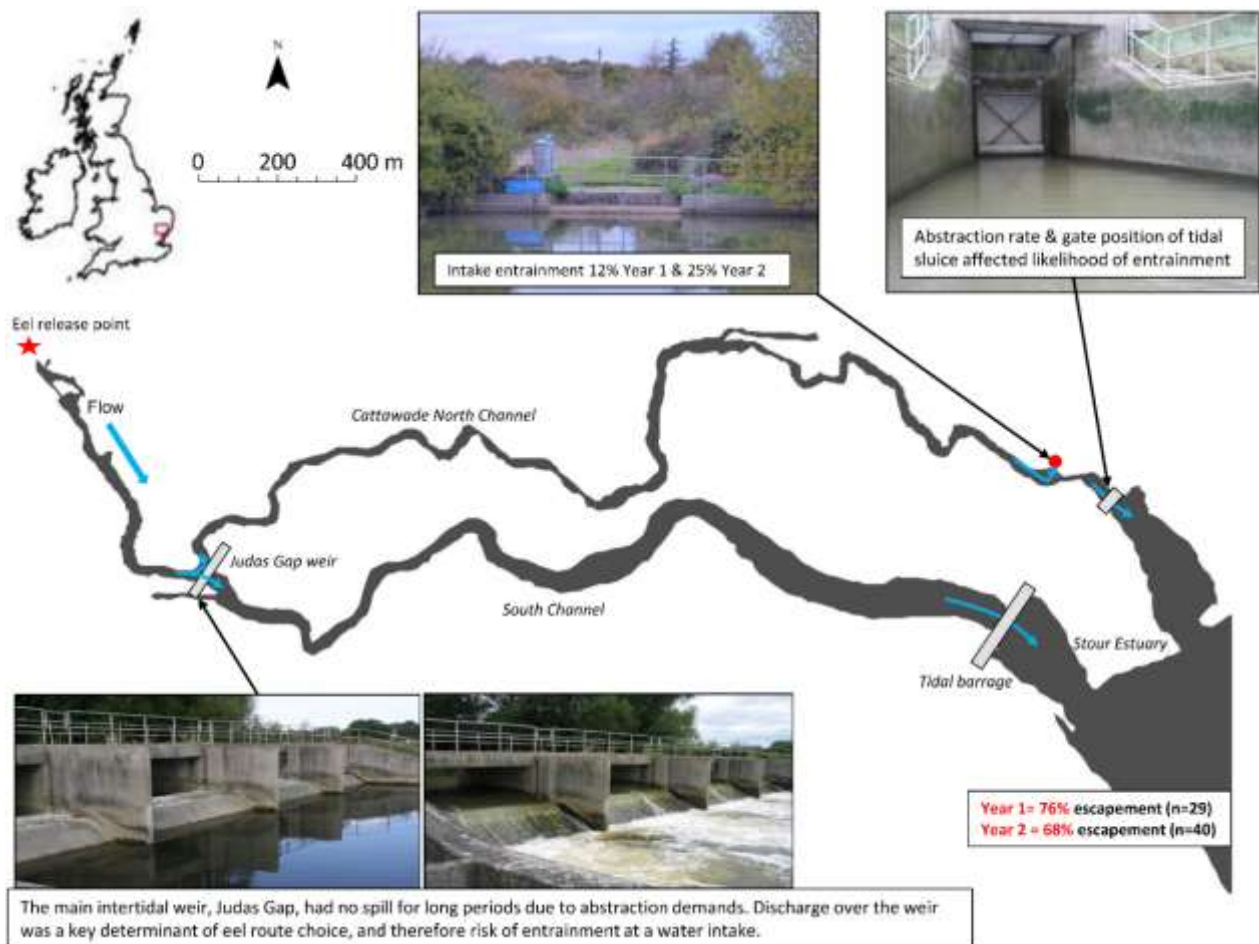


Figure 2.1 Study reach in the lower River Stour, Suffolk, indicating key locations of silver eel loss and delay

2.4 Management implications

- The Environment Agency will use data from the study to assess whether eel escapement targets are being met for the River Stour.

- Catchment managers can use the outputs to inform how to modify the operation of structures to reduce the mortality and delay of adult eel during their seaward migration. Adapting management regimes can be a cost-effective alternative to installing fish passage facilities.
- Distinct peaks in eel migration are typically observed and strategic non-pumping during these short periods can be highly effective at improving escapement.
- The abstraction rate was an important determinant of entrainment loss in this study. Cessation of abstraction during migration periods, combined with the opening of intertidal sluices, is likely to reduce eel loss.
- Where complete cessation of pumping is not viable, a slow start-up of pumps and provision of an alternate route of passage is likely to reduce entrainment loss at offtakes where eel entrance is volitional.
- Based on the recommendations of this research, adaptive management of water levels is now being implemented by the water company and screening of the deleterious intake in accordance with Environment Agency best practice is planned.

