Erwin Winter

A fisheye view on fishways

A fisheye view on fishways

Promotoren:
Prof. Dr. J.A.J. Verreth
Hoogleraar Aquacultuur en Visserij
Wageningen Universiteit

Prof. Dr. A.D. Rijnsdorp
Hoogleraar Visserijwetenschappen
Rijksuniversiteit Groningen / IMARES, IJmuiden

Co-promotor:
Prof. Dr. N. Daan
Emeritus Hoogleraar Toegepaste Hydrobiologie
IMARES, IJmuiden / Universiteit van Amsterdam

Promotiecommissie:
Prof. Dr. F. Schiemer (Universität Wien, Oostenrijk)
Prof. Dr. P.F.M. Opdam (Wageningen Universiteit)
Prof. Dr. M. Klaassen (Universiteit Utrecht, NIOO-KNAW)
Dr. Ir. A.D. Buijse (Rijkswaterstaat RIZA, Lelystad)

Dit onderzoek is uitgevoerd binnen de onderzoeksschool WIAS

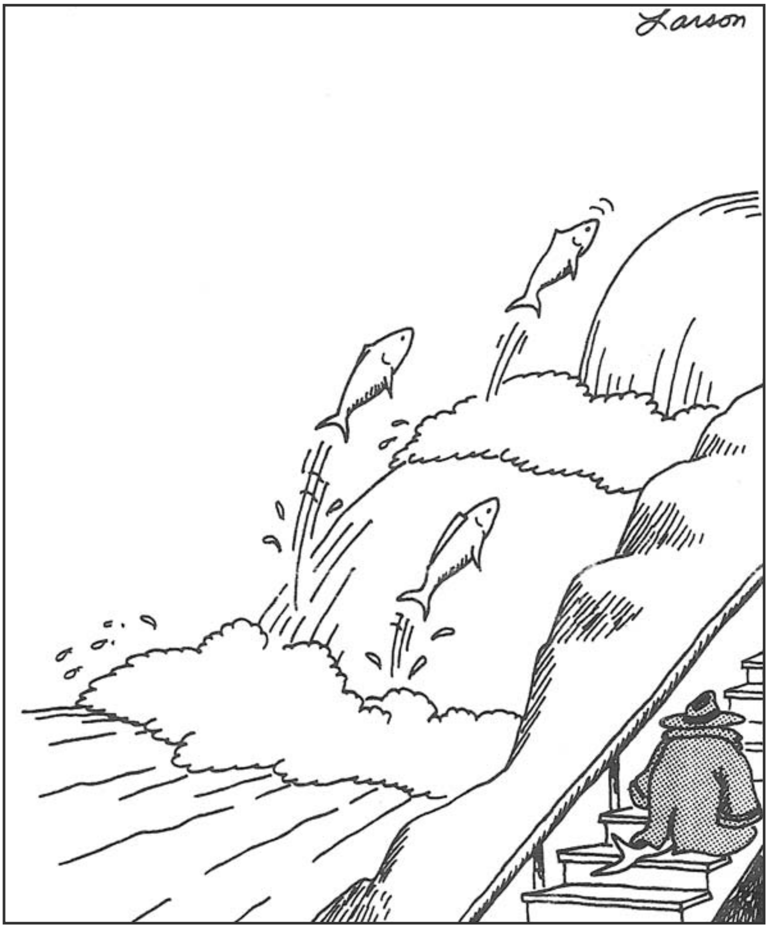
A fisheye view on fishways

Hendrik Volken Winter

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de Rector Magnificus
van Wageningen Universiteit
Prof. Dr. M.J. Kropff
in het openbaar te verdedigen
op vrijdag 7 december 2007
des namiddags te vier uur in de Aula

Winter, H.V., 2007. A fisheye view on fishways. PhD Thesis, Wageningen University,
The Netherlands.

ISBN: 978-90-8504-867-1


Larson

Abstract

Barriers in rivers severely obstruct fish migration. To mitigate the impact, different types of fishways have been developed to facilitate upstream movements of fish. In this PhD-thesis the effect of a series of V-stepped fishways alongside weirs in the regulated River Vecht, the Netherlands, was evaluated.

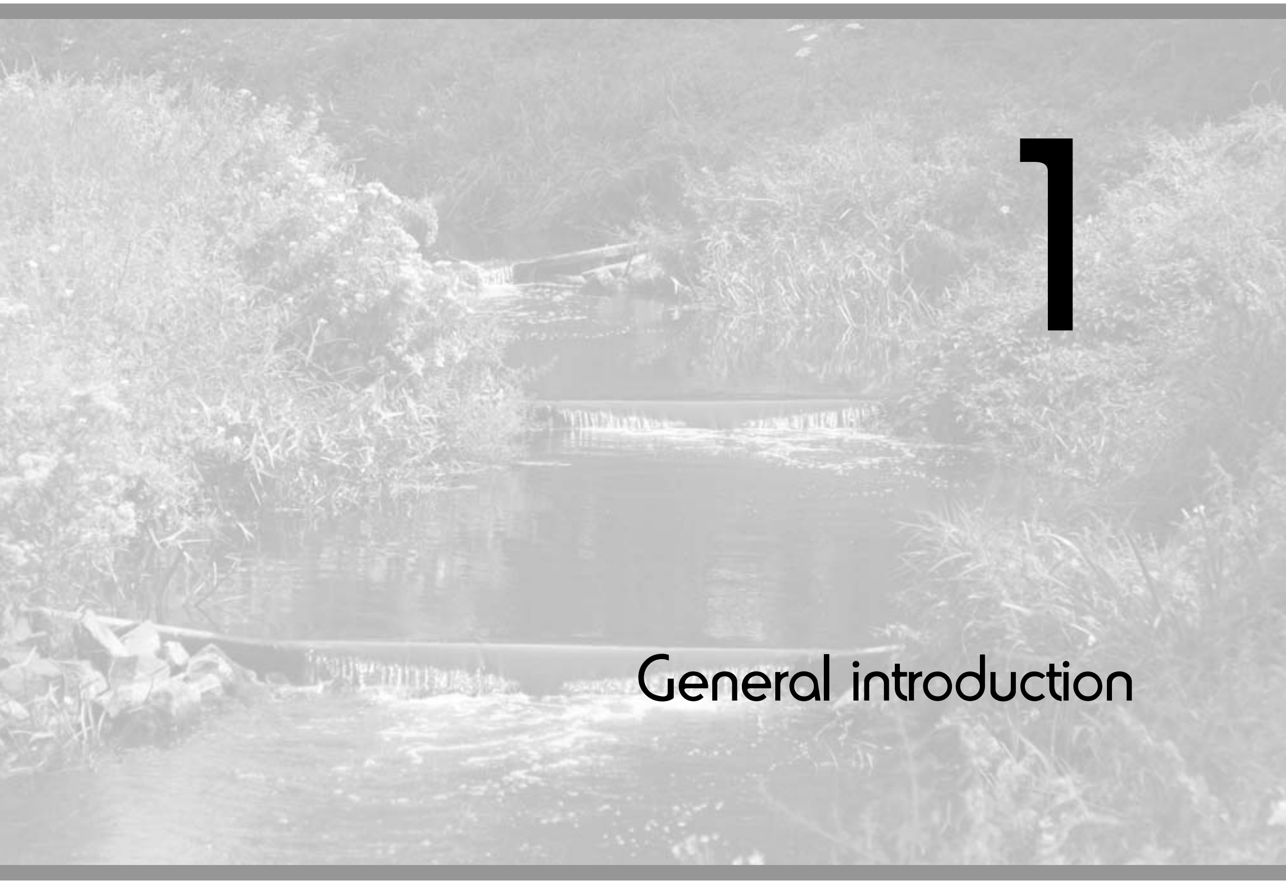
In the period before the fishways were built, only during high discharge events weirs were lowered and strong swimmers were able to pass. Based on daily water levels, discharge and a sprinting capacity model, an assessment was made of the migratory opportunities during the pre-fishway period. Only 10 out of 32 species present were able to pass the weirs but migratory windows were few and far between. The V-stepped fishways proved suitable to pass for most species and life stages. For 10 species, fish smaller than 10 cm have successfully passed. The fishways have resulted in an increased relative abundance in the river Vecht of those species that had a relative high fishway use. However, no major shifts in species assemblages were observed. Comparing the fish community at present with the more natural River Biebrza in Poland as a geographical reference and a reconstruction of the historical fish community in the Vecht around 1850 revealed that there is still a large deviation from the natural situation. Habitat degradation seems to play an important role in this. The effect of the fishways might have been higher if there was more to connect.

For ide, a river dwelling cyprinid, behaviour studies with mark-recapture and telemetric experiments were conducted to examine the role of migration within the population and passage behaviour at weirs and fishways. The scale of movements highly varied among individuals ranging from resident to migrations of more than 100 km. Passage success was related to the ratio between the attraction flow from the fishway entrance and the discharge over the weir.

To design solutions for migratory problems and optimize fishway performance, it is essential to invest in gaining knowledge on fish behaviour and comprehensive before and after evaluation studies.

Contents

Fishway in the Vecht / Vistrap in de Overijsselse Vecht



1

General introduction

Problem definition

Severe human impact in river ecosystems

Worldwide rivers are among the most heavily impacted aquatic ecosystems (Dynesius & Nilsson 1994, Malmquist & Rundle 2002) with important implications for fish populations, especially in the temperate climate zones. The strong anthropogenic influence has led to drastic morphological and hydrological changes, habitat loss and decrease of heterogeneity, the construction of barriers, thermal, organic and toxic water pollution due to cooling and waste water disposal, regulated flow for the purpose of navigation and agriculture, land reclamation in floodplains by building dikes and levees, overfishing and the introduction of exotic species. These impacts often have a long history.

Barriers disrupting longitudinal connectivity in rivers

The first fish populations that disappeared from whole river systems were migratory species, such as anadromous sturgeon and salmonid species (McDowell 1988, de Groot 2002). For these species, one of the main factors was that barriers disconnected the widely separated ocean habitat and the upstream tributaries of rivers.

Barriers appeared in all sizes and shapes varying from huge dams with heights over hundred meters in mainstem rivers posing a complete hindrance for upstream and downstream movements for all species, to small weirs that obstruct only upstream movements during part of the time and for part of the fish species (Lucas & Baras 2001). The construction of barriers has a long history. Even in the relatively undisturbed Bolivian Amazon area, a complex artificial network of hydraulic earthworks functioning as fish weirs covering 525 km^2 has been constructed starting 12,000 years ago (Erickson 2000).

Nowadays, many rivers are fragmented by dams, hydropower stations, sluices and weirs. In case of a complete obstruction, the impact on diadromous fish populations is obvious. How barriers that do not completely block fish movements affect migratory fish populations is less clear, as studies on upstream migratory opportunities through incomplete barriers like weirs and sluices are scarce.

Necessity of longitudinal connectivity

Fish need corridors between habitats for many reasons, which may vary by species (Northcote 1998). Some species need different and geographically separated habitats during different life stages to complete their life cycle such as the anadromous salmonids (McDowall 1988), which move upstream as adults to spawn in streams, use these as nurseries and then move downstream as juveniles to the open ocean to grow up to adults. Or the catadromous eels that spawn somewhere in the open ocean, while the larvae drift to continents to migrate into rivers and backwaters to grow up to adult size in freshwater (Dekker 2004).

However, not all fish species use these spectacular scales and movements between different habitats for spawning, feeding and wintering, although different life stages commonly require different habitats (Northcote 1998). For many species, the role of migrations in population biology is still unclear and limited to anecdotical information that they occur, but on what scale and which part of the population is involved is mostly not known.

Apart from migrations, i.e. directed movements that have a regular cyclic character (Northcote 1998), other types of movements are distinguished as well. Dispersal, i.e. the undirectional spreading of individuals, is another important strategy in the life history of many species, enabling them to deal with local extinction risks by recolonization, colonize newly appearing suitable habitats, provide gene flow between local populations to reduce the risk of inbreeding (Dieckmann et al. 1999). The distinction between movements classified as migration or dispersal is not always clear and many authors use different definitions.

Mitigation of barriers by providing fishways

Attention to constructions that mitigate artificial barriers has for a long time been mainly restricted to long-distance migrants with commercial value, especially salmonids (Clay 1995). These are strong swimmers that are used to deal with natural barriers. Images of salmons leaping over water falls of several meters high are well known to everyone. Therefore, the traditional solutions designed to facilitate passage of these species along barriers are only suitable for fish with a high swimming capacity. The construction of such artificial pathways has a long history. For instance, the aboriginals in Australia already constructed rocky ramp-like bypasses along natural barriers more than 5,000 years ago to trap fish moving upstream (Harris et al. 1998).

Over the years of human history a large variety of fishways, fish ladders, fish lifts, fish sluices and bypass-channels has been constructed everywhere around the world (Clay 1995). With the growing awareness that connectivity is important for many species attention shifted to designing solutions to facilitate upstream movement of a broad range of species and life-stages (Lucas & Baras 2001).

Evaluation of the effectiveness of providing fishways

Given the large number of fish-passage facilities that have been and are being constructed, surprisingly few evaluation studies on their effectiveness in rehabilitating fish populations have been performed (Gehrke *et al.* 2002). Most studies that do exist are restricted to determining the suitability of the hydraulic conditions within a fishway for upstream passage of target species or to monitoring the number of fish passing (Larinier 1998). Studies on the efficiency of fishways, i.e. the fraction of all fish that are motivated to move upstream succeeds in passing, are still relatively scarce, although the rapid developments in telemetric techniques has resulted in an increase in such studies (Bunt *et al.* 1998, Moser *et al.* 2002). Furthermore, data on fish communities or species abundance during the pre-fishway period are often lacking and therefore hampering before-after evaluations of providing fishways (Gehrke *et al.* 2002).

