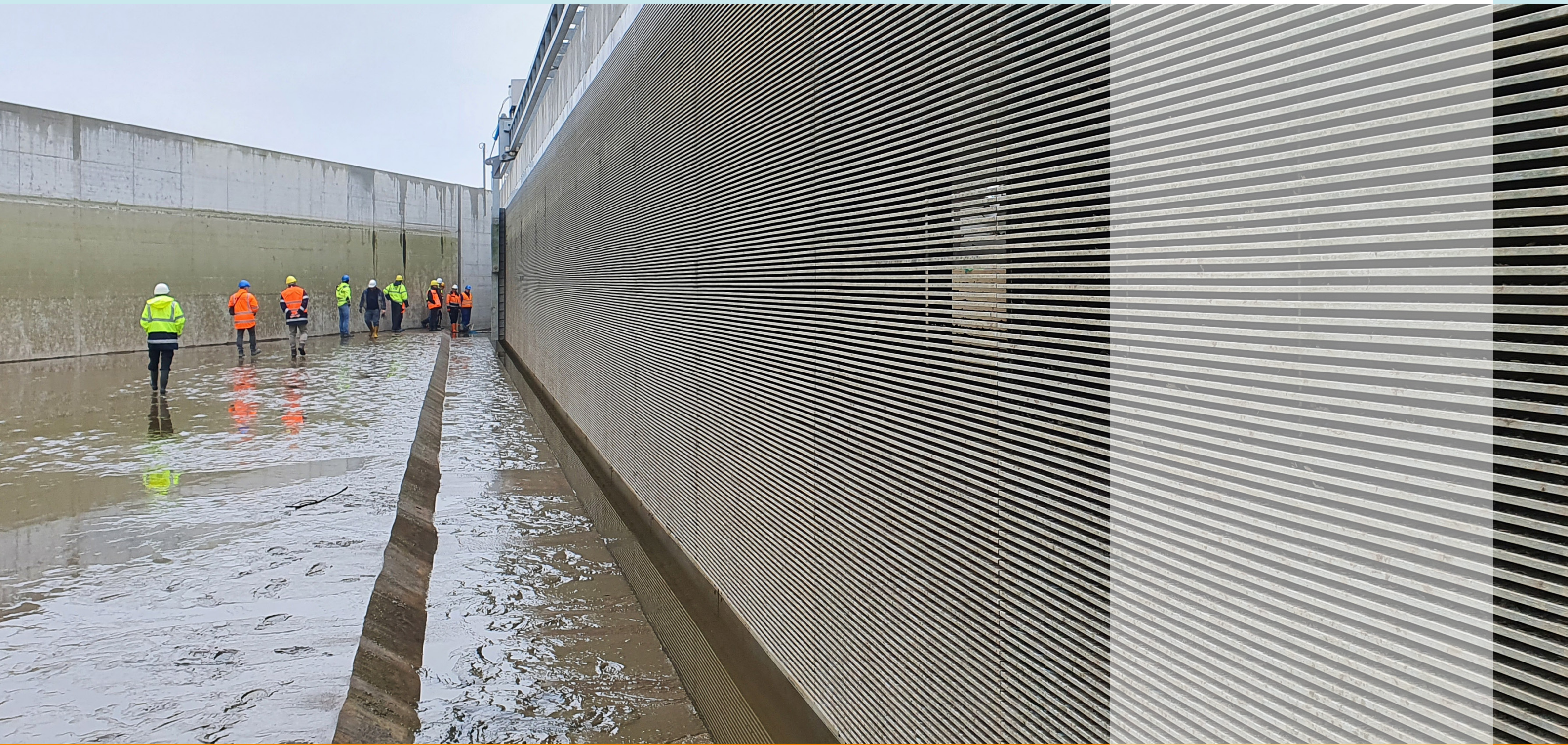
**Fact Sheet 05 EN**
June 2021

FORUM FISCHSCHUTZ & FISCHABSTIEG

# What makes a screen to a fish protection screen?

The functional components of a fish protection system



## Key messages

- A fish protection system must provide three functions: Blocking, guiding and transferring.
- Fish protection screens and bypasses form a functional unit in fish protection systems. Screens without bypasses or bypasses without a suitable screen do not constitute a protection system.
- Horizontally angled fish protection screens guide fish across the entire water column to the bypass. The fish can remain in their natural swimming horizon.
- Vertically angled fish protection screens can guide fish to bypass inlets or collection devices near the surface across the entire width of the turbine inlet.

## In fish protection systems, fish protection screens and bypasses form a functional unit

Mechanical barriers at hydropower sites are becoming increasingly important for the protection of fish and lampreys (in the following simplified assigned to fish). The task of trash racks in front of turbines has traditionally been to retain debris to protect the turbines from damage. Protecting fish at hydropower sites from entering turbines by means of screens, was added as a new function. This requirement is reflected in the current German Federal Water Act (Wasserhaushaltsgesetz, WHG 2009) and the German Federal States fishery laws (see Fact Sheet 02 [German]). Traditional screens for debris retention usually do not protect fish sufficiently.