Peer-reviewed journal article

PIPER, A.T., WRIGHT, R.M., WALKER, A.M. AND KEMP, P.S. 2013. Escapement, route choice, barrier passage and entrainment of seaward migrating European eel, *Anguilla anguilla*, within a highly regulated lowland river. *Ecological Engineering*, 57, 88-96.

3 Silver eel behaviour and hydrodynamics

3.1 Background

Fish passes are widely used to restore and maintain connectivity for fish at river structures such as dams, weirs and sluices. However, their effectiveness is variable and sometimes low, particularly for non-salmonid species such as the European eel. To design effective fish passage solutions, fundamental knowledge of swimming capabilities is needed, combined with an understanding of behavioural response to environmental stimuli (both those that attract or repel fish).

During downstream migration, fish tend to move with the flow so it is expected that they will rely more on behavioural responses than swimming capabilities. The high proportion of river flow diverted through water offtakes (such as at hydropower plants or other abstraction points) presents a strong directional cue. Seaward migrating adult eels tend to follow routes of bulk flow and are particularly vulnerable to being entrained at water offtakes. Mitigation efforts and research have focused on physically excluding eels from harmful areas (for example, by installing screens across offtakes), but eels may still suffer damage and mortality by being impinged on screens.

Fish react to localised changes in flow-field characteristics including turbulence and velocity acceleration. The rapid acceleration of flow at constrictions such as at offtake channels and downstream fish bypasses can elicit rejection behaviour among downstream migrating juvenile salmonids; however, understanding is currently limited for other fish species. Eels are thought to be less sensitive to changes in velocity because previous flume studies have shown that they reject upstream after making physical contact with screens.

Greater understanding of how eels behave in the vicinity of structures such as water offtakes and respond to the hydrodynamics created around them is crucial for the development of better methods to deter eels from entering harmful areas and improving the design of bypass facilities.

3.2 Study outline

Acoustic positioning telemetry combined with high resolution flow mapping and modelling were employed in a 2-year field study to investigate the route choice and responses of silver eel to accelerating flow at a water offtake.

A total of 65 eels were tagged and released in the forebay upstream of a water offtake at a redundant hydropower plant on the River Stour, Dorset. In year 1, route choice over the 5 available passage routes was compared with that predicted by discharge alone. In year 2, flow at the offtake was manipulated to create 2 treatments:

- high velocity constricted flow
- low velocity unconstricted flow

Eel positions were logged every second as they passed through the study site. The resultant movement paths were analysed in relation to underlying flow velocities to explore behavioural responses to the local hydrodynamics.

3.3 Key findings

- The eels showed clear rejection behaviour on encountering accelerating velocities due to flow constriction in the vicinity of the water offtake. All individuals abruptly changed direction and swam upstream before turning and ultimately passing through the offtake (Figure 3.1).
- When velocity acceleration was lower, most eels changed direction and exhibited slower 'searching' movements immediately upstream of the offtake.
- Route choice did not correspond to the proportion of discharge passing each route. Eels were reluctant to pass underneath a floating debris boom, with individuals reacting by swimming back upstream or tracing along the upstream edge of the boom before passing by an alternate route.
- Movement paths were non-randomly distributed across the forebay. Before encountering structures, eels aligned with the flow and tended to move within a band 2–4m from the channel banks.