Study objectives

The overall objective of this thesis is to assess the effects of providing fishways on the rehabilitation of fish populations and communities in regulated lowland rivers with incomplete barriers. The effectiveness of providing fishways is studied on different scales: varying from fishway and weir site to river basin, and from the individual fish to the entire fish community. The study focuses on developing approaches to assess fishway effectiveness, revealing underlying mechanisms and determining which factors are most important in affecting these mechanisms.

Selected approach, methods and study area

To evaluate the effect of providing fishways in regulated rivers with incomplete barriers, different methods and approaches were used:

- Fish sampling in river stretches downstream and upstream of barriers and fishways;
- Monitoring fish passage through fishways;
- Comparison of the present state with historical datasets on fish assemblages and river morphology;
- Modelling species specific swimming capacity to assess migratory opportunities within fishways and through incomplete barriers in relation to hydrological datasets;
- Individual behaviour studies by mark-recapture and radio telemetry experiments.

The Dutch part of the River Vecht was selected as a case study. Main regulatory works had been carried out during the 1890s-1950s when among others weirs were constructed to guarantee maintaining water levels at the target level during periods of low flow. During 1987-1994, a series of V-stepped fishways (Cowx & Welcomme 1998) was constructed alongside each of the six weirs in the Dutch section of this river (see Box 1.1 for a more detailed historical overview on the River Vecht). From the period before fishways were constructed, different datasets on fish abundance were available, especially those collected during the 1970s (Cazemier 1978) and directed on ide, *Leuciscus idus*, a river dwelling migratory cyprinid (Cala 1970). Therefore, this species was selected as the target species to zoom in on the individual behaviour. Various additional experimental field studies were carried out on the River Vecht during 1995-1999, including electrofishing surveys in the different river stretches throughout the year, fishway passage monitoring, tagging and telemetry experiments.

Box 1.1 Historical overview of human influence on the River Vecht

In a chronological overview of the main changes in the River Vecht region, three periods can be distinguished: 1) a period when the river was still relatively undisturbed by human impact and freely meandering (before 1850); 2) a period when major regulatory works were carried out, starting in the 1850s and with an increasing human impact lasting to at least the 1960s); and 3) a period when the concern about ecological degradation arose and resulted in a series of rehabilitation measures, which lasts until the present time. In addition, future plans are discussed.

1) Period of a naturally meandering river (before 1850)

The pristine River Vecht was a meandering lowland river with extensive floodplains along the lower parts. The river discharged directly into the former Zuiderzee estuary. The meandering process characteristic of lowland rivers resulted in the regular formation of natural cutoffs. The annual growth of shore line was 4.2 ha/yr and maximum erosion of outside bends was 3.5 m/yr (Wolfert et al. 1996). The other shores were very shallow sloping (Staring & Stieltjes 1848) and there were many shallow banks in the mainstream, especially during summer.

Since the Middle Ages, wetland forests and peat moors bordering the River Vecht were gradually replaced by extensive grasslands grazed by cattle and used for hay harvests (Tauw 1992). The first feature to disappear from the river was the large amount of woody debris and shading of part of the river banks (Duursema 2004). Secondly, the buffering capacity of the catchment area was reduced through digging of ditches, which led to a quicker response of discharge to local rainfall. At a local scale, small dikes and levees had been built already from the 14th century onwards (Wolfert et al. 1996), but until 1900 the floodplains were mostly inundated for long periods during winter (Tauw 1992).

Because of the limited depth and frequent bars, a special type of shallow-draught transport vessel ("Vecht ship") was developed (Schutten 1981). Navigation was more important during the 17th to the 19th century than in later years, but did not lead to measures that changed the morphology in a persistent manner. Only under extreme conditions, small temporary dams were made locally to raise the water just enough to let the ships pass a shallow bank (Schutten 1981).

2) Period of strict regulation (1850 – 1970)

In 1853 and 1858, two weirs were constructed at Ane and De Haandrik, respectively, to maintain draught in two shipping canals crossing the river at these locations. During the period 1896-1914 and again during 1932-1957, extensive measures were taken to regulate discharge and water levels. To enlarge the discharge capacity during periods with high precipitation, 69 meanders were cut off, reducing the length of the Dutch river section from 90 to 60 km (Wolfert et al. 1996). In addition, five more weirs (with associated locks) were constructed (1896-1914) downstream from Ane to Vechterweerd to prevent water level dropping too low during dry summers. The upstream German part of the river became also strongly regulated (1952-1960; Permanente Nederlands-Duitse Grenswater-commissie 1992). To fix the river in the landscape, most banks were protected against erosion with riprap. Through all these interventions, the meandering process was banned completely.

In the downstream Zuiderzee estuary, drastic changes also have occurred after a large dam had been built in 1932. Effectively, the dam created a large freshwater, Lake IJsselmeer, and posed a severe obstruction for upstream migrating diadromous fish from the sea. Several land reclamation projects thereafter have reduced the surface. The river Vecht is now connected with Lake IJsselmeer by two remnants of the former lake, Ketelmeer and Zwarte Meer.

The increased water velocities in the main channel during winter have caused an average erosion of the bottom of 2 m during 1850-1990. As a consequence, the river stretches in between weirs have a much more impounded appearance now than just after the weirs were constructed. Moreover, the originally abundant aquatic vegetation has completely vanished along most of the banks.

Because of limited urban development in the catchment area, water quality has remained relatively good compared to other Dutch rivers such as Rhine and IJssel, except during the 1950s and 1960s when a potato processing industry was responsible for occasional hypoxic events.

3) Period of rehabilitation (after 1970)

Early in the 1970s, water treatment plants for urban waste water were built, and especially phosphate concentrations have become much reduced (Tauw 1992). Hypoxic events no longer occurred because the spills of organic sewage from the potato processing industry were terminated. The weir at Ane was removed in 1970 and in 1984 all weirs with removable boards were replaced by hydraulic weirs.

After a fish migration study of Cazemier (1978), the awareness among the responsible agencies arose that the weirs created a severe obstruction for fish to perform longitudinal movements. To improve the conditions for fish migration and provide at least a few windows for upstream movements, a provisional management scheme was established according to which the weirs were lowered alternatingly for some days during spring. This initiative was ceased shortly thereafter because target water levels could not be maintained. However, this experiment initiated the development of a master plan for constructing fishways along each of the remaining six weirs in the Dutch river section.

The first fishway was built at the most downstream weir in 1987 and the last one was finished in 1994. In the tributary Regge, the four most downstream weirs were also facilitated with fishways. In the German part, a series of fishways has been constructed in the 1980s, but their functioning appears to be poor compared with the Dutch design. There is also one weir without a fishway in the downstream part of the tributary Dinkel.

Alongside a small fraction (< 2 %) of the riprap banks, so-called 'nature-friendly' banks have been constructed in the 1990s. The riprap line of defense against erosion was kept intact, but some openings were made to allow fish to enter a water body with shallower sloping banks behind. The philosophy behind these constructions was that they would provide new habitats with water plants for fish to spawn, but most of these areas have been filled up with sand transported by the river in only a few years.

One sidearm at the Maat (at 21 km from the German border) was reconnected at both sides in 1996, creating a slow-flowing side channel.

4) Future restoration plans (until 2050)
Various scenarios for partly restoring the meandering process at some stretches are presently being evaluated (Vechtvisie 1997, Duursema 2004), based on a study aimed at identifying those stretches that offered the best possibilities (Wolfert et al. 1996).

Measures that are being considered for the period 2008-2015 are 1) the reconnection of isolated cutoffs to the main channel; 2) the creation of longer and gradual bypasses along some weirs; 3) the replacement of riprap banks by shallower sloping banks to facilitate development of aquatic vegetation along those stretches where erosion is expected to be limited; 4) the leveling off of floodplain areas to allow inundation for prolonged periods; and 5) the planting of trees to re-establish wetland forests along some banks (Duursema 2004).

Measures considered for the period after 2015 are: 1) the removal of all unnatural shore protection; 2) the reconnection of old meanders, possibly in combination with fencing off the current main channel; 3) a further expansion of the inundation area of the floodplains; and 4) the removal of all weirs (Duursema 2004).

Figure 1.1 *A map of the River Vecht region in 1648, when the river was freely meandering and discharged directly in the Zuiderzee Estuary.*

Outline of the thesis

To investigate the effects of facilitating fishways in the River Vecht, the thesis is subdivided into chapters according to the following research questions. Chapters 2-5 consider all species in examining the effects of facilitating fishways and rehabilitating fish communities in the River Vecht. In chapters 6 and 7, focus is directed towards individual behaviour with ide as the target species, and towards mechanisms underlying migration patterns and fishway efficiency in relation to environmental factors.

What was the degree of obstruction posed by the weirs before fishways were built?
The weirs in the River Vecht are lowered at high discharge, which occasionally provided temporal migratory windows for upstream movement of species having sufficient swimming capacity to ascend the water velocities occurring during these events. For 1960-1984, daily discharge and water levels at each of the six weir were available. Based on this and a review on burst swimming capacity of the species present, a barrier assessment was carried out to determine the migratory opportunities for each of these species during the period before fishways were available (**Chapter 2**).

How suitable are the V-stepped fishways for upstream passage of fish?
The suitability of this type of V-stepped fishways (developed in the Netherlands) was studied by monitoring fish passage through these fishways and by electrofishing surveys directly downstream of weirs and on river stretches. Based on the results, the suitability of these fishways was estimated for each species encountered in the River Vecht (Chapter 3).

Did providing fishways result in changes in the fish community?
The relative abundances of fish species in the period before the construction of the fishways were compared with the period thereafter. By determining the 'relative fishway use', i.e. the ratio between the relative abundance in fishway passage and relative abundance on river stretches, for each species, the question is addressed whether species with high relative fishway use have increased in abundance compared to species with low or no fishway use (Chapter 4).

How far deviates the current fish community from the natural situation?
Because regulation started more than a century ago and historic fish data are merely anecdotic, the current fish community was first compared to a river that is supposed to have a similar community to the original River Vecht and is still relatively unaffected by human impact. Pristine rivers are extremely rare in western Europe, but the River Biebrza appeared to be the best available candidate for this comparison (Duursema 2004). Based on the community of this geographical reference and adjusted for differences in zoogeographical distribution of species, a natural reference community of the River Vecht is reconstructed and this reconstruction is cross-checked against the written evidence available on this topic (Chapter 5).

What is the role of migration in adult ide populations?
Using telemetric experiments with transpondered individuals, movements of adult ide were followed over long periods (one to four years) to determine the variation in migration patterns among individuals within a population and within individuals between years. The results were compared to a similar study performed on ide in the River Elbe, to examine differences between these two populations and to get an indication of the general applicability of the patterns in spatial use found (Chapter 6).

How efficient are the fishways for passage of ide and which factors determine this?
A mark-recapture and telemetry study has been carried out to determine the behaviour of individual ides during their approach to, and their eventual passage of, the fishway alongside the weir. Based on the results, the 'attraction flow' hypothesis, i.e. that the ratio of flow through the fishway relative to the flow over the weir is an important factor in finding the entrance of the fishway and therefore in determining overall efficiency (Baras *et al.* 1994), is tested (Chapter 7).

A synthesis of all the results obtained is given in Chapter 8. Different approaches and concepts of assessing the effectiveness of providing fishways will be reviewed, with special attention to behavioural aspects. In addition implications of the findings for river management will be discussed.

References

- Bunt, C.M., C. Katapodis, and R.S. McKinley, 1999. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. North American Journal of Fisheries Management 19, 793-803.
- Cala, P., 1970. On the ecology of ide *Idus idus* (L.) in the River Kavlingean, South Sweden. Reports of the Institute of Freshwater Research Drottningholm 50: 45-99.
- Cazemier, W.G., 1978. Study on the necessity of fishways in the River Vecht. RIVO-report ZS78-03, IMARES, IJmuiden, The Netherlands. (in Dutch).
- Clay, C.H., 1995. Design of fishways and other fish facilities. Lewis Publishers, London, UK.
- Cowx, I.G. and R.L. Welcomme (Editors), 1998. Rehabilitation of Rivers for Fish. FAO, Fishing News Books, Blackwell Science Ltd., Oxford, UK.
- De Groot, S.J., 2002. A review of the past and present status of anadromous fish species in the Netherlands: is restocking the Rhine feasible? Hydrobiologia 478 (1-3): 205-218.
- Dekker, W., 2004. Slipping through our hands: population dynamics of the European eel. PhD-thesis, University of Amsterdam, the Netherlands.
- Dieckmann, U., B. O'Hara B and W. Weisser, 1999. The evolutionary ecology of dispersal. Trends in Ecology and Evolution 14 (3): 88-90.
- Duursema, G., 2004. Leidraad voor ecologisch herstel van de Overijsselse Vecht. Waterschap Velt en Vecht, Coevorden, the Netherlands.
- Dynesius, M., and C. Nilsson, 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266: 753-762.
- Erickson, C.L., 2000. An artificial landscape-scale fishery in the Bolivian Amazon. Nature 408 (6809): 190-193
- Gehrke, P.C., D.M. Gilligan and M. Barwick, 2002. Changes in fish communities of the Shoalhaven River 20 years after construction of Tallowa Dam, Australia. River Research and Applications 18: 265-286.
- Harris, J.H., G. Thorncraft and P. Wem. 1998. Evaluation of rock-ramp fishways in Australia. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 331-347.
- Larinier, M., 1998. Upstream and downstream fish passage experience in France. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 127-145.
- Lucas, M.C. and E. Baras, 2001. Migration of freshwater Fishes. Oxford: Blackwell Science Ltd., 420 pp.
- McDowall, R.M., 1988. Diadromy in Fishes: Migrations between Freshwater and Marine Environments. London: Croom Helm, 308 pp.
- Malmqvist, B. and S. Rundle, 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29: 134-153.