There are proven and effective technical solutions for the retention and transfer of debris. Preventing fish from swimming into turbines by means of screens proves to be much more complicated. The problems here lie primarily in the protection of small fish, with low swimming performance and the transfer of the fish to the tailwater without great delay or additional physical stress. Simply reducing the bar spacing of existing screens typically is not a good solution. A screen with the function of a fish protection screen always forms a functional unit with the mandatory bypass as an alternative downstream migration corridor in the fish protection system. Separately and isolated from each other, both components are usually ineffective. Screens and bypasses must be closely harmonized with each other. An effective fish protection system must fulfill three basic functions:

» **Blocking**
  Prevent fish from entering the turbine

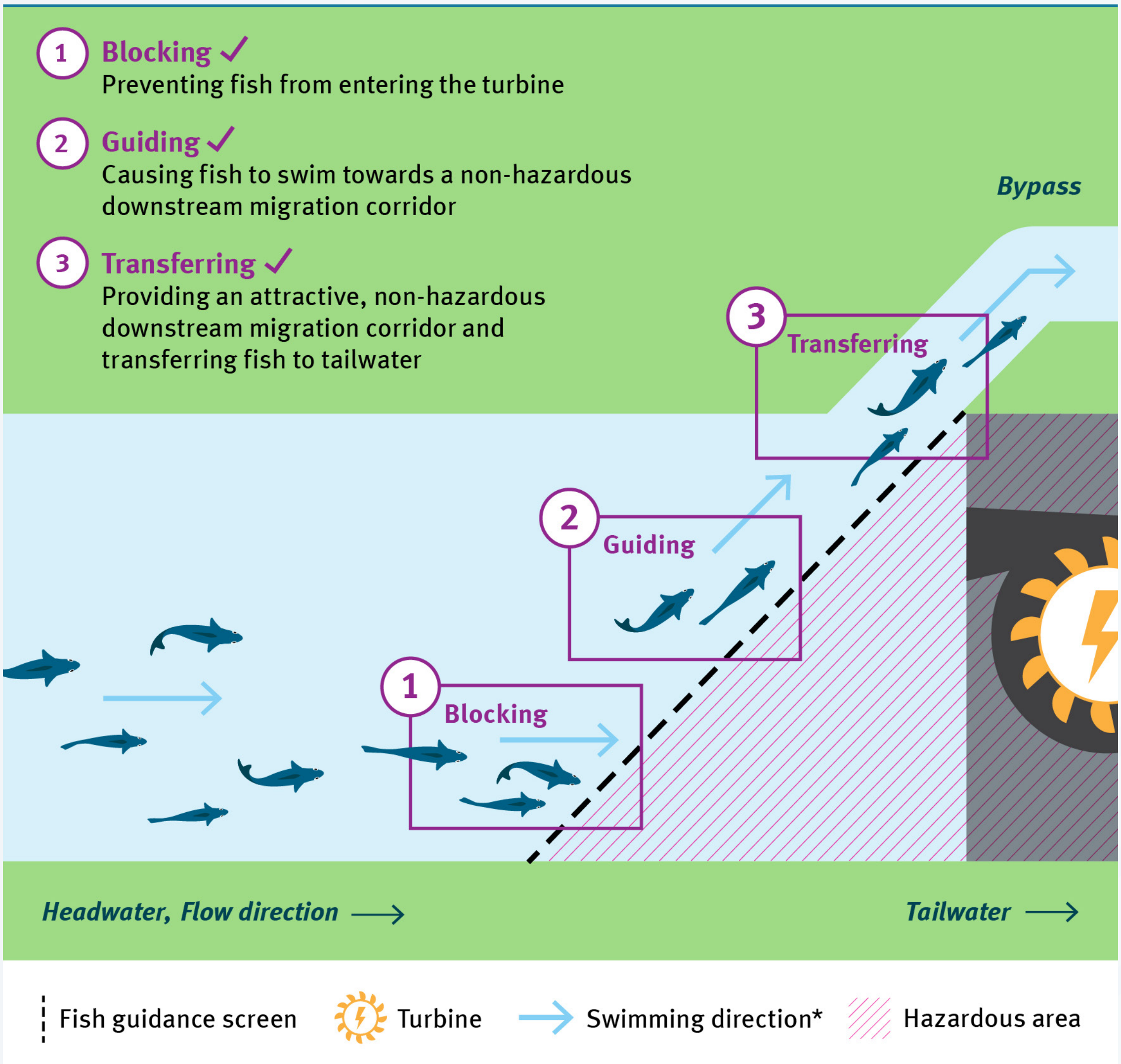
» **Guiding**
  Cause fish to swim along the screen toward a non-hazardous downstream migration corridor

» **Transferring**
  Provide an attractive, non-hazardous downstream migration corridor and harmless transfer of fish to tailwater

## Blocking

Screens can prevent fish from swimming into turbines. Target fish species and stages whose maximum body cross-section diameters exceed the bar spacing of a screen cannot physically pass through it. However, with the current state of the art (see Fact Sheet 04 EN), a sufficiently reliable mechanical blockade is only feasible for larger target species or stages, for example silver eels, salmon smolts or catfish and pike from the first year of life. If all fish species and stages occurring, for example in Germany were to be protected by screens with a protection efficiency of 100%, a bar spacing of less than 2 mm would be necessary.

