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Supplementary material

Surface bypass as a means of protecting downstream-migrating fish: lack of standardised evaluation criteria complicates evaluation of efficacy

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Table S1. Details of bypass studies including bypass specifications and bypass efficiency for studies performed in Europe

For 'Area surface bypass', the bypass area is defined as bypass width times bypass height; if several openings exist, total opening area is used; if opening is not totally submerged only submerged area is used. Efficiency definition in compliance with Table 3 of this paper. Efficiency results from different years, experimental designs or batches are considered separately as individual datasets; if a range of efficiencies is given the lowest value is chosen for analysis

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective–ness	Additional information
Larinier (2008)	France	Atlantic salmon	Several bypasses, without specifications	–	6	60–85%	–	–
Gosset *et al*. (2005)	France	European eel	With flap gate 0.9 m wide	–	1	8–14%	–	Vertical trash rack (30-mm spacing), additional bottom bypass, bottom bypass was more efficient
Croze *et al*. (1999)	France	Atlantic salmon	Built into trashrack,	–	4	1996: 34% 1997: 73% 1998: 73%	–	Vertical trash rack (40-mm spacing), end of 1996: submerged horizontal screen added
Larinier and Travade (1999)	France	Atlantic salmon	With flap gate 1 m wide 1.25–1.55 m deep	1.25–1.55 m^2	3	17%	–	Vertical trash rack (30-mm spacing)
Larinier and Travade (1999)	France	Atlantic salmon	2 bypasses at different elevations 0.8 m wide and 0.7–0.95 m deep	0.56–0.76 m^2	3	79%	–	Vertical trash rack (25-mm spacing)
Larinier and Travade (1999)	France	Atlantic salmon	1 m wide, 1 m deep (6 m upstream of trashrack)	1 m^2	3	20–35%	–	Vertical trash rack (35-mm spacing)
Larinier and Travade (1999)	France	Atlantic salmon	0.9 m wide, 0.3–0.85 m deep	0.27–0.77 m^2	3	25–40%	–	Vertical trash rack (35-mm spacing)
Larinier and Travade (1999)	France	Atlantic salmon	1.8 m wide, 0.3–0.85 m deep	0.54–1.53 m^2	3	50–80%	–	Vertical trash rack (35-mm spacing), submerged horizontal plate
	Norway		Surface spillway	–	3	1993: 62%	–	Impassable trash rack

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective–ness	Additional information
Arnekleiv *et al*. (2007)		Brown trout smolts and kelts				1997: 44%		
Calles *et al*. (2012)	Sweden	Trout smolts and kelts	Surface trash gate on the side of trash rack	–	3	Trout smolts: 0% Trout kelts: 58%	Trout smolts: 0 Trout kelts: 2.3	Vertical trash rack (90-mm spacing)
Calles *et al*. (2012)	Sweden	European eel	Surface trash gate on the side of trash rack	–	3	0%	0	Vertical trash rack (90-mm spacing)
Calles *et al*. (2012)	Sweden	Atlantic salmon smolts and kelts	Surface trash gate on the side of trash rack	–	3	salmon smolts: 17% salmon kelts: -	salmon smolts: 0.68 salmon kelts: –	Vertical trash rack (90-mm spacing)
Økland *et al*. (2017)	Germany	European eel	Integrated in trash rack (six openings)	–	3	2014: 24% 2015: 27%	–	Vertical trash rack (10-mm spacing)
Aarestrup and Koed (2003)	Denmark	Brown trout smolts	Weir overflow at four weirs	–	6	29% 69% 70% 82%	–	No hydropower, no alternative passage route
Aarestrup and Koed (2003)	Denmark	Atlantic salmon smolts	Weir overflow at four weirs	–	6	47%	–	No hydropower, no alternative passage route
Calles and Greenberg (2009)	Sweden	Brown trout smolts and kelts	Trash gate, 3.5 m wide	–	1	Trout smolts: 4–14% Trout kelts: 70%	–	Vertical trash rack (30-mm spacing), trash deflector
Calles and Greenberg (2009)	Sweden	Brown trout smolts	Trash gate, 1.9 m wide	–	1	20–50%	–	Vertical trash rack (20-mm spacing), trash deflector
Greenberg *et al*. (2012)	Sweden	Brown trout smolts	Trash gate, 3.5 m wide	–	3	52%	3.1	Vertical trash rack (30-mm spacing)
Greenberg *et al*. (2012)	Sweden	Brown trout smolts	Trash gate, 1.9 m wide	–	3	0%	–	Vertical trash rack (20-mm spacing)