- Moser, M.L., A.L. Matter, L.C. Stuehrenberg, and T.C. Bjornn, 2002. Use of an extensive radio receiver network to document Pacific lamprey (*Lampetra tridentate*) entrance efficiency in the lower Columbia River, USA. Hydrobiologia 483: 45-53.
- Northcote, T.G., 1998. Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors) Fish Migration and Fish Bypasses, Oxford: Fishing News Books, Blackwell Science Publications, pp. 3-18.
- Permanente Nederlands-Duitse Grenswatercommissie, 1992. Beheersplan Vecht, interim-rapportage Subcommissie Vecht en Dinkel.
- Schutten, G.J., 1981. Varen waar geen water is. Reconstructie van een verdwenen wereld. Geschiedenis van de scheepvaart ten oosten van de IJssel van 1300 tot 1930. Broekhuis, Hengelo, the Netherlands.
- Staring, W. and T.J. Stieltjes, 1848. De Overijsselse wateren. Zwolle.
- TAUW Infra Consult B.V., 1992. Bouwstenen voor een natuurontwikkelingsvisie voor de Overijsselse Vecht. In opdracht van Minsterie van LNV, Directie natuur, Bos, Landschap en Fauna
- Werkgroep Vechtvisie, 1997. De Vechtvisie: stap voor stap naar een duurzame Vecht. Arcadis Heidemij Advies-Rapport 634/OA97/7108/45545/djm
- Wolfert, H.P., G.J. Maas and G.H.P. Dirkx, 1996. Het meandergedrag van de Overijsselse Vecht; historische morfodynamiek en kansrijkdom voor natuurontwikkeling. DLO-Staring Centrum Rapport 408, Wageningen, the Netherlands.

Inleiding

Rivieren zijn wereldwijd vaak fors op de schop gegaan door toedoen van de mens. Ze zijn op grote schaal aangepast, verdiept en rechtgetrokken om geschikt te worden gemaakt voor scheepvaart. Vaak dienden ze als open riool om afvalwater kwijt te raken. Ze werden bedijkt om gebieden tegen overstromingen te beschermen. Dammen en stuwen zijn aangelegd om elektriciteit uit waterkracht te winnen of de waterafvoer te regelen. En vaak vond er intensieve visserij plaats. Dit alles heeft grote gevolgen gehad voor vele vissoorten die in de rivieren leven.

De eerste soorten die van het toneel verdwenen waren vaak lange-afstands-trekkers. Deze hebben een serie opeenvolgende leefgebieden nodig om hun levenscyclus te kunnen voltooien: van beken in de bovenloop van rivieren tot de open oceaan. Het bekendste voorbeeld is de zalm. Eenmaal volwassen geworden op de open oceaan trekken ze naar hun geboorterivieren terug om te paaien in de bergbeken waarin ze vandaan kwamen. Het is dus niet verwonderlijk dat de vele ingrepen in rivieren juist vissoorten treft die afhankelijk zijn van open trekroutes tussen leefgebieden die ook nog eens aan hoge kwaliteitseisen moeten voldoen. Zij zijn het meest kwetsbaar, omdat één zwakke schakel in de noodzakelijke keten van leefgebieden en trekroutes al te veel kan zijn.

Inmiddels zijn er maatregelen genomen om rivieren weer gezonder te maken. Zuivering van afvalwater heeft gezorgd voor een sterk verbeterde waterkwaliteit. Om de migratie van trekvissen langs barrières zoals stuwen en dammen weer mogelijk te maken zijn er verschillende typen vistrappen ontwikkeld. De meeste vistrappen volgen het principe dat via een omleiding langs een stuw of dam het (onoverbrugbaar) grote verschil in waterhoogte wordt opgeknipt in kleine stappen met zó weinig hoogteverschil dat vis hier wel tegen op kan komen. De aanleg van vistrappen zou de verbinding tussen verschillende leefgebieden moeten herstellen. Dit geldt niet alleen voor lange-afstands-trekkers, maar ook voor vis die op kleinere schaal migreert. En daarnaast ook om gebieden waar soorten zijn verdwenen weer toegankelijk te maken. Of om uitwisseling van individuen tussen verschillende populaties weer mogelijk te maken en zo inteelt te voorkomen.

In Nederland zijn intussen veel vistrappen gebouwd. De Overijsselse Vecht (verder kortweg de Vecht genoemd) was de eerste grotere rivier in Nederland waar een complete serie vistrappen langs alle stuwen zijn aangelegd in de jaren 80 en 90 van de vorige eeuw. Omdat hier ook in de jaren 70 vismigratie-onderzoeken zijn uitgevoerd en er daarnaast nog steeds een populatie riviertrekvis aanwezig was (namelijk de winde), was dit een geschikt gebied om het effect van de aanleg van vistrappen te onderzoeken. In dit proefschrift breng ik het effect van vistrappen in beeld en is onderliggende kennis ontwikkeld aan de hand van een aantal onderzoeksvragen die in de verschillende hoofdstukken aan bod komen:

- In welke mate was er optrek langs de stuwen mogelijk in de periode voordat er vistrappen zijn gebouwd (hfst. 2)?
- Hoe goed zijn deze vistrappen passeerbaar voor verschillende vissoorten en levensstadia (hfst. 3)?
- Hebben de vistrappen geresulteerd in veranderingen in de visgemeenschap (hfst. 4)?
- Hoe verhoudt de huidige visgemeenschap zich tot de natuurlijke situatie in een ver verleden (hfst. 5)?
- Hoe belangrijk is migratie en trekgedrag binnen de populatie winde (hfst. 6)?
- Hoe groot is de kans op succesvolle passage van windes die via de vistrappen willen optrekken en welke factoren bepalen dit (hfst. 7)?

Ten slotte worden de conclusies en bevindingen geïntegreerd en in een breder kader geplaatst in de synthese (hfst. 8).

Weir (W1) at Vechterweerd / Stuw bij Vechterweerd

2

Assessing migratory opportunities for fish in the weir-regulated River Vecht before fishways were built

Erwin Winter
Wim van Densen

Published as:
Winter H.V. & van Densen W.L.T. 2001. Assessing the opportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8, 513-532

Abstract

The degree of obstruction posed by weirs to potential upstream movements of fish (predominantly cyprinids) in the River Vecht, the Netherlands, was assessed. This rain-fed river shows high variability in discharge, providing opportunities for passage at high discharge when weirs were free-flowing. Daily recorded discharge and water levels during 1960-1984 and an analysis of swimming capacities and migratory behaviour were used to assess whether hydraulic conditions per each day and species were suitable for ascent. The assessment demonstrates that migratory opportunities along the six weirs were extremely limited. Only 10 of 32 species were able to ascend all weirs, and only in 5 to 30 % of the years. Opportunities were greatest for large-sized species during November-March at the downstream-situated weirs, whereas small-sized species had no opportunities year-round. The approach used is widely applicable for barrier assessment in other rivers, because it requires only basic hydraulic measurements that are often available.

Introduction

Weirs, sluices, locks or dams have been built on many rivers to optimize water levels for navigation, generating power, or agricultural land use. These man-made barriers may affect migration of fish to a variable degree, from short delays to complete obstruction (Ward & Stanford 1989, Larinier 1998). The effect depends on the dimensions and characteristics of the barriers, the hydrology of the river and species-specific features, such as swimming capacities and timing of migration (Northcote 1998). Large dams pose a complete obstruction for all upstream-migrating fish, whereas smaller weirs that are inundated or free-flowing during high discharge events still provide limited opportunities for some upstream migrants. While much information is available on upstream passage problems for salmonids, little is known about constraints to non-salmonids (Smith 1991, Lucas & Frear 1997). There is a growing awareness, however, that migration plays an important role in many non-salmonid species such as cyprinids (Cowx 1998; Lucas et al. 2000).

The lowland River Vecht has been regulated in the Dutch part by six weirs which were built between 1850 and 1914. The fish fauna consists almost exclusively of non-salmonid species, mainly cyprinids (Cazemier 1978). To improve conditions for upstream fish migration, fishways that bypass all weirs were built between 1987 and 1994. An evaluation of the degree of obstruction during the period before these fishways were constructed was never attempted. The aim of this study is to quantify the constraints posed by the weirs to potential upstream movements for all the fish species recorded in the River Vecht. The method applied evaluates for each species whether the hydraulic conditions per day at a weir were suitable for ascent, taking into account size and temperature effects on burst swimming speeds, and available information on migratory behaviour.

The assessment was based on: (1) daily recorded water levels upstream and downstream of each of the six weirs between 1960 and 1983; (2) daily discharge data between 1965 and 1983; and (3) a literature review and analysis of migratory behaviour and maximum swimming speeds for different species and size-groups.

The occurrence of free-flowing conditions during high discharge events when the weirs were lowered set the broadest constraint to fish migration. From the frequency of free-flowing events, estimated water velocities through the different weir-gaps, and swimming capacities of two cyprinids, the fast-swimming dace *Leuciscus leuciscus* (L.) and the slow-swimming gibel carp (goldfish) *Carassius auratus* (L.) (Bainbridge 1960, 1963), seasonal patterns and year-to-year variation in migratory opportunities were examined. As a measure of the degree to which upstream movement was obstructed, the fraction of years in which migration was possible was assessed at each weir for all species recorded in the River Vecht.

Material and methods

Study area

The River Vecht (52°30'N, 6°30'E) is the third largest river flowing through the Netherlands with a total length of 177 km (117 km in Germany) and a catchment area of 3800 km^2 (1800 km^2 in Germany). It discharges into the shallow eutrophic freshwater lakes Zwarte Meer and IJsselmeer, both remainders of the former Zuiderzee estuary after the building of a large dam (Afsluitdijk) in 1932 (Fig. 2.1).

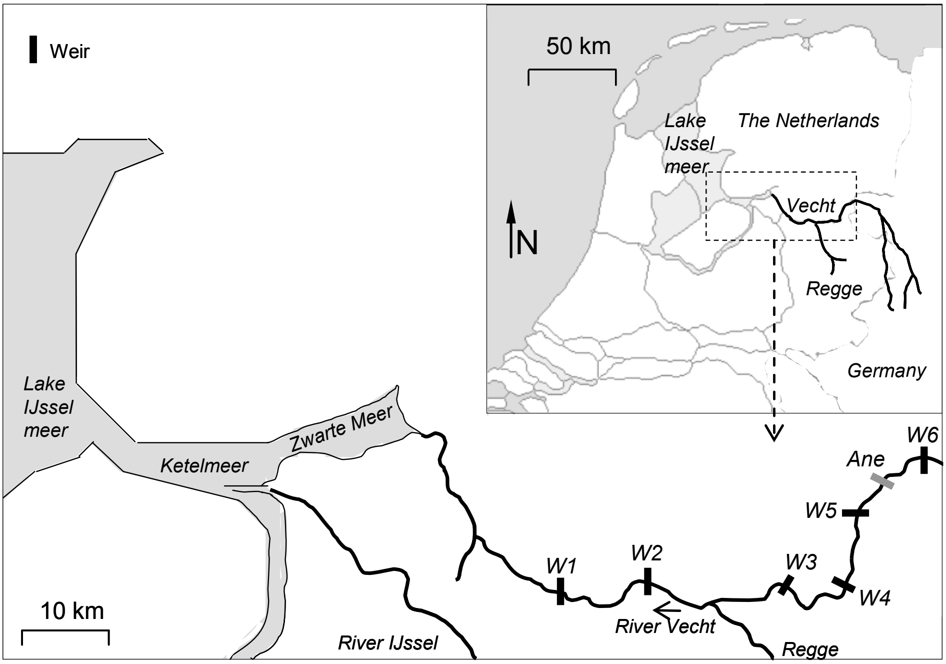


Figure 2.1 *Map of the River Vecht; weir at Ane has been removed in 1970*

Originally the River Vecht was a freely meandering river that discharged directly into the Zuiderzee estuary. In the 1850s, two weirs were built (at Ane and De Haandrik; Fig. 2.1 and Table 2.1) to control water levels for navigation. Moreover, the length of the Dutch part was reduced from 90 to 60 km by cutting off many meanders between 1896 and 1914, resulting in a drop in water level during dry periods. To maintain enough water for agricultural purposes, five more weirs were constructed between 1907 and 1914 (Wolfert et al.1996). In 1970 the weir at Ane was removed. Because the weir at Ane posed less constraints to fish movements than both downstream- and upstream-situated weirs (Fig. 2.1), it has not been considered further.

Table 2.1. Characteristics of weirs in the Dutch part of the River Vecht

No.	Name weir	River km	Catch-ment area (%)	N of gaps	Weir-gap bottom (m asl)**	Target level	
						Downstr. (m asl)	Upstr. (m asl)
1	Vechterweerd	166	99.0	4	-1.48	-0.20	1.25
2	Vilsteren	156	97.7	4	0.15	1.25	2.65
3	Junne	144	71.4	3	2.20	2.65	4.45
4	Mariënberg	137	67.6	3	3.49	4.45	5.50
5	Hardenberg	130	63.2	2	4.85	5.50	7.10
6	De Haandrik	120	46.9	2	6.59	7.10	9.10

* Width of all weir-gaps is 9 m, length is 7 m.
† During winter, target levels for all weirs are 0.2-0.4 lower, except for upstream weir 6 (9.1 m all year round)
** asl= above sea level.

The River Vecht is a rain-fed river with maximum discharge during winter (Fig. 2.2). Response time to rainfall is rapid, resulting in a high short-term variability in discharge (Parmet & Raak 1997). The height of each weir was manually adjusted by placing boards in the weir-gaps. Boards of 0.25 and 0.5 m were used on top of 1 m boards for fine tuning the upstream target level at low discharge. The number of weir-gaps varies per weir, but the dimensions of each gap are similar (Table 2.1).