### Functions of a fish protection system




Schema (top view) of the three functions of a fish protection system: blocking, guiding, transferring.

* Fish pictograms are simplified. Most fish species usually keep their positive rheotactic orientation when approaching fish protection screens.

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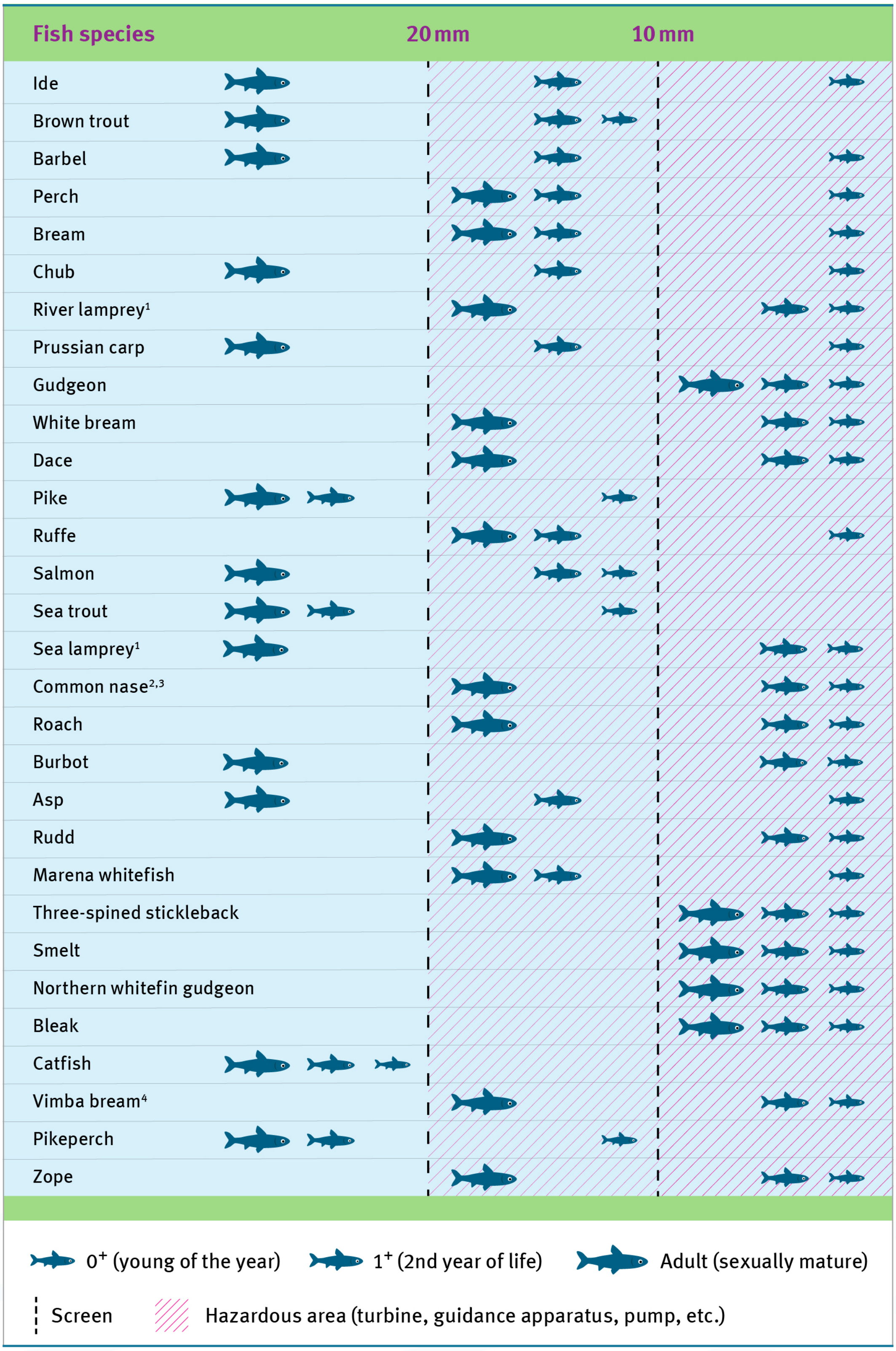
The legislation of many German Federal States demands maximum bar spacing of ≤20 mm for the protection of fish. In waters with special designations, e.g. for the protection of diadromous species, smaller bar spacing of 10 to 15 mm are required (see Fact Sheet 02 [German]). Fish protection screens with bar spacing ≤10 mm, which would be required to protect fish of a wide range of species and a minimum age of one year, are technically feasible but have rarely been implemented (see Fact Sheet 04 EN).