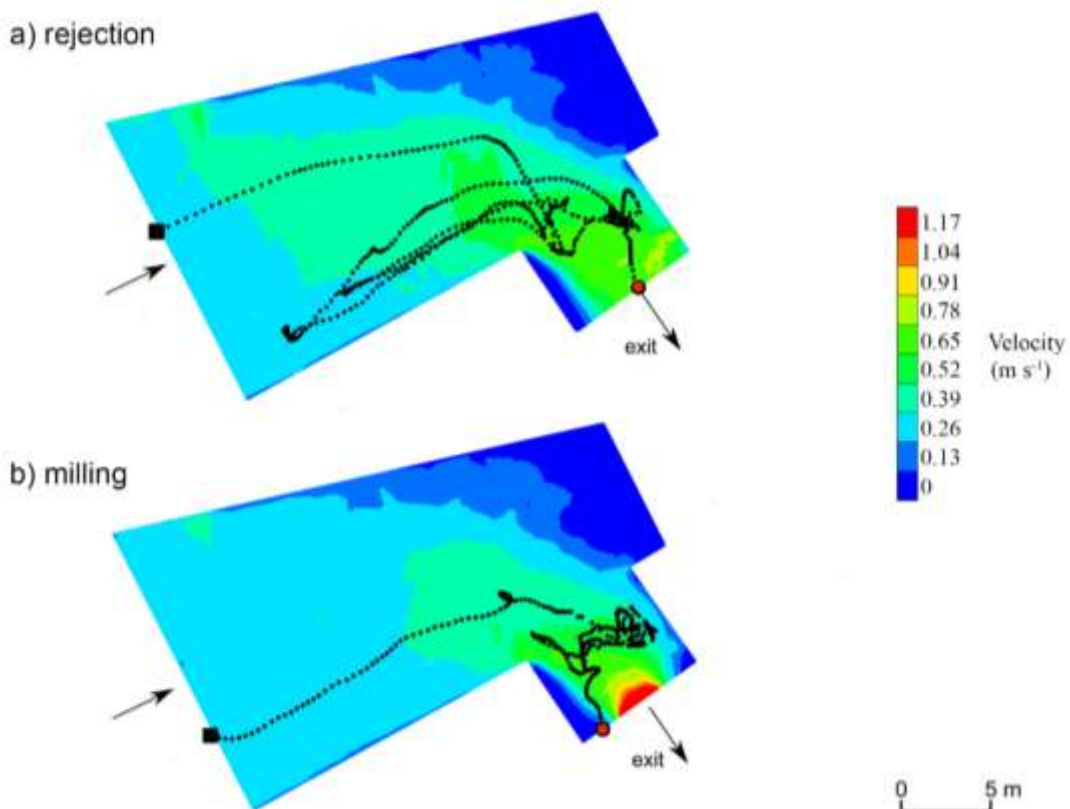


Figure 3.1 Example of trajectories of downstream migrating adult eel through the forebay of a redundant hydropower facility

Notes: Tracks show: (a) initial passive drift followed by milling/exploratory behaviour in the offtake channel under the unrestricted flow, low velocity treatment; and (b) initial passive drift followed by swimming back upstream at the offtake under the constricted flow, high velocity treatment. Black squares denote start locations of eel tracks; red circles denote point of passage. Flow direction is indicated by arrows.

3.4 Management implications

- The findings challenge historical preconceptions and reveal a strong behavioural component to downstream eel movements. This knowledge can be used to develop more effective guidance and passage solutions.
- Eel bypasses should be designed to avoid abrupt velocity acceleration at the entrance, as is currently advised for salmonids, with the aim of minimising rejection.
- Conversely, avoidance behaviours present an opportunity to guide eels away from dangerous areas and towards safe passage routes. The observed avoidance behaviours indicate a clear potential for hydrodynamic-based guidance and/or surface guidance devices to enhance the effectiveness of traditional physical screens. These can be expensive to install and maintain, reduce power generation or pumping efficiency, and may still induce fish damage and mortality through collision and impingement.

Peer-reviewed journal articles

PIPER, A.T., MANES, C., SINISCALCHI, F., MARION, A., WRIGHT, R.M. AND KEMP, P.S., 2015. Response of seaward-migrating European eel (*Anguilla anguilla*) to manipulated flow fields. *Proceedings of the Royal Society B: Biological Sciences*, 282 (1811), DOI: 10.1098/rspb.2015.1098.

PIPER, A.T., SVENDSEN, J., WRIGHT, R.M. AND KEMP, P.S., 2017. Movement patterns of seaward migrating European eel (*Anguilla anguilla*) at a complex of riverine barriers: implications for conservation. *Ecology of Freshwater Fish*, 26 (1), 87-98.

4 Eel and fish behaviour and passage at an Archimedes screw hydropower turbine

4.1 Background

Under EU renewable energy legislation, the UK had a target to produce 15% of its energy by renewable sources by 2015. Hydropower is expected to form a significant component of this. The most efficient types of turbines rely on substantial head drops and most opportunities for high-head hydropower in Europe have already been exploited. In response to government levies and feed-in tariffs, there has been a proliferation of small-scale low-head hydropower installations.

The impacts of high-head dams on fish have received much attention and include hindering or preventing migration. Other potential impacts on fish are damage and mortality caused by contact with the moving parts of the installation, most notably the turbine blades.

Although low-head hydropower facilities are perceived to be fish friendly, few studies have examined this, particularly for fish moving in the downstream direction. Information on potential impacts is urgently needed by regulatory bodies such as the Environment Agency to:

- underpin decisions within the consenting process
- effectively balance the need to increase renewable energy with legislative demands to maintain and improve connectivity for fish

4.2 Study outline

A study was conducted between March 2013 and March 2015 to investigate fish passage and behaviour at an Archimedes screw hydroelectric power (HEP) turbine and associated structures at Flatford Mill on the River Stour, Suffolk. The Flatford complex consists of the hydropower turbine, 6 undershot penstock sluice gates, a Larinier fish pass and 2 trough-type elver passes.