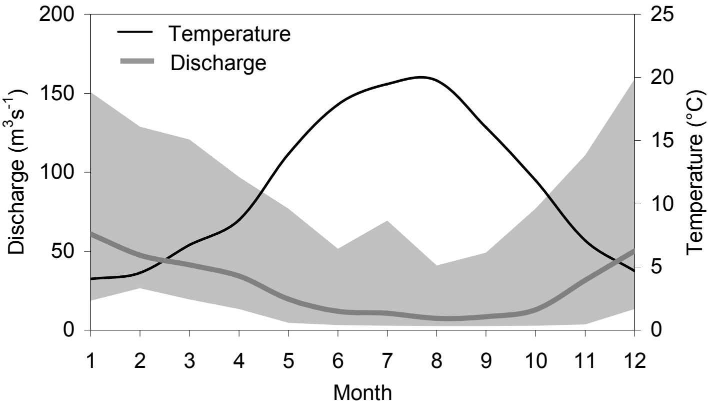


Figure 2.2 *Seasonal changes in the 5 (lower limit shaded area), 50 (grey line), and 95 (upper limit shaded area) percentiles of average monthly discharge during 1965-1983; and average monthly water temperature (black line) during 1970-1996, for the River Vecht.*

During periods of low discharge, the placing of stacked boards caused abrupt water level differences at each weir. With increasing discharge, the downstream water level of a weir rose, whereas the upstream level was kept as close as possible to the target by removing boards. At high discharge, all remaining 1 m boards were removed resulting in free-flowing conditions characterized by small differences between downstream and upstream level, and upstream level usually exceeding the target. At extreme high discharge, the riverbanks are flooded and fish can use the floodplains along weir 1 and 2 to bypass these weirs; at weir 5 an extra spillway in the floodplain becomes available. At the other three weirs, however, all water flowed exclusively through the weir-gaps at all discharge rates.

Hydraulic conditions at weirs

From 1960 through 1983, water levels were recorded almost daily to the nearest cm at a distance of approximately 4 m upstream and downstream of each weir by reading water-gauges. Data for 1965 were not available. For other years the number of days without records varied per weir (3 %, 0.5 %, 3 %, 8 %, 12 %, and 3 % for weirs 1-6, respectively). Missing records per month varied between 0.3-1.5 % and showed no seasonal trend.

The frequency distribution of water level differences for all weirs showed a peak for differences less than 0.25 m (Fig. 2.3). It was assumed that this peak represented free-flowing conditions with no boards in position. For differences higher than 0.25 m it was assumed that at least a few boards were in position. Under these 'obstructed' conditions fish may ascend weirs only by jumping or swimming against the cascading water. The fish fauna in the river is dominated by cyprinids and percids, whereas strong jumpers like salmonids are virtually absent (Cazemier 1978). Therefore, efforts were concentrated on free-flowing conditions and the frequency of occurrence for each weir was calculated as an indication of the maximum windows available for upstream movements. Because both discharge (Fig. 2.2) and migratory behaviour of fish (Northcote 1998) vary throughout the year, seasonal patterns in the average fraction of free-flowing conditions were examined for each weir.

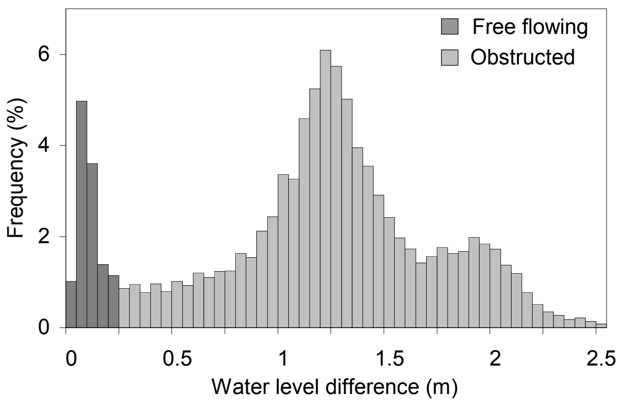


Figure 2.3 *Frequency distribution (%) of differences between upstream and downstream water levels at all six weirs combined in the River Vecht (1960-1983). A water level difference of 0.25 marks the transition from 'free-flowing' conditions (dark grey bars) to 'obstructed' conditions, with at least some boards in position (light grey bars).*

As an index of the degree to which upstream migration was hampered per weir throughout the year, the probability that fish encountered at least one free-flowing day per month was calculated. When data on water levels were missing for a particular weir, information from neighbouring weirs and other dates was used to estimate whether that weir was free-flowing or not. When comparing the frequency of free-flowing conditions disregarding days with missing records with the frequency obtained by including estimates for missing records, differences were smaller than 0.3 % for four weirs. The estimated fraction of free-flowing conditions was 1.7 % higher than observed for weir 1; and 0.9 % lower than observed for weir 4, indicating that missing records exhibited minimal bias for discharge.

Water velocities in the weir-gap under free-flowing conditions were estimated by using discharge data and water levels. Daily discharge data at weir 1 were available for 1965-1983 (Parmet & Raak 1997) and at Emlichheim since 1970 (Fig. 2.1). The data from the nearest of these two locations were used to calculate daily discharge at each weir, corrected for proportional catchment area (Table 2.1). For each day i and weir j with a free-flowing condition, mean water velocity v_{ij} (m.s^{-1}) was estimated by:

$$v_{ij} = \frac{Q_{ij}}{n_j W \left(H_{ij} - B_j \right)} \qquad (1)$$

where Q_{ij}= discharge (m^3.s^{-1}), n_j= number of weir-gaps, W= width of the weir-gap (m), H_{ij}= downstream water level above sea level (m asl), and B_j= level of the bottom of the weir-gap (m asl).

Table 2.2 Estimated water velocities compared with measured water velocities through the six weirs in the River Vecht during an extremely high discharge event in March 1998, when all weirs were free-flowing.

Date	Weir	Discharge Q_{total} - $Q_{fishway}$ (m^3.s^{-1})*	Water level $H_{downstr.}$ (m asl)**	Estimated v†† (m.s^{-1})	Measured v ± SD (n) (m.s^{-1})	Difference (%)
9 Mar.	6	118	9.60	2.19	2.10 ± 0.22 (4)	4
	5	117†	7.59	(2.97)	2.01 ± 0.13 (4)	
	4	167	6.56	2.02	1.95 ± 0.13 (6)	4
	3	154	5.48	1.74	1.50 ± 0.11 (6)	16
	2	260†	2.62	(2.93)	1.95 ± 0.32 (8)	
	1	254†	2.04	(2.01)	1.61 ± 0.14 (8)	
11 Mar.	1	192	1.69	1.72	1.79 ± 0.12 (47)	- 4
12 Mar.	1	132	1.25	1.34	1.41 ± 0.06 (8)	- 5

* Estimated discharge through the weir derived from total discharge corrected for discharge through the fishway (fishways along the weirs were constructed between 1987 and 1994).

† Discharge through the weirgaps could not be estimated, because an unknown fraction of total discharge flowed through the floodplains along the weir, as a result the estimated v will be an overestimation and is therefore in parentheses

** asl= above sea level.

†† Using equation 1 and Table 2.1.

To indicate the precision of estimated water velocities using equation 1, these were compared to real measurements in the present situation with fishways along the weirs. During an extremely high discharge event in March 1998 (e.g. only three events during 1965-1983 yielded higher discharges), all weirs were free-flowing and water velocities through each weir-gap and upstream and downstream water levels at each weir were measured. On 9 March when discharge peaked at125 $m^3.s^{-1}$ at Emlichheim, these measurements were carried out at each weir and on 11 and 12 March at weir 1. Based on measured water levels at each weir and discharge at Emmlichheim and the tributary Regge, corrected for discharge flowing through the fishways, mean water velocity through each weir was estimated using equation 1 and Table 2.1, and then compared to measured water velocity (table 2.2). The estimated velocities differed less than 5 % from the measured velocities, except for weir 3 where the difference was 16 %. This comparison was not feasible for weir 1, 2 and 5 on 9 March because an unknown fraction of total discharge flowed through the floodplains along these weirs.

Mean water velocity through the weir-gaps, however, may not be the true constraint, because fish are more likely to ascend where velocities are lowest, i.e. near the walls and bottom. Therefore, in each weir-gap of weir 1 on 11 March 1998 water velocity profiles were measured with an Ott flow-meter at water depths ranging from 0.25 to 2.75 m, at 0.5 m intervals, and at a distance of 0.2 m and 3.0 m from the walls. Measured mean water velocity was 1.79 $m.s^{-1}$ (SD 0.12, n=47) at 3.0 m distance from the wall; and 1.65 $m.s^{-1}$ (SD 0.30, n=20) at 0.2 m distance from the wall. There was no difference between 0.2 m from the wall and 0.25 m from the bottom. The higher SD at 0.2 m than at 3.0 m indicates more turbulent water at the margins. Water velocities at the margins of the weir-gap were thus a factor of 0.9 lower than the mean. Because dimensions and construction of all weir-gaps are similar (Table 2.1), these results can be applied to all weirs.

Burst swimming capacity

To assess whether fish can ascend a weir-gap at the estimated water velocities, burst swimming speeds and endurance were considered. Burst swimming is always accompanied by low endurance, because fast ('white') muscle contraction is anaerobic and fuelled by stored glycogen (Wardle 1980). Downstream and upstream of a weir-gap, water velocity drops directly and eddies provide suitable resting areas for fish.

Burst swimming speed of fish is determined by the maximum distance covered by one tail beat (stride length) and the maximum tail beat frequency (Wardle 1975). Although disease and condition may affect individual performances (Beamish 1978), only maximum stride length and tail beat frequency per species were considered. Maximum stride length S, when expressed in body length l, depends only on species and typically varies between 0.4 and 1.1 l (Videler & Wardle 1991, Videler 1993). Maximum tail beat frequency F depends on species, temperature and size (Wardle 1975). Videler & Wardle (1991) found that F approximately doubles for each 10 °C increase in temperature, and increases by a factor of 0.87 for each 10 cm increase in size (range 0.84-0.89 for different species). If for a given species of length x and at temperature y the measured maximum tail beat frequency is F_{xy} (s^{-1}), then F_{lt} at other lengths l and temperatures t can be estimated by (Videler & Wardle 1991):

$$F_{lt} = F_{xy} \cdot 0.87^{\frac{l-x}{10}} \cdot 2^{\frac{t-y}{10}}$$ (2)

The maximum swimming speed Ult (m.s-1) can be estimated if the species-specific maximum stride length S is known:

$$U_{lt} = S \cdot l \cdot F_{lt}$$ (3)

Endurance of burst swimming ranges from 5 to 15 s (Blake 1983). Thus, to ascend a weir-gap with an average length of 7 m (Table 2.1), using 10 s for mean endurance, fish need a surplus speed of 0.7 m.s-1 on top of the speed required to match the water velocity. Using a correction factor of 0.9 for the slightly lower velocities occurring close to the margins of the weir-gap, the maximum water velocity in the weir-gap Vlt (m.s-1) that can be overcome by a fish of length l at temperature t can be calculated by:

$$V_{lt} = \frac{U_{lt} - 0.7}{0.9}$$ (4)

If v_{ij} (equation 1) was smaller or equal to V_{lt} (equations 2, 3 and 4), ascending weir j on day i was considered possible for a fish of length l at temperature t.

Assessment of migratory opportunities

Data on maximum swimming speeds that encompass length, temperature, stride length and tail beat frequency for fish species occurring in River Vecht are limited to dace and gibel carp. Maximum stride length found for dace was S=0.73 (Bainbridge 1960) and for gibel carp S= 0.71 (Bainbridge 1963). Maximum tail beat frequencies for dace are F_{xy} =25 s^{-1} for a size of 9 cm at 15 °C, and for gibel carp F_{xy} =15 s^{-1} for a size of 7 cm at 15 °C (Bainbridge 1960). Dace is a relatively fast swimmer among the cyprinids, whereas gibel carp is a relatively slow swimmer. Size and temperature effects on migratory opportunities for fast and slow swimmers throughout the year are demonstrated by calculating the fraction of free-flowing conditions when ascent was possible for dace and gibel carp of 10, 20 and 30 cm length at 5, 10 and 15 °C for each weir.

Variability in migratory opportunities for different species and timing of migration were examined by calculating the number of days when ascent was possible for dace and gibel carp of maximum size (30 cm) for each year and weir. Upstream spawning migration of dace occurs during February-March (Mann 1991, Mills 1991), thus representing early spring, fast-swimming migrants. Little is known, however, about the migratory behaviour of gibel carp. Therefore, it was assumed that a local pre-spawning migration started one month before spawning, during May-June, which is a common feature in riverine cyprinids (Mills 1991, Waidbacher & Haidvogl 1998), to demonstrate the opportunities for late spring, slow-swimming migrants. For 1960-1964, when no discharge data were available and therefore no water velocities v_{ij} could be estimated, the number of days with free-flowing conditions per weir per year for the average fraction of days when v_{ij} did not exceed V_{lt} at each weir during 1965-1983 were corrected, assuming that distributions of water velocities at free-flowing events were the same during both periods.