## Passability oft 20- and 10 mm screens

Permeability for juveniles and adults of different fish species




[1] 0+ and 1+ animals living as larvae in the sediment, therefore rather low mobility
[2] Data 0+ length according to Hauer et. al. 2008
[3] Data adult length according to Ebel 2013,
[4] Data according to Lusk et al. 2005

Data source for all other species: Schwevers & Adam 2020

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## Finding

- Fish protection screens with bar spacing of 20 mm (see Fact Sheet 02 [German]) are passable by adults of many species, as well as the majority of $0^+$ and $1^+$ fish.
- Fish protection screens with bar spacing of 10 mm are not passable by adults of numerous potamodromous species, and by salmon from age 1. Yet, protection of the vast majority of $1^+$ and $0^+$ fish is not provided (see Fact Sheet 02 [German]).
- If all adult fish included in the infographic „Passability of 20 and 10 mm screens“ were to be protected, the bar spacing would have to be less than 4.7 mm (Three-spined stickleback measurement type*). To protect all age 2 and older fish (> $1^+$), spacing would be required to be less than 3.1 mm (measurement type smelt*) and for all age 1 and older fish (> $0^+$), spacing would be required to be less than 1.2 mm (measurement type smelt*).

* Calculation of body width using functions from Schwevers and Adam 2020. Lampreys are not included because they live as larvae in the sediment at the $0^+$ and $1^+$ stages and tend to show low mobility.

For a screen to become a fish protection screen, another protective effect is relevant in addition to physical impassability. Screens can be perceived by fish via hydraulic, tactile and visual stimuli which can trigger an avoidance reaction (Ebel 2013). Thus, a screen can cause a behavioral blockage in addition to a physical one (Wagner 2016, de Bie et al. 2018, Wagner et al. 2019, Meister 2020). Through this effect, protection efficiency of 90.5% for rainbow trout (Simmons 2000) and up to 92.5% for salmon (Travade & Larinier 2006), for example, have been demonstrated at hydropower sites. A higher approach flow velocity may enhance the avoidance reaction (Gosset et al. 2005, Meister 2020). Nevertheless, flow velocity must be low enough to allow fish to actively swim upstream at any time without exceeding their continuous swimming velocity. This is especially true for physically impermeable screens. Otherwise, there is a high risk for the animals to be pressed against the barrier. If they are injured or killed as a result, this can, in the worst case, cause more severe damage than the turbine passage. Specific design recommendations for screens in relation to the approach flow velocity and the bar spacing can be found in DWA (2005) and Ebel (2013).

### ★ Recommendation

- A fish protection screen should have a bar spacing that is physically impermeable to the site-specific target species and stages.
  Because of its behavioral effects, smaller fish can be protected, too.
- Physically impermeable screens may cause a high risk of injury at high approach flow velocities. Approach flow velocity and bar spacing should each be matched to each other and to the swimming ability of the target fish species.
- When optimizing behavioral blockage, approach flow velocity, approach flow angle, bar orientation, and screen geometry must be considered. Further systematic studies are needed to derive generally applicable recommendations for optimizing the behavioral protection function.