Fish were captured, PIT tagged and released upstream ($n = 442$ coarse fish, $n = 74$ yellow eels) and downstream ($n = 966$ coarse fish, $n = 216$ yellow eels) of Flatford Mill during 2013 and 2014. Their movements past the structures were monitored using an array of PIT antennas installed on all the potential passage routes. In addition, 127 actively migrating silver eels were tagged with acoustic transmitters and released upstream of Flatford Mill during autumn 2013 and 2014 to assess passage through the complex and overall escapement rate to the estuary. Fine-scale fish behaviour in the vicinity of the structures was investigated using a high resolution sonar camera (adaptive resolution imaging sonar, ARIS).

4.3 Key findings

- Overall, 18% ($n = 38$) of tagged coarse fish and 89% ($n = 50$) of yellow eel that approached downstream of the structures passed successfully upstream.
- The overall attraction efficiency of the Larinier fish pass was 64% and varied between species with >90% for chub, perch and pike; the lowest (27%) was for yellow eel. Passage efficiency ranged from 8% (roach) to 100% (dace).
- Behavioural observations of coarse fish shoals near the downstream entrance of the Larinier pass showed they rapidly dispersed when the HEP started up, but quickly habituated and returned to the area (typically within 2–5 minutes).
- The majority (82%) of downstream migrating adult eels passed via the lock as opposed to the HEP and fish pass complex. River discharge was a principal determinant of route choice.
- Of the eels that approached the HEP complex, only 10% passed with no apparent delay (that is, <4 minutes after first approach). Some individuals swam upstream before returning, and delays of up to 25.7 hours (median 1.8 hours) were recorded.
- Footage of adult eels from the sonar camera showed clear milling and rejection behaviour immediately upstream of the HEP complex during operation.

4.4 Management implications

- In low flow systems such as the one studied, there may be limited opportunity for power generation while maintaining effective upstream fish passage routes during the summer. Observations of fish behaviour and the timing of upstream passage suggest that periods of non-operation would be preferable to the frequent stop–start generation caused by rapid flow fluctuation during low discharge (Figure 4.1).
- There was no apparent mortality of those eels that migrated through the HEP complex before reaching the estuary. However, observed delay and milling/rejection in the vicinity of the complex suggests that such facilities have the potential to impose delay and energetic costs. This is particularly important in systems where there is no alternative migration route, that is, where schemes are ‘run of river’.
- For small freestanding sectional Larinier passes such as the one studied, it is essential that regular (that is, daily) checking/maintenance is carried out to prevent blocking by woody debris, particularly during peak migration periods (Figure 4.2).

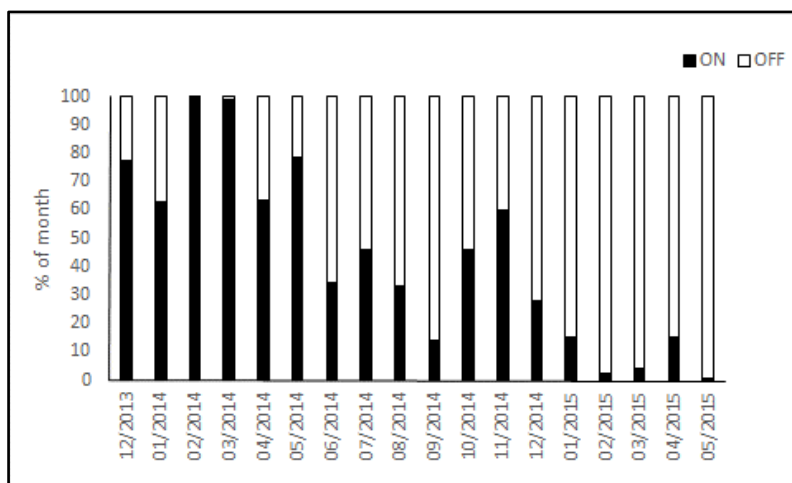


Figure 4.1 Operation pattern of hydropower facility over the study period



Figure 4.2 Woody debris and vegetation causing partial blockage in the lower section of the Larinier pass

5 Trap and transport of landlocked eels

5.1 Background

Large drinking water reservoirs potentially hold significant stocks of European eel. Eels may originate from a former watercourse or lake that was flooded during reservoir formation, or have subsequently been recruited into the system. Juveniles may enter such water bodies within natural gravity-fed or pumped water inputs if individuals are small enough to pass through screens and can survive passage through pumps.

For adult life stages, often the only means of connection between freshwater and marine habitats for seaward migration is via a dam/weir overflow or via pumps. Both options can be problematic. Dam spill is often limited and erratic, while pumped routes may not reconnect with a viable migration path. Furthermore, their elongated body morphology and poor swimming capabilities mean that adult eels are highly susceptible to damage and mortality at screens and pumps.