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective–ness	Additional information
Greenberg *et al*. (2012)	Sweden	Brown trout smolts	Trash gate, 1.9 m wide	–	3	31%	3.1	Vertical trash rack (20-mm spacing) with overhead cover
Dumont and Hermens (2012)	Netherlands	Atlantic salmon smolts	2 m upstream of trash rack, 0.45 m deep	–	6	41%	–	Vertical trash rack (10-mm spacing)
Travade *et al*. (2010)	France	European eel	Three surface bypass openings; 2 m wide, 1m deep; 0.8 m wide, 0.65 m deep	3.04 m^2	3	2004: 18% 2006: 24%	–	Vertical trash racks (20-mm and 30-mm spacing), additional bottom bypass
Croze (2008)	France	Atlantic salmon smolts	New surface bypass, 1.1 m wide, 0.7 m deep	0.77 m^2	3	71%	–	Vertical trash racks (20–60-mm spacing)
Croze (2008)	France	Atlantic salmon smolts	Retrofit surface bypass, 2.3 m wide, 0.3 m deep	0.69 m^2	3	32%	–	
Croze (2008)	France	Atlantic salmon smolts	Retrofit surface bypass, 1.9 m wide, 0.5 m deep	0.95 m^2	3	40%	–	Vertical trash racks (27– 66-mm spacing)
Croze (2008)	France	Atlantic salmon smolts	New surface bypass, 1.4 m wide, 0.6 m deep	0.84 m^2	3	66%	–	Vertical trash rack (30-mm spacing)
Fjeldstad *et al*. (2012)	Norway	Atlantic salmon smolts	Bypass (type not specified)	–	6	2003: 11% 2004: 54% 2008: 64%	–	2004: variation in discharge distribution 2008: discharge distribution + lights
Ovidio *et al*. (2017)	Belgium	Atlantic salmon smolts	Next to trash rack, 0.8 m wide, 0.4 m deep	0.32 m^2	3	14% 17%	–	Vertical trash rack (41-mm spacing)
Marohn *et al*. (2014)	Germany	European eel	Next to flap gate	–	6	0.70%	–	Bottom bypass (0.3-m diameter) 67.1%, Trash rack (20-mm spacing)
Travade *et al*. (1999)	France	Atlantic salmon smolts	Next to trash rack, two openings (0.8 m wide)	–	4	79%	–	Behavioral barrier (acoustic), Trash rack (25-mm spacing)

Table S2. Details of bypass studies including bypass specifications and bypass efficiency for studies performed in North America

For 'Area surface bypass', the bypass area is defined as bypass width times bypass height; if several openings exist, total opening area is used; if opening is not totally submerged only submerged area is used. Efficiency definition in compliance with Table 3 of this paper. Efficiency results from different years, experimental designs or batches are considered separately as individual datasets; if a span of efficiencies is given the lowest value is chosen for analysis

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
Johnson *et al.* (2000)	USA	Steelhead smolts	Surface bypass collector	95.22 m^2	3	45% 39%	5.7 6	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Steelhead smolts	Surface bypass collector	84.64 m^2	3	44% 30%	5.4 4.4	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Steelhead smolts	Surface bypass collector	84.64 m^2	3	39%	8.8	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Steelhead smolts	Surface bypass collector	190.44 m^2	3	40%	6.1	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Chinook salmon smolts	Surface bypass collector	95.22 m^2	3	45% 39%	5.7 6	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Chinook salmon smolts	Surface bypass collector	84.64 m^2	3	44% 30%	5.4 4.4	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Chinook salmon smolts	Surface bypass collector	84.64 m^2	3	39%	8.8	Guiding screen at turbine intake
Johnson *et al.* (2000)	USA	Chinook salmon smolts	Surface bypass collector	190.44 m^2	3	40%	6.1	Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Steelhead smolts	Surface bypass collector	101.88 m^2	3	62%	–	Guiding screen at turbine intake Floating wall
Johnson *et al.* (2005)	USA	Steelhead smolts	Surface bypass collector	165.36 m^2	3	58%	–	Guiding screen at turbine intake Floating wall
Johnson *et al.* (2005)	USA	Steelhead smolts	Surface bypass collector	18.98 m^2	3	53%	–	Guiding screen at turbine intake Floating wall
Johnson *et al.* (2005)	USA	Steelhead smolts	Surface bypass collector	29.56 m^2	3	55%	–	Guiding screen at turbine intake