## Guiding

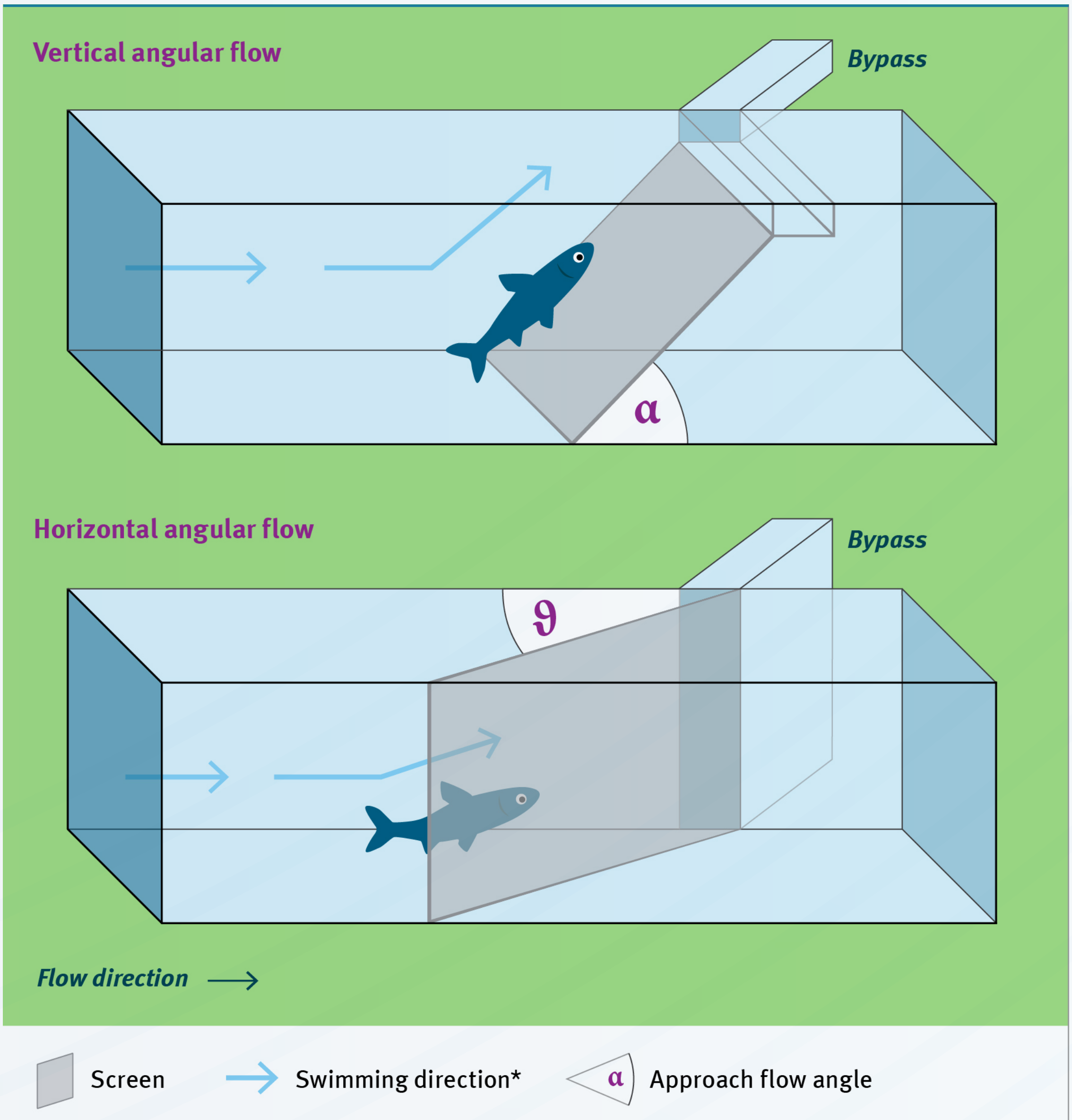
While blocking at the fish protection screen protects fish from injury during turbine passage, it also fundamentally prevents downstream fish migration into the tailwater, which is necessary for population biological reasons. Therefore, regardless of any physical or behavioral blockage function, a **fish protection screen** must guide the fish toward a safe downstream migration corridor. In addition to the approach flow velocity, which must match the swimming ability of the target species at the site, an angular flow towards the screen is crucial for this.

Screens positioned at right angles to the flow direction, as can be found in many existing sites (Schwevers & Adam 2020), do not have a guiding effect. There is often an evasive movement against the flow, which is followed by a drift back to the screen. This causes fish to reach different screen areas, so that bypass inlets are at best and under favorable conditions only found by chance by individual fish (Wagner 2016). There is no targeted guidance towards safe migration corridors.

An angled arrangement of the fish protection screen in relation to the approach flow is crucial for a guidance effect. The approach flow angle required to guide fish efficiently towards bypasses, with as little loss of time and energy as possible, depends on the inclination direction of the screen, its length and its approach flow velocity. Design recommendations for fish screens are given in DWA (2005), Courret & Larinier (2008), Ebel (2013) and Fjeldstad et al. (2018).

For **horizontally angled fish protection screens**, an angle of <45° is recommended (Ebel 2013). At this angle, fish are guided downstream along the barrier without changing their natural swimming horizon. No evidence is yet available on the maximum guiding distances in practice (see Fact Sheet 04 EN). Bed baffles and near-surface baffles can enhance the guiding effect for bed- or near-surface migrating fish (Ebel 2013). Studies of **vertically angled fish protection screens** suggest that an approach flow angle of less than 45° should be used (Calles et al. 2013, Schwevers & Adam 2020). But angles of less than 25° improve the guiding effect considerably (Cuchet 2014). Courret & Larinier (2008) recommend ≤26°.

### Inclination directions and approach flow angles of fish protection screens relevant for guiding function




Fish protection screens with vertical angular flow have a guiding effect towards the surface and guide the fish to the bypass close to the surface. Fish protection screens with horizontal angular flow have a lateral guiding effect towards the bypass. The approach flow angles of the screens have a decisive influence on their guiding function (horizontal approach flow angle $\vartheta$, vertical approach flow angle $\alpha$).

* Fish pictograms are simplified. Most fish species usually keep their positive rheotactic orientation when approaching fish protection screens.

Source: modified after Ecologic Institute & IGF Jena 2015

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If the fish follow these fish protection screens, which are inclined towards the water surface, they are forced to leave their original swimming horizon – except for those swimming near the surface. For strongly bed-oriented species such as eel, the guiding effect towards near-surface bypasses may be limited (Gosset et al. 2005, Travade et al. 2010). Results of ethohydraulic laboratory experiments showed that horizontally angled fish protection screens have a better guiding effect than vertically angled ones at moderate approach flow velocity (Russon et al. 2010, de Bie et al. 2018). At real hydropower sites with much larger water depths in the headwater, this effect might even be more pronounced, as fish must deviate further from their natural swimming horizon here. However, results of comparative studies at hydropower sites are not available. For physically impassable, horizontally angled fish protection screens, a high guiding efficiency of 95% has been documented for eels in field studies (Calles et al. 2015), and 82% for vertically angled screens (Calles et al. 2013).