Trap and transport involves capturing adult eels during the natural migration period, and transporting and releasing them at a location with good connectivity to the sea. This approach has been proposed as a feasible and more cost-effective method of facilitating adult eel migration from reservoirs than the provision of fishways. Although this approach is increasingly used in river systems to reduce eel mortality at hydropower and pumping facilities, the feasibility of trap and transport to enhance adult eel spawner stock from landlocked water bodies has not previously been investigated. It is not known whether eels from reservoirs would migrate naturally when translocated, or remain resident in a river system and potentially impact the ecology.

5.2 Study outline

A telemetry study was conducted October 2014 to February 2015 in which adult eels ($n = 80$) were captured from 2 reservoirs (Alton Water, Suffolk, and Hanningfield Reservoir, Essex) (Figure 5.1), transported, tagged with PIT and acoustic transmitters, and released into the lower River Stour, Suffolk. Movements of translocated individuals were compared with those of a tagged control group of actively migrating adult eels ($n = 30$) captured from the River Stour.

5.3 Key findings

- Overall, 88% of reservoir eels and 90% of river eels migrated through the 25km study reach and into the sea. The source of eels did not affect either their propensity to migrate or their route choice through the freshwater catchment.
- Eels took between 2.48 hours and 62.51 days to reach the estuary (Figure 5.2), with movements almost exclusively occurring in the hours of darkness between 17:00 and 05:30 (Figure 5.3). River discharge was the most important determinant of the time taken to escape.

- River eels travelled faster through an unobstructed reach than individuals translocated from the reservoirs, although they generally had a smaller body and some took longer to escape.

5.4 Management implications

- The findings indicate that trap and transport of adult eel from disconnected reservoirs to nearby catchments represents a feasible method of enhancing local spawner escapement without having a negative impact on the ecology of the receiving river.
- Trap and transport schemes are generally considered a short-term solution to facilitate the seaward migration of adult eels, while other mitigation measures such as screening of pumps and installation of fish passes are implemented for the long-term management of the stock.
- The catch per unit effort of one study reservoir was low, requiring high fishing effort. The findings highlight the importance of understanding eel abundance and population structure in a reservoir in order to design an effective trap and transport programme.