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effectiveness	Additional information
Johnson *et al.* (2005)	USA	Steelhead smolts	Surface bypass collector	42.5 m^2	3	62%	–	Floating wall Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Chinook salmon smolts	Surface bypass collector	101.88 m^2	3	62%	–	Floating wall Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Chinook salmon smolts	Surface bypass collector	165.36 m^2	3	58%	–	Floating wall Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Chinook salmon smolts	Surface bypass collector	18.98 m^2	3	53%	–	Floating wall Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Chinook salmon smolts	Surface bypass collector	29.56 m^2	3	55%	–	Floating wall Guiding screen at turbine intake
Johnson *et al.* (2005)	USA	Chinook salmon smolts	Surface bypass collector	42.5 m^2	3	62%	–	Floating wall Guiding screen at turbine intake
Adams *et al.* (2014)	USA	Steelhead smolts (hatchery)	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	Day: 31–83% Night: 15–45%	Day: 6–10.8 Night: 2.5–5.3	Behavioral guidance structure Surface bypass collector
Adams *et al.* (2014)	USA	Steelhead smolts (natural)	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	Day: 61–78% Night: 31–42%	Day: 8.1–9 Night: 4–5	Behavioral guidance structure Surface bypass collector
Scruton *et al.* (2007)	Canada	Atlantic salmon smolts and kelts	Surface spill Next to turbine intake		4	Smolts: 2003: 62% 2004: 72% 2005: 62% Kelts: 2004: 92% 2005: 96%	–	–
Hanson (1999)	USA		Log and ice sluice	6.5 m^2	1	94%	48	Fish diversion boom

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
		Atlantic salmon smolts	Two entrances, 2.7 m wide, 2.4 m deep					
Hanson (1999)	USA	Atlantic salmon smolts	Fish pipe, surface fed, 2.3-m diameter	4.2 m^2	1	1991: 16% 1992: 22%	–	Louver to fish pipe
Hanson (1999)	USA	Atlantic salmon smolts	Fish pipe, surface fed, 2.3-m diameter, Fish tube, surface fed, 1 m wide, 1.8 m deep	6 m^2	1	1994: 73% 1995: 61% 1996: 74%	–	Louver to fish pipe
Willis and Uremovich (1982)	USA	Steelhead smolts	Log and ice sluice Four openings, ~8 m wide each	–	5	83%		
Willis and Uremovich (1982)	USA	Steelhead smolts	Log and ice sluice Four openings, ~8 m wide each	–	5	63%		
Willis and Uremovich (1982)	USA	Pacific salmon smolts	Log and ice sluice Four openings, ~8 m wide each	–	5	58% 50% 42% 10% 4%		
Willis and Uremovich (1982)	USA	Pacific salmon smolts	Log and ice sluice Four openings, ~8 m wide each	–	5	52% 46% 38% 13% 5%		
Plumb *et al.* (2004)	USA	Steelhead smolts	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	41% 38%	9.9	Trash shear boom
Plumb *et al.* (2004)	USA	Pacific salmon smolts	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	33%	8.3	Trash shear boom
Skalski *et al.* (1996)	USA	Steelhead smolts	Retrofit smolt bypass system, surface spill	–	3	89%	9	
Skalski *et al.* (1996)	USA	Pacific salmon smolts	Retrofit smolt bypass system, surface spill	–	3	89%	9	
Plumb *et al.* (2003)	USA	Steelhead smolts	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	62% 61%	7.2 7.1	Trash shear boom

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
Plumb *et al.* (2003)	USA	Pacific salmon smolts	Removable spillway weir, 15 m wide, 4 m deep	60 m^2	1	56%	6.5	Trash shear boom
Khan *et al.* (2012)	USA	Pacific salmon smolts	Surface spillway	–	1	72%	2.7	
Axel *et al.* (2010)	USA	Steelhead smolts	Removable spillway weir	–	1	45%	1.5	Juvenile bypass system
Axel *et al.* (2010)	USA	Pacific salmon smolts	Removable spillway weir	–	1	28% 27%	4 1.3	Juvenile bypass system
Faber *et al.* (2011)	USA	Steelhead smolts	Surface flow outlet	–	1	70%	–	-
Faber *et al.* (2011)	USA	Pacific salmon smolts	Surface flow outlet	–	1	33% 39%	–	-
Faber *et al.* (2011)	USA	Steelhead smolts	Surface flow outlet	–	1	59%	–	Behavioral Guidance Structure (BGS)
Faber *et al.* (2011)	USA	Pacific salmon smolts	Surface flow outlet	–	1	40% 52%	–	Behavioral Guidance Structure (BGS)
Khan *et al.* (2013)	USA	Adult steelhead	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	44 m^2	3	95% 95%	23.8 23.8	
Khan *et al.* (2013)	USA	Adult steelhead	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	29 m^2	3	92% 97%	23 24.3	
Nyqvist *et al.* (2017)	Canada	Atlantic salmon smolts	One open entrance to surface bypass in intake rack and surface spill	–	1	77%	–	Intake rack (25-mm spacing) 3 m deep
Nyqvist *et al.* (2017)	Canada	Atlantic salmon smolts	One open entrance to surface bypass in intake rack and surface spill	–	4	50%	–	Intake rack (25-mm spacing) 3 m deep
Perry *et al.* (2016)	USA	Pacific salmon smolts	Surface spillway, 2.9–25 m wide	–	1	38%	–	Juvenile bypass system Additional sub-surface spillway
Peven and Mosey (1999)	USA	Pacific salmon smolts	Surface collector, 4.6 m wide, 17.4 m deep	80 m^2	4	12% 23% 9%	–	Diversion screen
Peven and Mosey (1999)	USA	Steelhead smolts	Surface collector, 4.6 m wide, 17.4 m deep	80 m^2	4	7% 46%	–	Diversion screen