**★ Recommendation**

» Mechanical barriers should have an approach flow angle $< 45°$ . This is a prerequisite for not only blocking the corridor into the turbines, but also guiding fish out of the hazardous area.

» At horizontally angled fish protection screens, fish can remain in their original swimming horizon when guided to a bypass compared to vertically angled fish protection screens.

## Transferring

In addition to the fish protection screen, a fish protection system must include permanently functioning downstream migration corridors, which are referred to simply as bypasses in the following. They must be easily found by the fish. The transition area from the headwater as well as the corridors themselves must represent an attractive way downstream for the fish. They must not trigger avoidance behavior and must be free of injury risks.

Bypass inlets must be placed exactly where the fish are guided by the fish protection screen. Therefore a position directly at the downstream end of the screen is crucial. If the bypass inlet is located laterally or offset towards the headwater, the ability of fish to locate the bypass may be severely limited (Wagner et al. 2019). The consequence is, at very least, a delay in the downstream migration process. In the worst case, the bypass is not found and fish swim to the screen again. The originally good guiding effect of a screen can diminish significantly after multiple unsuccessful attempts to migrate downstream (Wagner et al. 2019).

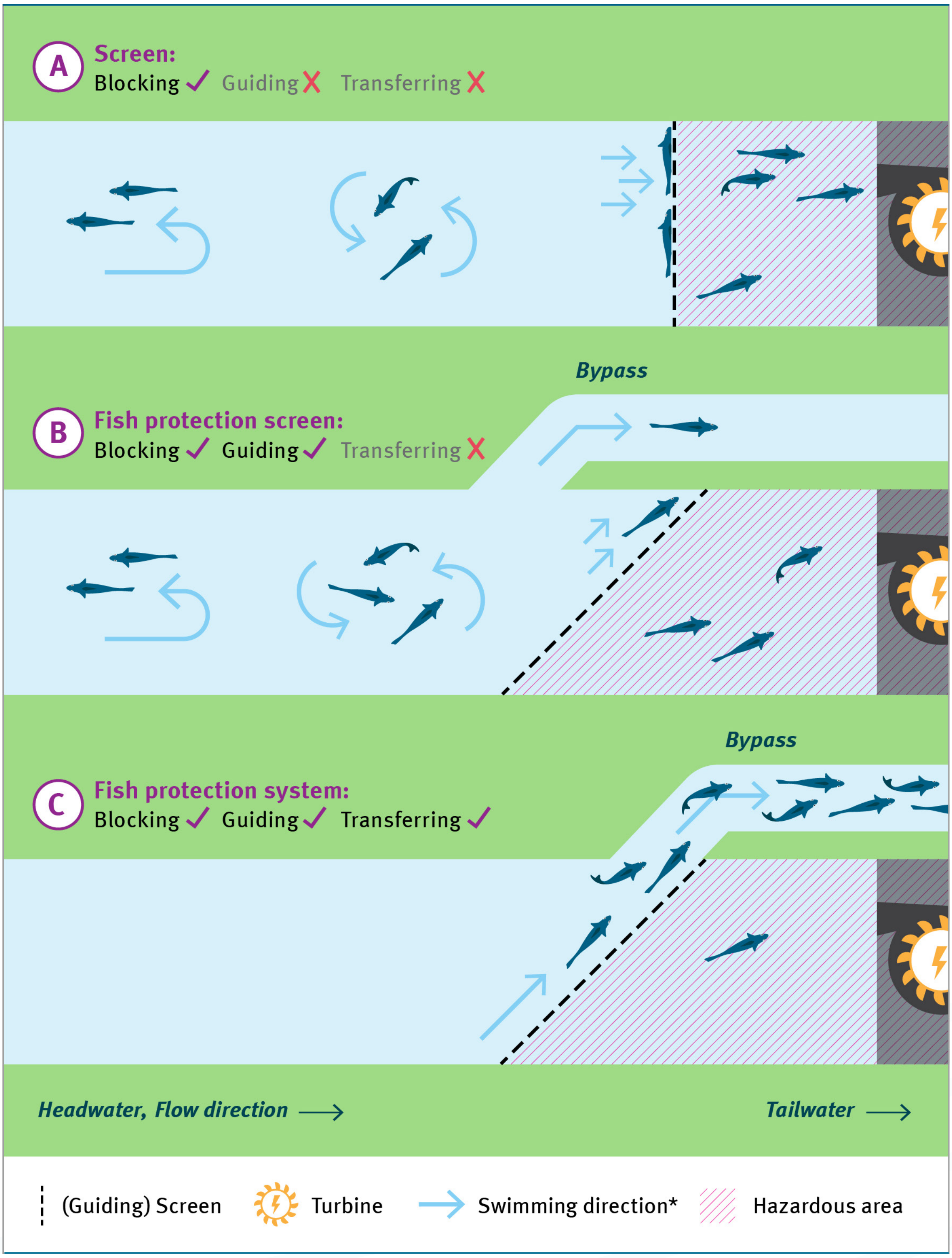
If all fish species are to be successfully transferred into the tailwater, neither a single near-bottom nor a near-surface bypass inlet is usually sufficient (Ebel 2013, Wagner 2016, Fjeldstad et al. 2018, Schwevers & Adam 2020). A continuous bypass inlet across the entire water column would be optimal. If this is not possible, several bypass inlets must be provided distributed throughout the water column, but at least near the bottom and surface, depending on the water depth. Depending on the system, it is possible to guide bed-oriented species to near-bottom bypass inlets with horizontally angled fish protection screens. With vertically angled fish protection screens, however, fish are always guided towards the surface and thus away from bypasses near the bed. An exception are eels, for which evasive movements close to the bed are documented in the case of initial screen contact, so that they can be guided into special bypass systems (Schwevers & Adam 2020).