Figure 5.1 Fyke netting for silver eels in Alton Water, Suffolk

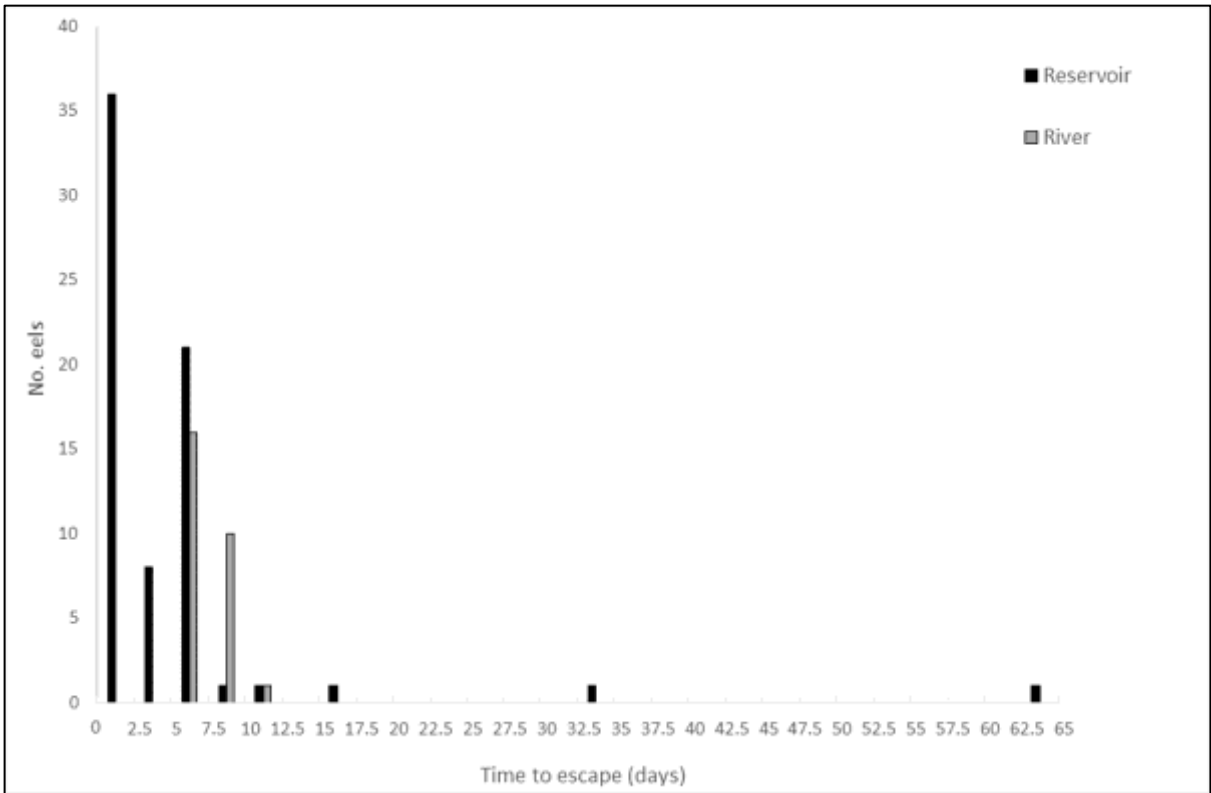


Figure 5.2 Time taken to escape to the estuary after release by eels originating from the Alton Water and Hanningfield reservoirs and the River Stour

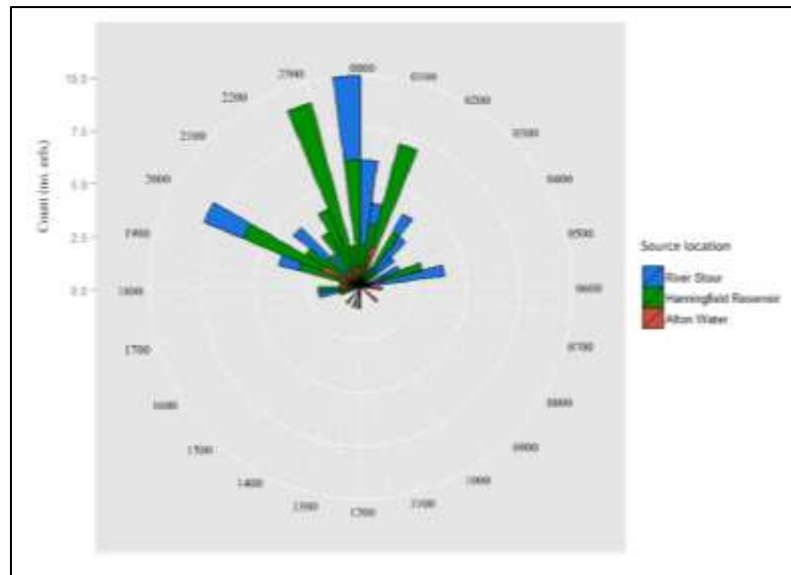


Figure 5.3 Time at which tagged and released eels originating from Alton Water and Hanningfield reservoirs and the River Stour escaped the freshwater Stour catchment

Notes: Time is that when the eels were first detected in the estuary.

6 Understanding juvenile eel responses to hydrodynamics to enhance upstream passage

6.1 Background

European eels migrate upstream into freshwater systems as juveniles (glass eels and elvers). Glass eels move up tidal estuaries and rivers using coastal currents and tidal stream transport, while the larger pigmented glass eels and elvers swim actively upstream in response to flow and olfactory cues.

Tidal barriers and other water control structures are widespread in European catchments for both flood alleviation and retention of water for abstraction. However, they may severely restrict upstream eel migration. Upstream eel passes (or eel ladders) are widely installed to enhance immigration and have been shown to aid the recovery of freshwater eel stocks. There is little consensus, however, as to the optimum pass positioning or attraction conditions that should be present to maximise efficiency.

For a fish pass to be effective, conditions should be such that fish are guided to the entrance (attraction) and then compelled and able to rapidly ascend (or descend) the pass. Effective fish pass design therefore relies on a thorough knowledge of the conditions that attract (or repel) fish and their swim capabilities. A field and a flume study were conducted to:

- test the effectiveness of attraction flow on upstream eel pass efficiency
- assess the influence of water velocity and turbulence on the movements and swimming capabilities of juvenile European eel

6.2 Study outline

In a field study conducted over 11 weeks in 2010, 4 upstream eel traps were deployed across the main intertidal barrier on the River Stour in Suffolk. Attraction flow was delivered to each pass entrance either overhead as 'plunging flow' or underwater as 'streaming flow' (Figure 6.1). The numbers of eels that passed daily under each treatment were compared (Figure 6.2).

A field flume was used to make fine-scale observations of the swimming behaviour of juvenile eels presented with 'plunging' and 'streaming' attraction flow under both low and high background flow conditions.

6.3 Key findings

- Plunging flow (Figure 6.3) was over 2 times more effective at attracting juvenile eels to the pass than streaming flow.

- More eels, particularly the smallest size classes, ascended the passes located near the channel banks (Figure 6.4).
- Eels selected routes that avoided the highest intensities of turbulence and flow velocities.