To assess opportunities for upstream migration of all fish recorded in the river, data from the literature on timing of migration, spawning period, and approximate size range of the fish were used. For catadromous species timing and size-ranges of upstream-migrating juveniles were used. For anadromous and potamodromous species (McDowall 1988) size-ranges of adult fish were used. To assess the migratory opportunities that fish may at least have had, pre-spawning migration was assumed to start one month before spawning for species with little or unknown migratory behaviour. Even though some of these species might not migrate at all, it was estimated whether ascent was potentially possible. In the absence of data on stride length for most species, S=0.7 was assumed for species using a carangiform or sub-carangiform swimming mode (most cyprinids, percids, salmonids and osmerids, Videler 1993), S=0.5 for species using an anguilliform swimming mode (anguillids, petromyzontids and cobitids, Videler 1993), S=0.4 for esocids (Webb 1988), and S=0.5 for pleuronectids, cottids and gasterosteids. The high maximum tail beat frequency F_{xy} as found for dace was used for the rheophilic cyprinids (Schiemer & Waidbacher 1992), the piscivorous percids and esocids (usually good sprinters), the salmonids and the gasterosteids; the low F_{xy} of gibel carp was used for the high-bodied cyprinids and the species using an anguilliform swimming mode (anguillids, petromyzontids and cobitids); and an intermediate F_{xy} (20 s^{-1} for a size of 8 cm at 15 °C) was used for the remaining cyprinids and percids, and osmerids, pleuronectids and cottids. The number of days when weir ascent was possible was calculated for mean size, and for the approximate upper and lower limit of the size-range of each species, as described for dace and gibel carp above, using mean water temperatures per month and equations 1-4. As an index of the degree to which upstream migration was hampered for each species, the fraction of years in which ascent was possible for at least one day was calculated for each weir.

Unfortunately, most literature on swimming speed of fish lists either temperature or size (Videler & Wardle 1991), and therefore provide only a rough indication of swimming capacity. For those species where burst swimming speeds in combination with size and temperature were available from the literature, measured velocity was compared to estimated velocity based on S and F_{xy} as used in the assessment and equations 2 and 3 (Table 2.3). For these seven species and Atlantic salmon, closely related to brown trout and assumed to have a very similar swimming capacity, estimated burst speeds are close to measured speeds, except perhaps for chub, where estimated speed is 32 % higher than measured. The F_{xy} for chub might be closer to intermediate than high. Therefore, the assessment for chub was also calculated using intermediate F_{xy}, to indicate the possible error in assigning species in three classes of F_{xy}.

Table 2.3 *Comparison between measured burst swimming data from literature and estimated burst swimming as used in the assessment of migratory opportunities in River Vecht.*

Species*	Measured burst swimming †				Estimated burst swimming††				Difference
	l (cm)	*t* (°C)	U_{lt} ** (/.s^{-1})	U_{lt} (m.s^{-1})	*l* (cm)	*t* (°C)	U_{lt} (/.s^{-1})	U_{lt} (m.s^{-1})	(%)
Stone loach (1)	< 10	15	19.7		5	15	15.2		-23
	> 10	15	14.2		12	15	14		-1
3-sp. stickleback (2)	5.8-6.3	16-18		0.62-0.94	5.8-6.3	16-18		0.64-0.79	-8
3-sp. stickleback (3)	3.3-7.4	16-18	15.8-16.6		3.3-7.4	16-18	13.7-16.7		-6
Carp (3)	3.6-7.6	16-18	13.6-15.6		3.6-7.6	16-18	15.1-18.3		14
Roach (3)	4.5-10	16-18	13.3-17.2		4.5-10	16-18	14.6-18.1		7
Chub (3)	3.8-6.4	16-18	15.2-17.0		3.8-6.4	16-18	19.4-23.2		32
Gudgeon (3)	5.3-9.5	16-18	15.0-16.7		5.3-9.5	16-18	14.7-17.9		3
Atlantic salmon (4)	48.3-54.8	10.1 ± 1.6		3.17 (mean)	51.6	10.1		3.7	17
	49.5	10.1 ± 1.6		4.06 (max)	49.5	11.7		4.09	1
Eel (5)	7.5	13.3		0.54	7.5	13.3		0.5	-7

* For scientific names see Table 2.5, except Atlantic salmon *Salmo salar* (L.).

† Source (1) Stahlberg 1985; (2) Taylor & McPhail 1985; (3) Zerrath 1996; (4) Colavecchia *et al.*1998; (5) McCleave 1980.

** For data from Zerrath 1996: *U*lt 95 % confidence intervals.

†† Based on Videler & Wardle 1991, Videler 1993, Bainbridge 1960, 1963 (equations 2 and 3, see text for more details).

Results

Hydraulic conditions at weirs

The maximum water level differences varied between weirs from 1.5 m for weir 2, to 3 m for weir 6 at low discharge rates (Fig. 2.4). At water level differences less than 1 m, cumulative frequency distributions were similar for weirs 1-4 and considerably lower for weirs 5-6. Free-flowing conditions (water level differences < 0.25 m) occurred in 16-18 % of the time at weirs 1-4 and in only 4 % at weir 5 and 2 % at weir 6. The aberrant shape of the curve for weir 6 may be explained by the removal of the weir at Ane in 1970, which caused an increase of water level differences at low discharge of about 1 m.

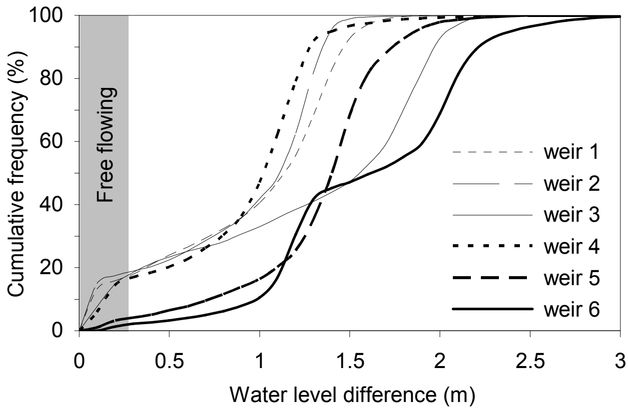


Figure 2.4 *Cumulative frequency (%) of differences between upstream and downstream water levels at each weir (1960-1983).*

At weirs 1-4, free-flowing conditions were most frequently observed in January, about 50 % of the time (Fig. 2.5), and decreased to less than 5 % in May. During summer, hardly any opportunities for upstream migration occurred and from September onwards occurrence of free-flowing conditions increased again. The pattern for weirs 5 and 6 was broadly similar but at a much lower level (less than 10 %). Between April and October virtually no opportunities for migration were present.

For each weir, the probability that upstream-migrating fish encountered at least one day with a free-flowing condition per month (Fig. 2.5) may be a more significant parameter, because fish may delay their migration if conditions are unfavourable. The pattern of probability per month was broadly similar to the average fraction per month (Fig. 2.5), during November-March there was at least a 50 % chance of meeting a free-flowing condition at weirs 1-4, whereas during summer, this was reduced to10-20 %. At weirs 5-6, the probability never exceeded 40 % and was less than 5 % during summer.

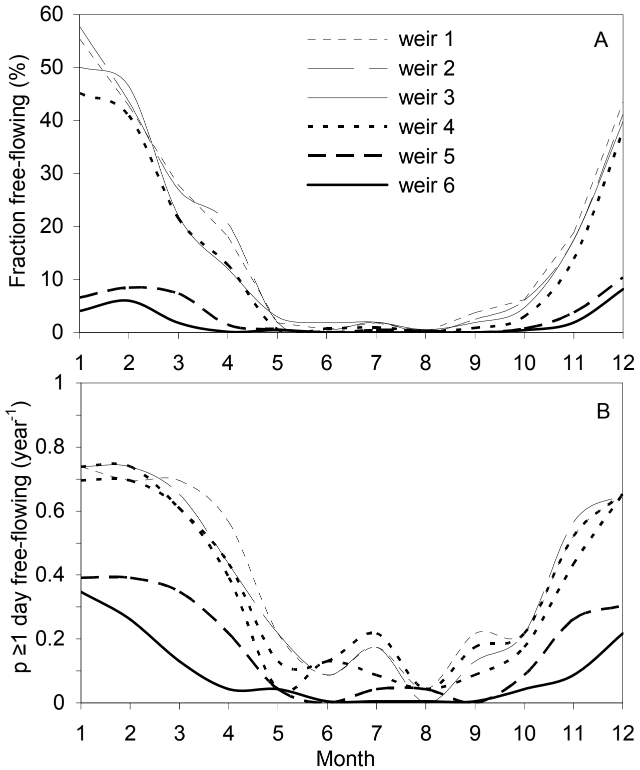


Figure 2.5 Seasonal variations in (A) the fraction of days with free-flowing conditions and (B) the probability of encountering at least one day with free-flowing conditions per month at each weir, 1960-1983.

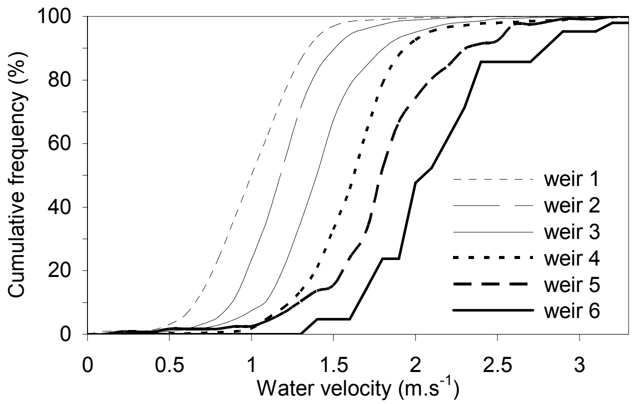


Figure 2.6 Cumulative frequency of estimated water velocities through each weir-gap at free-flowing conditions (1970-1983).

Mean water velocities per weir under free-flowing conditions gradually increased when moving upstream from 1.1 m.s-1 at weir 1 to 2.1 at weir 6 (Fig. 2.6). Weir 6 was only free-flowing at extreme high discharges and consequently the number of days recorded with free-flowing conditions was very low (n=18 in 14 years), thus explaining the irregular shape of this curve.

Migratory opportunities

Size of fish and temperature conditions may have a profound effect on whether weir ascent during free-flowing conditions can be achieved, as shown for dace and gibel carp (Table 2.4). At a length of 10 cm, gibel carp appears incapable of ascending any weir at all temperatures, while dace of this size may be able to ascend only during a small fraction of these days at 15 °C. These fractions increase with fish size and most dace of 30 cm (maximum length) should encounter no constraints during their migration due to water velocity at any weir, except at the upstream weirs at temperatures of 5 °C. For gibel carp, only 30 cm fish should be able to ascend the downstream weirs at high temperatures.

Table 2.4. *Fraction of free-flowing conditions at each weir, when ascent was estimated possible for dace Leuciscus leuciscus and gibel carp Carassius auratus at each weir, based on maximum swimming speeds at different sizes and temperatures*

Species	l	t	U_{lt}*	V_{lt}†		Fraction when ascent was possible					
	(cm)	(°C)	(m.s^{-1})	(m.s^{-1})	weir	1	2	3	4	5	6
Dace	10	5	0.9	0.2		0	0	0	0	0	0
		10	1.3	0.6		0.1	0	0	0	0	0
		15	1.8	1.2		0.8	0.5	0.2	0.1	0.1	0
	20	5	1.6	1.0		0.5	0.2	0.1	0	0	0
		10	2.2	1.7		1	1	0.8	0.6	0.3	0.1
		15	3.1	2.7		1	1	1	1	1	0.9
	30	5	2.0	1.5		1	0.9	0.7	0.3	0.2	0
		10	2.9	2.4		1	1	1	1	0.9	0.9
		15	4.1	3.7		1	1	1	1	1	1
Gibel carp	10	5	0.5	0		0	0	0	0	0	0
		10	0.7	0		0	0	0	0	0	0
		15	1.0	0.3		0	0	0	0	0	0
	20	5	0.9	0.2		0	0	0	0	0	0
		10	1.2	0.6		0.1	0	0	0	0	0
		15	1.7	1.1		0.6	0.4	0.1	0.1	0	0
	30	5	1.1	0.5		0	0	0	0	0	0
		10	1.6	1.0		0.5	0.2	0.1	0	0	0
		15	2.2	1.7		1	1	0.8	0.6	0.3	0.1

* Maximum swimming speeds based on Videler & Wardle 1991 and Bainbridge 1960 (see text; equations 2, 3)

† Maximum water velocity through weir-gap that can be conquered within 10 s (see text equation 4, compare Fig. 2.7)

Table 2.5 *Assessment of migratory opportunities for all fish species in River Vecht during 1960-1983, expressed as fraction of years in which upstream weir ascent was possible for at least one day during the migration period.Assessment of migratory opportunities for all fish species in River Vecht during 1960-1983, expressed as fraction of years in which upstream weir ascent was possible for at least one day during the migration period.*

Species recorded in River Vecht	Migr. type†	Migr. period	Mean size, size-range	Swim. cap*	Source ††	Fraction of years with migratory opportunities **	
		(month)	(cm)	*S*	*F*	Weirs 1-4	Weirs 5-6
Ide *Leuciscus idus* (L.)	pot.	2-4	40 (30-50)	0.7 h	*3,4*	0.8 (0.7-0.9)	0.4 (0.2-0.6)
Barbel *Barbus barbus* (L.)	pot.	3-5	50 (30-70)	0.7 h	*15*	0.7 (0.6-0.7)	0.3 (0.2-0.4)
Pikeperch *Stizostedion lucioperca* (L.)	pre.	(3-4)	60 (40-80)	0.7 h	*1,2*	0.7 (0.7)	0.3 (0.2-0.4)
Nase *Chondrostoma nasus* (L.)	pot.	3-4	40 (30-50)	0.7 h	*2,8,9*	0.7 (0.6-0.7)	0.3 (0.2-0.4)
Perch *Perca fluviatilis* (L.)	pre.	(3-4)	25 (15-35)	0.7 h	*2*	0.7 (0.1-0.7)	0.2 (0-0.4)
Brown trout *Salmo trutta* (L.)	ana.	6-11	60 (40-80)	0.7 h	*1,5*	0.6 (0.6-0.7)	0.2 (0.1-0.3)
Dace *Leuciscus leuciscus* (L.)	pot.	2-3	20 (15-30)	0.7 h	*1,9,11*	0.6 (0.1-0.9)	0.2 (0-0.5)
Chub *Leuciscus cephalus* (L.) †††	pot.	4-6	40 (30-50)	0.7 h	*9,14*	0.5 (0.4-0.6)	0.2 (0.1-0.3)
Pike *Esox lucius* (L.)	pot.	2-3	70 (50-90)	0.4 h	*2,4,17*	0.5 (0.1-0.7)	0.1 (0-0.1)
Bream *Abramis brama* (L.)	pot.	4-6	40 (30-55)	0.7 l	*2,9*	0.4 (0.1-0.6)	0 (0-0.2)
Rudd *Scardinius erythrophthalmus* (L.)	pre.	(4-6)	25 (15-35)	0.7 i	*2*	0.4 (0-0.6)	0 (0-0.2)
Roach *Rutilus rutilus* (L.)	pot.	4-5	20 (15-35)	0.7 i	*2,7,11*	0.3 (0-0.6)	0 (0-0.2)
Carp *Cyprinus carpio* (L.)	pre.	(5-6)	60 (40-80)	0.7 i	*2*	0.2 (0.1-0.3)	0
Bleak *Alburnus alburnus* (L.)	pot.	4-6	15 (10-20)	0.7 i	*1,11*	0.2 (0-0.5)	0
Tench *Tinca tinca* (L.)	pre.	(5-6)	35 (20-50)	0.7 l	*1,2*	0.2 (0-0.3)	0