In addition to the positioning of the bypass inlet, its dimensions and the hydraulic situation upstream and in the bypass determine whether fish pass it without delay. Strong flow gradients trigger avoidance reactions (Enders et al. 2012, Vowles & Kemp 2012, Wagner 2016). Dead water zones between screens and bypass inlets reduce their detectability (Wagner et al. 2019). At one site, this and unfavorable flow conditions at the inlet and further course of the bypass resulted in only 12% of the fish being guided to the screen end reaching the inlet despite the good guiding effect, and again only 23% of these animals entered the bypass (Wagner et al. 2019). However, such differentiated results from field studies are rarely available. When using radio or acoustic telemetry for fish bypass studies, the aspects of detectability and entering rate are usually integrated into the guiding efficiency parameter. A clear separation from the pure guiding effect is then not possible.

### ★ Recommendation

- Bypass inlets shall be located directly downstream of the fish protection screen.
- Dead water zones between fish protection screens and bypass inlets limit their ability to be found.
- Optimally, a bypass inlet would be continuous throughout the entire water column. If this is not possible, several bypass inlets must be provided throughout the water column, depending on the water depth, but at least close to the bottom and surface.
- Strong flow gradients upstream of and in bypass inlets must be avoided.
- Bypass passage must be free of risks of injury.

## A simple screen is not a fish protection system




A fish protection system always consists of a fish protection screen and a bypass, designed as a functional unit.

* Fish pictograms are simplified. Most fish species usually keep their positive rheotactic orientation when approaching fish protection screens.

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## A screen is not a fish protection system

A **screen** alone is basically not a fish protection system and does not reliably protect fish from injury. As a component of a **fish protection system**, it is only effective if it can develop a guiding effect through angular flow. As a **fish protection screen**, it guides the fish away from the hazardous area and towards the second component of the **fish protection system**, the bypass. In the best case, the fish reach the bypass inlet directly in front of a clearly detectable bypass inlet. The bypass must provide them with a harmless migration corridor into the tailwater and should not trigger any avoidance reaction. Under these conditions, the behavioral protection effect of a fish protection screen can also contribute significantly to fish protection.

### Definition of fish protection screen

**A screen that blocks the migration corridor towards the turbine without causing damage to the target stages of the target fish species and guides them to bypass inlets due to its angular flow is a fish protection screen.**

### List of references


Calles, O., Karlsson, S., Vezza, P., Comoglio, C. & Tielman, J. (2013): Success of a low-sloping rack for improving downstream passage of silver eels at a hydroelectric plant. – Freshwater Biology. 10/58: 2168-2179.

Calles, O., Christiansson, J., Kläppe, S., Alenäs, I., Karlsson, S., Nyqvist, D. & Hebrand, M. (2015): Slutrapport Hertingprojektet: förstudie och uppföljning av åtgärder för förbättrad fiskpassage 2007–2015. – Technical report. Naturresurs Rinnande Vatten, Biologi, Karlstads Universitet, Karlstad, Sweden.

Courret, D. & Larinier, M. (2008): Guide pour la conception de prises d'eau << ichtyocompatibles >> pour les petites centrales hydroélectriques. – Rapport GHAAPPE RA.08.04. 60p + annexe.

Cuchet, M. (2014): Fish protection and downstream migration at hydropower intakes. Investigation of fish behavior under laboratory conditions. – Diss. TU München– Berichte des Lehrstuhls und der Versuchsanstalt für Wasserbau und Wasserwirtschaft 132.

De Bie, J., Peirson, G. & Kemp, P. S. (2018): Effectiveness of horizontally and vertically oriented wedge-wire screens to guide downstream moving juvenile chub (Squalius cephalus). – Ecological Engineering 123: 127-134.

DWA (2005): Fischschutz- und Fischabstiegsanlagen – Bemessung, Gestaltung, Funktionskontrolle, 2. korrigierte Auflage, Hennef.

Ebel, G. (2013): Fischschutz und Fischabstieg an Wasserkraftanlagen. – Mitteilungen aus dem Büro für Gewässerökologie und Fischereibiologie 4, Halle (Saale).