6.4 Management implications

- The findings showed that simple manipulation of hydrodynamic conditions can modify juvenile eel behaviour and significantly enhance passage efficiency.
- The provision of plunging attraction flow, which creates turbulent conditions near the pass entrance, should become a standard design feature for upstream eel passes (Figure 6.4). However, there is a trade-off. Turbulence and flow velocities within the pass itself should be within the swim capabilities of the smallest life stages and should not deter eels from ascending.
- To maximise recruitment, upstream eel passes should be preferentially located near the channel banks.

Peer-reviewed journal article

Piper, A.T., Wright, R.M. and Kemp, P.S., 2012. The influence of attraction flow on upstream passage of European eel (*Anguilla anguilla*) at intertidal barriers. *Ecological Engineering*, 44, 329-336.

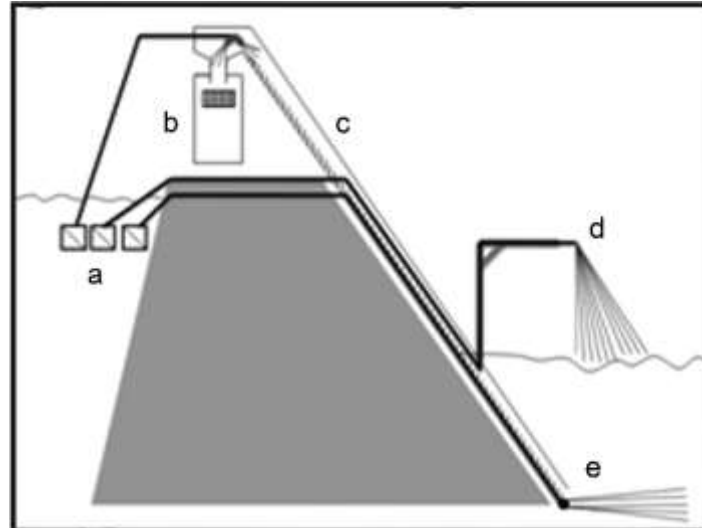


Figure 6.1 Schematic of the eel trap configuration used within the study

Notes: Submersible pumps (a) supply conveyance flow to the catch pot (b) and bristle-lined climbing trough (c), and flow to experimental treatments, plunging flow (d) and streaming (e).

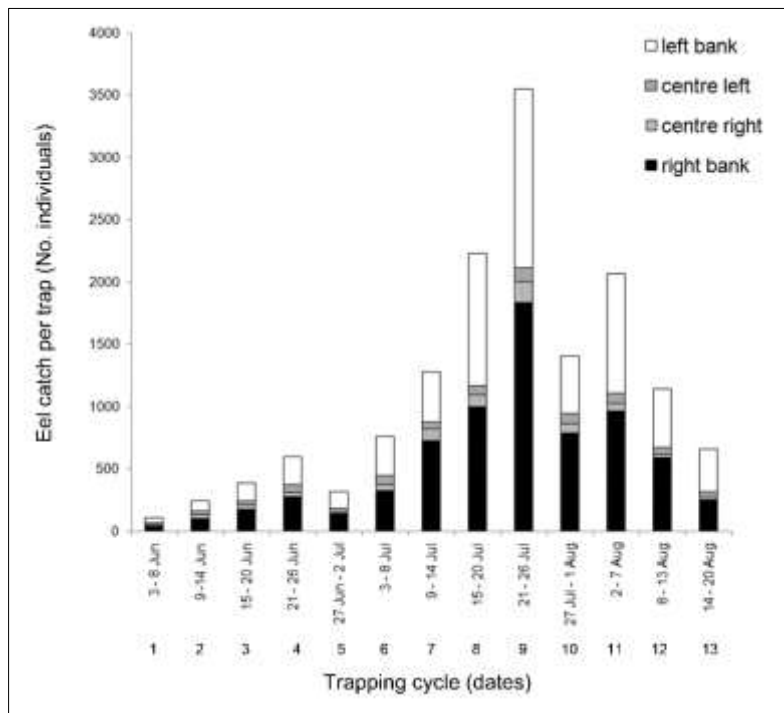


Figure 6.2 Total numbers of eel of 5 length classes captured in 4 traps (right bank, centre right, centre left and left bank) across Judas Gap weir, River Stour, June–August 2010



Figure 6.3 Plunging attraction flow delivered to the base of an eel pass



Figure 6.4 Recently constructed elver pass at Nieuwe Statenzijl, Netherlands, employing multiple plunging flow outlets at the downstream end of the pass to enhance attraction and passage

Notes: Photo courtesy of Peter Paul Schollema

7 Flow gauging weirs and riverine connectivity

7.1 Background

The UK has a network of over 1,500 active flow gauging stations for the purposes of hydrometric monitoring, with the majority owned and operated by the Environment Agency.