Gudgeon *Gobio gobio* (L.)	pot.	4-5	15 (10-20)	0.7 i	*1,2,11*	0.1 (0-0.5)	0
Lampern *Lampetra fluviatilis* (L.)	ana.	9-4	35 (30-45)	0.5 l	*5,12*	0.1 (0-0.4)	0
Crusian carp *Carassius carassius* (L.)	pre.	(4-5)	20 (15-30)	0.7 l	*1*	0.1 (0-0.4)	0
Gibel carp *Carassius auratus* (L.)	pre.	(4-5)	20 (15-30)	0.7 l	*1*	0.1 (0-0.4)	0
White bream *Blicca bjoerkna* (L.)	pot.	5-6	20 (15-30)	0.7 l	*1,2,14*	0.1 (0-0.3)	0
Smelt *Osmerus eperlanus* (L.)	ana.	2-3	10 (8-20)	0.7 i	*1*	0 (0-0.4)	0
Ruffe *Gymnocephalus cernuus* (L.)	pre.	(3-5)	10 (7-15)	0.7 i	*1*	0 (0-0.3)	0
Flounder *Pleuronectes flesus* (L.)	cat.	5-7	10 (5-20)	0.5 i	*1,10*	0 (0-0.2)	0
Weatherfish *Misgurnus fossilis* (L.)	pre.	(3-5)	20 (15-25)	0.5 l	*1*	0	0
Spined loach *Cobitis taenia* (L.)	pre.	(4-5)	10 (8-12)	0.5 l	*1*	0	0
Stone loach *Barbatula barbatula* (L.)	pre.	(3-4)	8 (5-10)	0.5 l	*1*	0	0
Three-spined stickleback *Gasterosteus aculeatus* (L.)	ana.	3-4	8 (5-10)	0.5 h	*1,13,18*	0	0
Bullhead *Cottus gobio* (L.)	pre.	(3-4)	8 (5-10)	0.5 i	*1*	0	0
Eel *Anguilla anguilla* (L.)	cat.	4-5	7 (7-8)	0.5 l	*6,16,19*	0	0
Sunbleak *Leucaspius delineatus* (L.)	pre.	(4-6)	7 (5-8)	0.7 i	*1*	0	0
Bitterling *Rhodeus sericeus* (L.)	pre.	(4-6)	7 (5-8)	0.7 l	*1*	0	0
Ten-spined stickleback *Pungitius pungitius* (L.)	pre.	(3-4)	5 (4-7)	0.5 h	*1*	0	0

† Migration type: ana.= anadromous, cat.= catadromous, pot.= potadromous. If migration type was unknown then local pre-spawning migration starting one month before spawning was asssumed as a maximum estimate of migratory behaviour: pre.= assumed pre-spawning migration (migration period between brackets)

* Estimated swimming capacity, where *S* is stride length, *F* is maximum tail beat frequency, h indicates a relative high *F*represented by dace (25 s-1 at 15 °C for size 9 cm), l indicates relative low *F* represented by gibel carp (15 s-1 at 15 °C for 7 cm), i represents intermediate *F* (20 s-1 at 15 °C for 8 cm), (see text for more details)

†† *1* Lelek 1987; *2* Mann 1996, *3* Cala 1971; *4* Cazemier 1978; *5* Hartgers, Buijse & Dekker 1998; *6* Dekker 1997; *7* L'Abée-Lund & Vollestad 1985; *8* Waidbacher & Haidvogl 1998; *9* Mills 1991; *10* Kerstan 1991; *11* Mann 1991; *12* Holcik 1986; *13* McDowall 1988; *14* Prignon *et al*. 1998; *15* Lucas & Batley 1996; *16* White & Knights 1997; *17* Webb 1988; *18* Taylor & McPhail 1985; *19* McCleave 1980

** Mean fraction per group of weirs for mean size; and range of fractions for different sizes and weirs

††† For chub, using F=i (cf Table 3), yielded fractions of 0.5 (0.4-0.6) for weirs 1-4 and 0.2 (0-0.3) for weirs 5-6

Variability between years and weirs in the number of days that ascent was possible was high, and ranged from no days for most years and weirs for gibel carp, to all 59 days for weirs 1 and 2 in February-March 1971 for dace (Fig. 2.7). For dace, representing early spring, fast-swimming migrants, ascent of weirs 1-4 was possible in most years for many days, whereas ascent of weirs 5-6 was limited to only a few days in only four years. For gibel carp, representing late spring, slow-swimming migrants, ascent of the four downstream weirs was possible in half of the years over only a few days, whereas migration through the two upstream weirs was impossible, except for two days in 1983 for weir 5.

In the assessment of opportunities for upstream migration of all species recorded in River Vecht (Table 2.5), weirs 1-4 and weirs 5-6 were combined, because of small differences between weirs within these groups (see also Figs 2.4 and 2.5). There were large differences in the degree of obstruction for individual species, but the fraction of years with migratory opportunities was higher for weirs 1-4 than for weirs 5-6 in all species. For the downstream weirs, 23 of 32 species had some opportunities, varying from 5 to 90 % of the years. For the upstream weirs, however, only 10 of 32 species had opportunities varying from 5 to 60 % of the years.

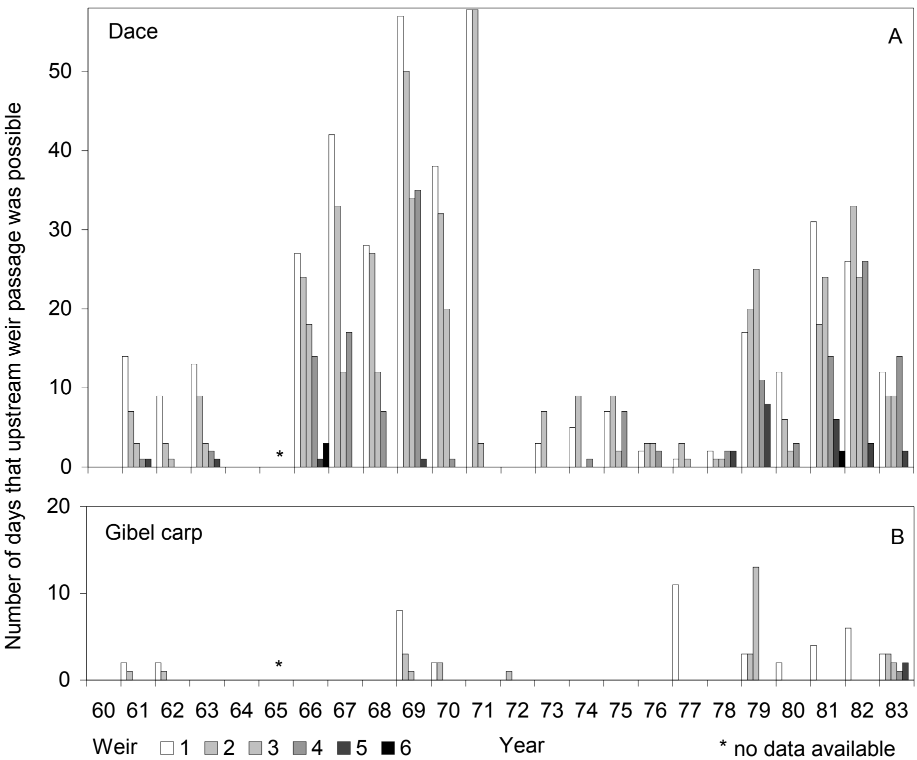


Figure 2.7 *Number of days per weir that (A) dace Leuciscus leuciscus, a fast swimmer and early spring migrant (February-March) and (B) gibel carp Carassius auratus, a slow swimmer and late-spring migrant (April-May), were able to ascend (at maximum length of 30 cm for both species), during 1960-1983.*

Discussion

The assessment demonstrated that opportunities for upstream movements of fish over the weirs in the Dutch part of the River Vecht were highly limited between 1960 and 1983. Only 10 of 32 species could have passed all six weirs in, at the most, 5 to 30 % of the years. Migratory windows for long distance migration to the German part of the river were limited to only a few days in less than 30 % of the years. None of the species was able to perform upstream migrations in every year, not even for a single weir.

There was a difference in migratory opportunities between the downstream-situated weirs and the upstream-situated weirs. Migration through weir 6, and to a lesser extent weir 5, was severely hampered; only a third of the species had limited opportunities to migrate upstream of weir 5 or 6. In contrast two third of the species had some opportunities to ascend the four downstream-situated weirs, although only 9 relatively large species were able to pass in more than 50 % of the years. Thus, larger migratory species with suitable spawning habitats available between weirs 1 and 5 may have been affected by the construction of weirs to only a small extent, whereas small migratory species and species depending on migration to spawning habitats in the upper part of the river are likely to have suffered markedly.

Timing of migration and, to a lesser extent size, seem to determine migratory opportunities for fish in this river. Probability of encountering free-flowing conditions were highest during November-March. Unfortunately, burst swimming speed during this period was at its lowest due to the low temperatures (Wardle 1975). As a consequence, only relatively large-sized, fast-swimming species can use these free-flowing conditions. With increasing temperatures during spring, medium-sized species are also capable of ascending, especially, weirs 1-4 (Table 2.4). However, probabilities of encountering free-flowing conditions rapidly decreases after March (Fig. 2.5). For small species, water velocities through weir-gaps at free-flowing conditions pose an almost complete obstruction for migration year-round. Only during extreme high floods, these small species can pass weirs 1, 2 and 5 by using the floodplains. These opportunities were restricted to only a few days between 1960 and1983, all occurring during December-March. Furthermore, even large-sized fast-swimming species migrating in late spring or summer encounter only a few days when migration is possible in less than 10 to 30 % of the years for weir 1-4, and complete obstruction for weirs 5-6, despite the higher burst swimming speeds due to higher temperatures.

The minor differences that were found between estimated and measured values of both water velocities in the weir-gaps (Table 2.2) and burst swimming speeds of eight species (Table 2.3), suggest that the assessment of the migratory opportunities that all species have had during 1960-1983 yielded accurate estimates. Even for chub, where the largest difference between measured and estimated swimming speeds were found (Table 2.3), the assessment using high F exhibited minimal difference from using the probably more accurate intermediate F (Table 2.5).

Measurements of water velocities in the weir-gaps of weir 1 during 11 March 1998, suggested that a major drop in water velocity, if any, is restricted to a very small layer close to the wall or bottom. It is not expected that fish were able to use such a thin layer with lower water velocities, therefore use of a correction factor of 0.9 seems valid except perhaps for very narrow- or shallow-bodied species such as lampern, eel and flounder. Juvenile eels are reknowned for their capacity to traverse natural barriers (Walker 1985). For these species the number of migratory opportunities might have been underestimated in the assessment.

Sea-run brown trout are able to negotiate water level differences considerably higher than 0.25 m by jumping (Stuart 1962). Also some other large and fast-swimming species may have been able to ascend weirs at level differences above 0.25 m, even though water velocities are presumably much higher than at free-flowing conditions, due to the effect of gravity. Differences between 0.25 and 0.5 m occur almost exclusively during a transition from a condition with all 1 m boards in position to a free-flowing condition. Thus, even if these fish species might be able to bridge water level differences between 0.25 and 0.5 m, and given that these conditions are associated with the occurrence of free-flowing conditions, no increase in fraction of years when migration is possible can be expected, only an increase in the number of days with migratory opportunities.

In the assessment, the probability of encountering at least one suitable day per migration period was calculated. However, not all fish can use a window lasting only one day, especially when a series of weirs has to be ascended. In contrast to expectation, the first free-flowing conditions in the course of a typical high discharge event occur at the most downstream-situated weir 1. This is due to the relatively low discharge needed to cause free-flowing conditions at weir 1, compared to the relatively high discharge needed at weir 6. At extreme discharge events, all weirs are free-flowing simultaneously. This enables fish to start migrating upstream at the start of a high discharge event, and to reach weir 6 during the peak of discharge, if it can ascend the increasing water velocities it meets at each consecutive weir (Fig. 2.6). After the high discharge event, the more downstream-situated weirs remain free-flowing for a longer period. As a result weirs 1-4 may be free-flowing for several weeks, whereas weir 6 is rarely free-flowing for more than a few days (Figs 2.4 and 2.7). Therefore, long distance migrants such as sea-run trout and lampern, both very rare in River Vecht (Cazemier 1978), must move rapidly to reach the most upstream weir in time.