Enders, E. C., Gessel, M. H., Anderson, J. J. & Williams, J. G. (2012): Effects of Decelerating and Accelerating Flows on Juvenile Salmonid Behavior. – Transactions of the American Fisheries Society 141: 357-364.

Fjeldstad, H.-P., Pulg, U. & Forseth, T. (2018): Safe two-way migration for salmonids and eel past hydropower structures in Europe: a review and recommendations for best-practice solutions. – Mar. Freshwater Res. 12/69: 1834–1847.

Gosset, C., Travade, F., Durif, C. M. F., Rives, J. & Elie, P. (2005): Tests of two types of bypass for downstream migration of eels at a small hydroelectric power plant. – River Research and Applications 21 (10): 1095-1105.

Hauer, C., Unfer, G., Schmutz, S., Habersack, H. (2008): Morphodynamic Effects on the habitat of juvenile Cyprinids (Chondrostoma nasus) in a restored Austrian lowland river. Environmental Management 42: 279–96.

Lusk, S., Lusková, V., Halacka, K., Šlechtová, V., Šlechta, V. (2005): Characteristics of the remnant Vimba vimba population in the upper part of the Dyje River. Folia Zoologica 54: 389–404.

Meister, J. (2020): Fish protection and guidance at water intakes with horizontal bar rack bypass systems. – VAW-Mitteilungen 258, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), (R. M. Boes, ed.), Dissertation. ETH Zürich, Zürich.

Økland, F., Havn, T. B., Thorstad, E. B., Heermann, L., Sæther, S. A., Tambets, M. et al. (2019): Mortality of downstream migrating European eel at power stations can be low when turbine mortality is eliminated by protection measures and safe bypass routes are available. – International Review of Hydrobiology 104 (3-4): 68-79.

Russon, I. J., Kemp, P. S. & Calles, O. (2010): Response of downstream migrating adult European eels (Anguilla anguilla) to bar racks under experimental conditions. – Ecology of Freshwater Fish 19 (2): 197-205.

Schwevers, U. & Adam, B. (2020): Fish protection technologies and fish ways for downstream migration. – 1. Aufl. Cham: Springer.

Simmons, R. A. (2000): Effectiveness of a fish bypass with an angled bar rack at passing Atlantic salmon and Steelhead trout smolts at the Lower Saranac Hydroelectric Project. – In: Odeh, M. (Hrsg.): Advances in Fish Passage Technology: Engineering design and biological evaluation. – Bethesda / Maryland: 95-102.

Travade, E. & Larinier, M. (2006): French experience in downstream migration devices. – Durchgängigkeit von Gewässern für die aquatische Fauna, DWA-Themen, Tagungsband Internationales DWA-Symposium zur Wasserwirtschaft, 3.-7. April 2006: 91-99.

Travade, F., Larinier, M., Subra, S., Gomes, P. & de Oliveira, E. (2010): Behaviour and passage of European silver eels (Anguilla anguilla) at a small hydropower plant during their downstream migration. – Knowledge and Management of Aquatic Ecosystems 398: 1.

Vowles, A. S. & Kemp, P. S. (2012): Effects of light on the behaviour of brown trout (Salmo trutta) encountering accelerating flow: Application to downstream fish passage. – Ecological Engineering 47: 247-253. DOI: 10.1016/j.ecoleng.2012.06.021

Wagner, F. (2016): Vergleichende Analyse des Fischabstiegs an drei Wasserkraftanlagen einer Kraftwerkskette. – Wasserwirtschaft (2-3): 35-41.

Wagner, F.; Warth, P. & Schmalz, W. (2021): UBA Themen 81/2021 – Evaluierung von Fischschutz- und Fischabstiegsmaßnahmen an einem Wasserkraftstandort für die Umsetzung des WHG § 35, Abschlussbericht, Jena. Online verfügbar unter https://forum-fischschutz.de/evaluierung-von-fischschutz-und-fischabstiegsma%C3%9Fnahmen-einem-wasserkraftstandort-f%C3%BCr-die-umsetzung

## Date

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This Fact Sheet was commissioned by the German Federal Environment Agency. The responsibility for the content of this Fact Sheet lies with the author. It is neither an agreed position within the Forum Fish Protection & Downstream Migration, nor an official opinion of the Federal Environment Agency or the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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Photo: Institute of Aquatic Ecology and Fish Biology (IGF Jena) - Fish protection screen at the hydropower site Muldestausee (Germany)

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## About the German Participatory Forum on Fish Protection and Downstream Migration

The German Participatory Forum on Fish Protection and Downstream Migration is a series of events that serves to exchange information and experiences on fish protection and downstream fish migration from a professional point of view and across interests. In the context of the forum, fish protection is understood to be site-related fish protection and not the general protection of fish to preserve fish populations and species.

The Forum was founded by the German Federal Environment Agency in 2012. It is funded within the framework of the Environmental Research Plan of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

More information on the Forum, on the results of the workshops, on fish protection and downstream fish migration facilities as well as on research projects is available at: www.forum-fischschutz.de [German].

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