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
Johnson *et al.* (2013)	USA	Pacific salmon smolts	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	22 m^2	3	23%	11.5	–
Johnson *et al.* (2013)	USA	Steelhead smolts	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	22 m^2	3	23%	11.5	–
Johnson *et al.* (2013)	USA	Pacific salmon smolts	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	44 m^2	3	34% 32% 25%	17 16 12.5	–
Johnson *et al.* (2013)	USA	Steelhead smolts	Sluiceway, several openings, 6.1 m wide, 1.2–2.8 m deep	44 m^2	3	34% 32% 25%	17 16 12.5	–
Adams *et al.* (2001)	USA	Steelhead smolts	Surface bypass collector with four openings	–	1	29% 16%	9.6 5.3	Juvenile fish collection
Adams *et al.* (2001)	USA	Steelhead smolts	Surface bypass collector with four openings	–	1	42% 12%	14.1 4.1	Juvenile fish collection Behavioral guidance screen
Adams *et al.* (2001)	USA	Pacific salmon smolts	Surface bypass collector with four openings	–	1	13%	4.3	Juvenile fish collection
Adams *et al.* (2001)	USA	Pacific salmon smolts	Surface bypass collector with four openings	–	1	14%	4.7	Juvenile fish collection Behavioral guidance screen
Evans *et al.* (2008)	USA	Steelhead smolts	Prototype surface collector, six entrances each 6 m wide and 12 m deep	432 m^2	1	83%	2.5	Guide wall Downstream salmonid migrant channel (like juvenile fish collection)
Evans *et al.* (2008)	USA	Steelhead smolts	Prototype surface collector, six entrances each 6 m wide and 12 m deep	432 m^2	2	60%	1.8	Guide wall Downstream salmonid migrant channel (like juvenile fish collection)
Evans *et al.* (2008)	USA	Pacific salmon smolts	Prototype surface collector, six entrances each 6 m wide and 12 m deep	432 m^2	1	CH1: 79% CH0: 83%	2.4 2.5	Guide Wall Downstream salmonid migrant channel (like juvenile fish collection)
	USA			432 m^2	2	CH1: 72%	2.2	Guide Wall

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
Evans *et al.* (2008)		Pacific salmon smolts	Prototype surface collector, six entrances each 6 m wide and 12 m deep			CH0: 67%	2	Downstream salmonid migrant channel (like juvenile fish collection)
Steig and Adeniyi (1999)	USA	Steelhead smolts	Prototype surface collector	–	3	48%	25.3	–
Steig and Adeniyi (1999)	USA	Steelhead smolts	Prototype surface collector	–	1	27%	24.4	Platform at bottom of PSC Sloping walls at PSC
Steig and Adeniyi (1999)	USA	Pacific salmon smolts	Prototype surface collector	–	3	48%	25.3	–
Steig and Adeniyi (1999)	USA	Pacific salmon smolts	Prototype surface collector	–	1	27%	24.4	Platform at bottom of PSC Sloping walls at PSC

Table S3. Details of bypass studies including bypass specifications and bypass efficiency for studies performed in Australia

For 'Area surface bypass', the bypass area is defined as bypass width times bypass height; if several openings exist, total opening area is used; if opening is not totally submerged only submerged area is used. Efficiency definition in compliance with Table 3 of this paper. Efficiency results from different years, experimental designs or batches are considered separately as individual datasets; if a span of efficiencies is given the lowest value is chosen for analysis

Author	Country	Fish species	Bypass specification	Area surface bypass	Efficiency definition	Efficiency	Effective-ness	Additional information
Boubée and Williams (2006)	Australia	Eels	Holes ~1 m below crest, 2.1-m diameter	3.5 m^2	4	10% 0%	–	Vertical trash rack (30-mm spacing)

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