Although the species-specific assessment is based on pre-spawning migrations for anadromous and potamodromous species, and migration of juveniles for catadromous fish, it can be concluded that other upstream movements such as feeding migration, seeking refuge, compensating downstream displacement by high discharge events or dispersal (McDowall 1988; Northcote 1998) are also severely hampered. This is especially so during May-October when fish are most active and can perform maximum swimming speeds, but free-flowing conditions are extremely rare. The role of migrations within populations of riverine fish is unclear for most species (Mills 1991; Smith 1991; Lucas & Frear 1997). For those species that need upstream migration during at least one phase to complete their life-cycle, populations will have been affected by the construction of weirs, especially small-sized fish and late-spring or summer migrants. Some of the species listed, however, may not be motivated to move upstream at all, even if the conditions allow them to do so. These non-migrating species may be able to complete their entire life-cycle on a single stretch between weirs. However, even these species might be affected, because upstream populations may become fragmented and isolated in the absence of immigration from other downstream populations, which makes them vulnerable to such disturbances as pollution or high discharge events (Bayley & Li 1992), especially in combination with limited availability of refuge habitats due to strong regulation. In case of local extinction, recolonization could only occur from upstream situated populations.

The approach used here is based on basic hydraulic measurements that are also available for many other river systems. Therefore, it provides a widely applicable tool in river management to assess the degree of obstruction posed by non-complete barriers to fish migrations in the present or the past. The accuracy of the assessment can be improved if daily temperatures are incorporated instead of average temperatures per month. With the assessment presented here, the opportunities for fish to ascend a weir were estimated, but whether they will actually do so depends on fish behaviour. With respect to factors triggering onset of migration (Smith 1985), behaviour of fish in the vicinity of weirs, passage behaviour through man-made constructions (Warren & Pardew, 1998), the effect of delay on migrating fish, and the time that a fish is willing to search or wait for migratory opportunities, very little is known (Northcote 1998, Williams 1998). With increasing knowledge on migratory behaviour and swimming capacities the approach used here can be further refined and extended.

Acknowledgements

We thank J. Heinen of Rijkswaterstaat Directie Oost for providing long time-series on water levels and discharge, F. Oosterbroek and J. Tacke of Rijkswaterstaat Meetdienst Rosannepolder for water velocity measurements in March 1998, D. de Vries and W. Boiten for assistance in the field and their insight in hydrology and hydraulics, A. de Groot and J. Nijeboer for information on weir management, and A.D. Buijse, N. Daan, W. Dekker, E.A. Huisman, J.J. de Leeuw and an anonymous referee for valuable comments on an earlier version of this paper. This research was funded by the Ministry of Agriculture, Nature and Food Quality, the Hague, the Netherlands.


Obstructed conditions / Gestuwde situatie


Free flowing conditions / Gestreken stuw

References

- Bainbridge, R., 1960. Speed and stamina in three fish. Journal of Experimental Biology 37: 129-153.
- Bainbridge, R., 1963. Caudal fin and body movement in the propulsion of some fish. Journal of Experimental Biology 40: 23-56.
- Bayley, P.B. and H.W. Li, 1992. Riverine fishes. In: P. Calow and G.E. Petts (Editors). The Rivers Handbook 1, Oxford: Fishing News Books, Blackwell Science Publications, pp. 251-281.
- Beamish, F.W.H., 1978. Swimming capacity. In: W.S. Hoar and D.J. Randall (Editors). Fish Physiology, Volume VII: Locomotion. New York; London: Acedemic Press, pp. 101-189.
- Blake, R.W., 1983. Fish locomotion. London: Cambridge University Press, 208 pp.
- Cala, P., 1971. On the ecology of the ide *Idus idus* (L.) in the river Kävlingeån, south Sweden. Reports Institute of Freshwater Research Drottningholm 50: 45-99.
- Cazemier, W.G., 1978. Onderzoek naar de wenselijkheid van vispassages in de Overijsselse Vecht. RIVO- Report ZS 78-03, IJmuiden., 55 pp. (in Dutch)
- Colavecchia, M., C. Katopodis, R. Goosney, D.A. Scruton and R.S. McKinley, 1998. Measurements of burst swimming performance in wild Atlantic salmon (*Salmo salar* L.) using digital telemetry, Regulated Rivers: Research and Management 14: 41-51.
- Cowx, I., 1998. Fish passage facilities in the UK: issues and options for future development. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 220-235.
- Dekker, W., 1997. Long-term trends in the glass eels immigrating at Den Oever, The Netherlands. Bulletin Français de la Pêche et de la Pisciculture 349: 199-214.
- Hartgers, E.M., A.D. Buijse and W. Dekker, 1998. Salmonds and other migratory fish in Lake IJsselmeer, Publications of the project Ecolological Rehabilitation of the Rivers Rhine and Meuse 76, 43 pp.
- Holcik, J. (Editor), 1986. The Freshwater Fishes of Europe. Vol.1.I Petromyzontiformes. Wiesbaden: AULA-Verlag, 313 pp.
- Kerstan, M., 1991. The importance of rivers as nursery grounds for 0- and 1-group flounder (*Platichthys flesus* L.) in comparison to the Wadden Sea. Netherlands Journal of Sea Research 27: 353-366.
- L'Abée-Lund J.H. and L.A. Vøllestad, 1985. Homing precision of roach *Rutilus rutilus* in Lake Årungen, Norway. Environmental Biology of Fishes 13: 235-239
- Larinier, M., 1998. Upstream and downstream fish passage experience in France. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 127-145.

- Lelek, A. (Editor), 1987. The Freshwater Fishes of Europe. Vol.9. Threatened Fishes of Europe. Wiesbaden: AULA-Verlag. 343 pp.
- Lucas, M.C. and E. Batley, 1996. Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management. Journal of Applied Ecology 33: 1345-1358.
- Lucas, M.C. and P.A. Frear, 1997. Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid. Journal of Fish Biology 50: 382-396
- Lucas, M.C. , T. Mercer, G. Peirson and P.A. Frear, 2000. Seasonal movements of coarse fish in lowland rivers and their relevance to fisheries management. In: I.G. Cowx (Editor). Management and Ecology of River Fishes. Oxford: Fishing News Books, Blackwell Science Publications, pp. 87-100.
- McCleave, J.D., 1980. Swimming performance of European eel (*Anguilla anguilla* L.) elvers. Journal of Fish Biology 16: 445-452.
- McDowall, R.M., 1988. Diadromy in Fishes: Migrations between Freshwater and Marine Environments. London: Croom Helm, 308 pp.
- Mann, R.H.K., 1991. Growth and reproduction. In: Winfield I.J. and J.S. Nelson (Editors). Cyprinid fishes. Systematics, Biology and Exploitation. London: Chapman & Hall, pp. 456-482.
- Mann, R.H.K., 1996. Environmental requirements of European non-salmonid fish in rivers. Hydrobiologia 323: 223-235.
- Mills, C.A., 1991. Reproduction and life history. In: Winfield I.J. and J.S. Nelson (Editors) Cyprinid fishes. Systematics, Biology and Exploitation. London: Chapman & Hall, pp. 483-508.
- Northcote, T.G., 1998. Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 3-18.
- Parmet, B. and M. Raak, 1997. Impact of climate change on the discharge of the river Rhine. A case study for a sub-basin in the lowland part of the Rhine system, the Overijsselsche Vecht. RIZA Report 97.049, Lelystad. 93 pp.
- Prignon, C., J.C. Micha and A. Gillet, 1998. Biological and environmental characteristics of fish passage at the Tailfer Dam on the Meuse River, Belgium. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 69-84.
- Schiemer, F. and H. Waidbacher, 1992. Strategies for conservation of a Danubian fish fauna. In: P.J. Boon, P. Calow and G.E. Petts (Editors). River Conservation and Management. Clucester: Wiley & Sons, pp. 363-382.
- Smith, R.J.F., 1985. The Control of Fish Migration. Berlin: Springer-Verlag, 243 pp.
- Smith, R.J.F., 1991. Social behaviour, homing and migration. In: Winfield I.J. and J.S. Nelson (Editors). Cyprinid fishes. Systematics, Biology and Exploitation. London: Chapman & Hall, pp. 509-529.

- Stahlberg, S., 1985. Das Schwimmverharten von Bachschmerle (*Noemacheilus barbatulus*) und Gründling (*Gobio gobio*) in strömendem Wasser. Thesis Zoological Institute, University Brauschweig. 179 pp.
- Stuart, T.A., 1962. The leaping behaviour of salmon and trout at falls and obstructions. Department of Agriculture and Fisheries for Scotland, Freshwater Salmon Fisheries Report 28, 28 pp.
- Taylor, E.B. and J.D. McPhail, 1986. Prolonged and burst swimming in anadromous and freshwater threespine stickleback, *Gasterosteus aculeatus*. Canadian Journal of Zoology 64, 416-420.
- Videler, J.J., 1993. Fish swimming. London: Chapman & Hall, 260 pp.
- Videler, J.J. and C.S. Wardle, 1991. Fish swimming stride by stride: speed limits and endurance. Reviews in Fish Biology and Fisheries 1: 23-40.
- Waidbacher, H.G. and G. Haidvogl, 1998. Fish migration and fish passage facilities in the Danube: past and present. In: M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses, Oxford: Fishing News Books, Blackwell Science Publications, pp. 85-98.
- Walker, K.F., 1985. A review of the ecological effects of river regulation in Australia. Hydrobiologia 125: 31-46.
- Ward, J. and J.A. Stanford, 1989. Riverine ecosystems: The influence of man on catchment dynamics and fish ecology. In: D.P. Dodge (Editor). Proceedings of the International Large River Symposium. Canadian Special Publications of Fisheries and Aquatic Science 106: 56-64.
- Wardle, C.S., 1975. Limit of fish swimming speed. Nature 225: 725-727.
- Wardle, C.S., 1980. Effects of temperature on the maximum swimming speed of fishes. In: Environmental Physiology of Fishes, London: Plenum Press, pp. 519-531.
- Warren, M.L. Jr. and M.G. Pardew, 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127: 637-644.
- Webb, P.W., 1988. 'Steady' swimming kinematics of tiger musky, and Esociform accelerator, and rainbow trout, a generalist cruiser. Journal of Experimental Biology 138: 51-69.
- White, E.M. and B. Knights, 1997. Dynamics of upstream migration of the European eel, *Anguilla anguilla* (L.), in the Rivers Severn and Avon, England, with special reference to the effects of man-made barriers. Fisheries Management and Ecology 4: 311-324.
- Williams, J.G., 1998. Fish passage in the Columbia River, USA and its tributaries: problems and solutions. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fish Migration and Fish Bypasses. Oxford: Fishing News Books, Blackwell Science Publications, pp. 180-191.

- Wolfert, H.P., G.J. Maas and G.H.P. Dirkx, 1996. Het meandergedrag van de Overijsselse Vecht; historische morfodynamiek en kansrijkdom voor natuurontwikkeling. Wageningen, DLO-Staring Centrum Report 408, 98 pp. (in Dutch)
- Zerrath, H., 1996. Sprintleistungen einheimischer Klein- und Jungfische in Sohlgleitenmodellen - Daten zur Bewertung von Fischaufstiegshilfen. Fischökologie 9: 27-48. (in German)

Gestuwde optrek

De eerste twee stuwen in de Vecht werden rond 1850 gebouwd om de waterpeilen in kanalen die de Vecht kruisen constant te houden. Om het water bij hoge rivierafvoer sneller af te voeren en de kans op overstromingen en dijkdoorbraken kleiner te maken, zijn er tussen 1896 en 1914 veel bochten afgesneden. De lengte van het Nederlandse deel van de Vecht werd daarmee van 90 naar 60 km teruggebracht. Maar omdat het water hierdoor ook sneller verdween in perioden met weinig rivierafvoer zijn er tussen 1907 en 1914 nog eens vijf stuwen gebouwd om het water langer vast te houden.

De stuwen bestonden uit schotten die boven elkaar werden geplaatst in de stuwopeningen. Bij weinig rivierafvoer werden er meer schotten geplaatst en was het waterhoogteverschil bij elke stuw het grootst (meestal 1 tot 2,5 m). Bij hogere rivierafvoer werden er schotten weggehaald en werd het verval in water steeds kleiner. Bij elke stuw wordt een vast bovenstrooms waterpeil nagestreefd. Bij piekafvoeren waren alle schotten weggehaald en stroomde het water vrijelijk met gering verval maar met een flinke snelheid door de stuwopeningen (‘gestreken’ stuw). In 1970 werd de stuw bij Ane verwijderd. In de jaren 80 zijn in alle stuwopeningen hydraulische klepstuwen geplaatst die traploos versteld kunnen worden, maar het principe van een groot verval bij weinig rivierafvoer en vrij stromend water met gering verval bij hoge rivierafvoer bleef gelijk.