The designs of flow gauging stations vary greatly and gauging increasingly occurs in open channel sections of river. However, the majority of flow gauging stations still consist of some form of weir, typically creating a head drop, located within an engineered channel. Water levels upstream, and in some cases downstream, are logged at fixed intervals enabling real-time determination of channel discharge through the structure.

There is concern that flow gauging structures may represent barriers to the free movement of fish. In Europe, the Water Framework Directive and Eel Regulations and, in the UK, the forthcoming Fish Passage Regulations all require managers to improve habitat connectivity for fish. Riverine structures are therefore being assessed for both functional necessity and porosity to fish. Those deemed redundant may be removed and mitigation will be necessary for others (for example, reducing head drop, modifying surface material, installing fish passes). Even relatively minor structures such as culverts and low-head weirs cause habitat fragmentation for fish species. To mitigate for potential impacts, there is a need to understand which structures pose a barrier to fish and the conditions (for example, flow rate, seasonality) under which this occurs.

7.2 Study outline

A telemetry study was conducted from 2011 to 2015 to investigate eel and trout passage at 2 flow gauging stations on the River Stiffkey in Norfolk. A total of 853 eels (142–572mm in length long) were captured by electrofishing. They were then PIT tagged or marked with visible implant elastomer (for those individuals too small for PIT tags) and released up or downstream of the gauging stations.

Eel movements were monitored using fixed PIT antennas that recorded when tagged individuals passed the flow gauging structures (Figure 7.1) and by recaptures during subsequent electrofishing sessions.

Movement data were analysed in relation to concurrent environmental data (river discharge, water temperature) to:

- quantify passage efficiency at each structure (approaches versus successful passage)
- explore seasonal activity patterns
- determine the effect of environmental conditions on passage success

7.3 Key findings

- Some 37% and 18% of PIT tagged eels from the study reaches directly downstream of Warham and Little Walshingham flow gauging stations were detected, respectively. Some 91% and 67% of these subsequently passed upstream, respectively.
- Passage attempt detection peaks occurred at discrete periods of higher flow (that is, rainfall events) during summer and early autumn (Figure 7.2).
- Between 1 and 73 separate passage attempts were detected before successful upstream passage.
- Few movements and no successful passage events occurred during the winter months – high flows and reduced temperatures induce more sedentary behaviour in juvenile and yellow eel life stages.

7.4 Management implications

- Although both flow gauging stations investigated were passable to eels of the size classes tagged, there was evidence of barrier effect and delay, particularly during low flow events.
- It is essential that the potential mitigation options available to enhance fish passage at flow gauging stations do not significantly alter the profile of the structure and thereby reduce the accuracy of gauging.
- ‘Bristle passes’ in which bristle boards are side-mounted to a wing wall to facilitate eel ascent are acceptable in certain circumstances. Where bristle passes are not suitable, ‘up and over’ passes in which sections of modular trough/gutter lined with bristle substrate form a sloping pass that circumvents the entire length of the structure may be the only option.
- Recent work indicated that altered weed clearing regimes to leave a strip of algal growth at flow gauging stations has the potential to enhance eel passage by providing a climbing substrate (Figure 7.3), though the influence on gauging requires further investigation.

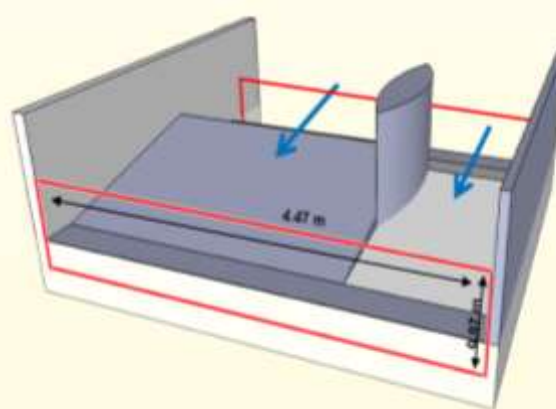


Figure 7.1 PIT telemetry configurations installed at 2 flow gauging weirs to track eel passage



Figure 7.2 Yellow eel (~300mm total length) attempting to ascend flow gauging weir after recent rainfall



Figure 7.3 Juvenile eel emerging from within the algal growth during its ascent of a flow gauging weir

List of abbreviations

EMP	Eel Management Plan
HEP	hydroelectric power
PIT	passive integrated transponder

**Would you like to find out more about us
or about your environment?**

Then call us on

03708 506 506 (Monday to Friday, 8am to 6pm)

email

enquiries@environment-agency.gov.uk

or visit our website

www.gov.uk/environment-agency

incident hotline 0800 807060 (24 hours)

floodline 0345 988 1188 / 0845 988 1188 (24 hours)

Find out about call charges: www.gov.uk/call-charges



Environment first: Are you viewing this on screen? Please consider the environment and only print if absolutely necessary. If you are reading a paper copy, please don't forget to reuse and recycle if possible.