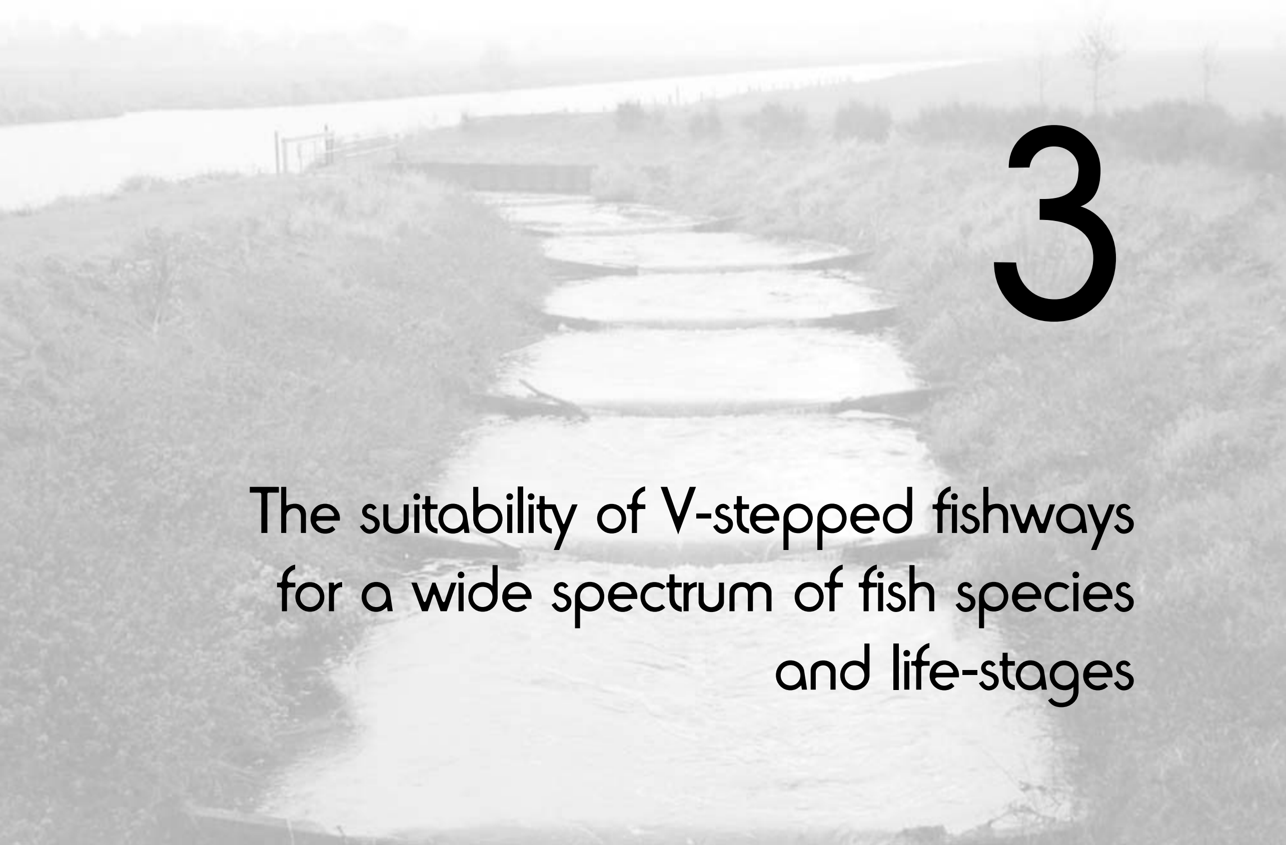
De stuwen vormden een ernstige belemmering voor vis die de rivier optrok. Een groot deel van de tijd was het waterhoogteverschil bij elke stuw voor vrijwel alle vissoorten veel te groot om te kunnen overwinnen. Alleen in tijden met hoge rivierafvoer konden vissen de gestreken stuwen passeren, mits ze snel genoeg konden zwemmen om de hoge stroomsnelheden in de stuwopeningen te overwinnen. Om de vismigratie te verbeteren zijn er tussen 1987-1994 langs alle stuwen vistrappen aangelegd. Om uiteindelijk het effect van de aanleg van deze vistrappen te kunnen bepalen, moeten we eerst inschatten in welke mate de visoptrek werd belemmerd in de periode daarvoor.

Er zijn in het verleden geen metingen gedaan aan visoptrek via de stuwopeningen tijdens perioden met hoge afvoer. Wel heeft rijkswaterstaat altijd nauwgezet de waterstanden direct bovenstrooms en benedenstrooms van elke stuw bijgehouden. Zo zijn er van 1960-1983 op vrijwel elke dag bovenstroomse en benedenstroomse waterpeilen beschikbaar. Vanaf 1965 is ook de dagelijkse rivierafvoer bepaald. Hierdoor was het mogelijk om voor elke dag te bepalen of een stuw al dan niet gestreken was. Voor elke dag met gestreken stuw kon hieruit ook de stroomsnelheid in de stuwopening worden berekenend. Tijdens een hoogwater in 1998 hebben we verschillende stuwopeningen doorgemeten om de verhouding tussen de gemiddelde stroomsnelheid en de iets lagere stroomsnelheid langs de randen te bepalen. Vis zal waarschijnlijk de weg met de minste stroming verkiezen.

Of een vis een gestreken stuw kan passeren hangt af van de sprintcapaciteit. Deze is sterk afhankelijk van de watertemperatuur (10 ^{o}C warmer geeft een verdubbeling van de sprintsnelheid), soort (je hebt snellere en tragere sprinters) en de lengte van de vis (kleine sprinten langzamer dan grote). Op basis van algemeen geldende verbanden en literatuurgegevens hebben we een rekenmodel gebouwd waarmee voor elke dag met gestreken stuw doorgerekend is welke soort en bij welke lengte de gestreken stuw kón passeren op die dag (zie ook box 8.1 op blz 155).

Gestreken stuw-situaties bleken vooral in het winterhalfjaar voor te komen en nauwelijks in het zomerhalfjaar, terwijl juist in de zomer de sprintcapaciteit het grootst is. Soorten die al vroeg in het voorjaar optrekken hadden meer optrekmogelijkheden dan soorten die later optrokken. Van de 32 vissoorten die op de Vecht voorkomen, bleken er slechts 10 over voldoende sprintcapaciteit te beschikken om de hele serie van 6 stuwen te kunnen passeren. De optrekmogelijkheden tijdens de paaitrek per soort waren meestal beperkt tot slechts enkele dagen en dan ook slechts in een beperkt deel van de onderzochte jaren. In hoeverre vis ook daadwerkelijk gebruik wist te maken van deze schaarse optrekmogelijkheden is onbekend, we hebben alleen bepaald of het fysiek mogelijk was.

V-stepped fishway (F3) / Bekkenvistrap met V-vormige overlaten (Junne)



3

The suitability of V-stepped fishways for a wide spectrum of fish species and life-stages

Erwin Winter
Wobbe Cazemier
Wim van Densen

(Submitted for publication)

Abstract

The suitability of seven V-stepped fishways, a type of fish pass designed for fish with poor swimming capacities, was evaluated in the Rivers Vecht and Regge (the Netherlands). Traditionally, most fishways are designed for diadromous fish species with strong swimming capacities. The V-stepped fishways were constructed in bypass channels alongside the weirs. They consist of large basins subdivided by V-shaped overfalls with surface overflow and small drops between basins. To determine suitability, upstream passage through the fishways was monitored during 4 years, hydraulics were measured and electrofishing was performed to determine abundance downstream weirs. V-stepped fishways proved suitable for the ascent of 22 fish species (14 cyprinid species) varying between 4-109 cm in length. Most abundant were roach *Rutilus rutilus* (of which 29% were juveniles), bream *Abramis brama* (4% juv.), ide *Leuciscus idus* (54% juv.) and perch *Perca fluviatilis* (66% juv.). Fish performed better than was expected from modelled burst swimming and hydraulic measurements. V-stepped fishways can be used to rehabilitate migratory opportunities for a wide species and size range and require relatively low maintenance.

Introduction

To improve upstream movements of fish in rivers alongside man-made barriers such as weirs and dams, many types of fishways have been constructed (Clay 1995, Katopodis 2005). Most of these were designed to facilitate migrations of anadromous salmonids (Cowx & Welcomme 1997, Naughton et al. 2007), usually resulting in hydraulic conditions not suitable for passage of fish with poor swimming capacities (Larinier 1998). There is a growing awareness that migration plays an important role in the life-history of many riverine fish species, although still relatively little is known about the migratory behaviour of species of less commercial or recreational interest (Lucas & Baras 2001, Knaepkens et al. 2006). Variation in migratory patterns is large; scale may vary from hundreds of meters to thousands of kilometres, life-history stages involved may vary from larvae to adults, and the motivation may be related to spawning, feeding or seeking refuge (Lucas & Baras 2001). To facilitate these migrations, as well as other movements, such as dispersal or compensation for downstream displacement by floods, for a wide range of species and sizes, several types of fishways have been designed, varying from modified traditional fishways (Schwalme et al. 1985) to more 'nature-mimicking' bypass-channels (Jungwirth 1996, Gebler 1998, Katopodis 2005).

In the Netherlands a type of fishway has been developed, which was especially designed for the ascent of fish with poor swimming capacities (Cazemier & Muyres 1981, Boiten 1991). These V-stepped fishways (Cowx & Welcomme 1998) are now commonly used in the Netherlands and, more recently, also in Belgium. They consist of large basins (length > 5 m) subdivided by V-shaped overfalls with surface overflow and small drops between basins (< 0.25 m). In contrast to many other types of fishways, such as Denil or Vertical Slot passes (Schwalme et al. 1985, Peake et al. 1997), in V-stepped fishways each basin provides large resting areas, so that the overfalls can be taken by short bursts of swimming. Strong endurance is therefore not required. In larger rivers, the V-stepped fishways are located in low-gradient bypass-channels alongside weirs. In smaller streams weirs were replaced by a fishway covering the entire stream width. So far, fish passage through these types of fishways has only been described in reports with limited distribution. The River Vecht was the first where a complete series of V-stepped fishways was constructed alongside each weir in the Dutch part (length 60 km of in total 177 km). Before this, these weirs severely limited migratory opportunities for all fish species (Winter & Van Densen 2001). Here we evaluate the functioning of these V-stepped fishways based on the monitoring of fish passage and electrofishing surveys during 1989-1998. Our objectives are 1) to determine which species and sizes use these V-stepped fishways, 2) to test if the hydraulic conditions in the fishways are suitable for the ascent of a broad range of fish species and life-stages, and 3) to identify if there are still other species-specific bottlenecks present that hinder successful upstream passage through these fishways.

Material and methods

Study area

The rain-fed River Vecht (52°30'N, 6°30'E; Fig. 3.1) drains a catchment area of 3 800 km^2, is 177 km long and originates in Germany. Its main tributary is the Regge. The downstream part of the river in the Netherlands discharges in Lake Zwarte Meer and Lake IJsselmeer, both shallow eutrophic lakes that are remainders of a former brackish estuary since a 32 km dam (Afsluitdijk) was built in 1932. The Dutch section is regulated with six weirs, where flow is controlled by overspilling gates that are automatically adjustable in height, keeping upstream water level close to the target (± 0.05 m). The main tributary Regge is regulated with four weirs. At low discharge rates, these weirs cause abrupt differences in water level, ranging from 1.5 to 3 m. At high discharge rates, weirs are lowered and water is 'free flowing' through the weir-gaps (Winter & van Densen 2001).

V-stepped fishways

A series of V-stepped fishways was constructed alongside each of the six weirs in the River Vecht and alongside the most downstream weir in the Regge during 1987-1994 (Fig. 3.1). These fishways are very similar in design, only F4 differs slightly from the others by having a larger total length and therefore larger basins and a lower gradient (Table 3.1). Basins are separated by V-shaped overfalls, with non-aerated overflow in the middle and aerated overflow at both sides (Fig. 3.2). The most upstream overfall is adjustable in height, allowing discharge through each fishway to be controlled. Flow patterns are characterized by a relatively strong flow along the longitudinal downstream axis, with eddies on both sides of the overfalls, and a weak flow in upstream direction along the borders of basins, providing resting areas for fish. These fishways were dimensioned for an optimal discharge of 1 $m^3.s^{-1}$, a basin drop of 0.18 m, average basin depth of 1 m, and water velocities not exceeding 1 $m.s^{-1}$ should be available at the overfall, based on an experimental study for hydraulic optimization (Boiten 1991). Because upstream water level is kept constant, discharge through fishways remains constant with increasing discharge in the mainstream (without the need to adjust the inflow), except when the weir is lowered at high discharge and upstream water level exceeds the target. Under these conditions, the fishways can be considered free-flowing side-channels.

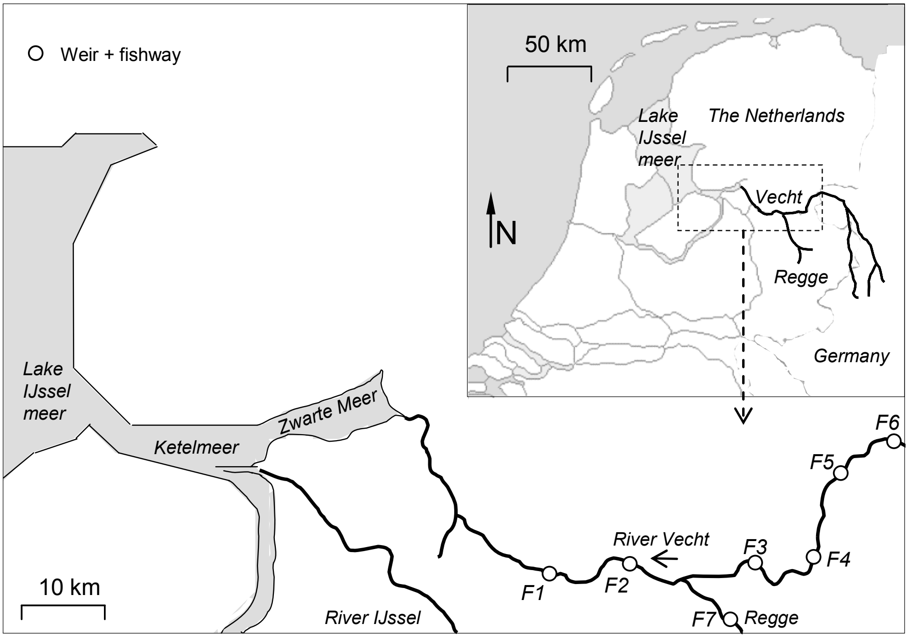


Figure 3.1 *The study area: the middle top panel situates the River Vecht and tributary Regge, the bottom panel zooms in on the positioning and numbering of the fishways along each of the weirs.*

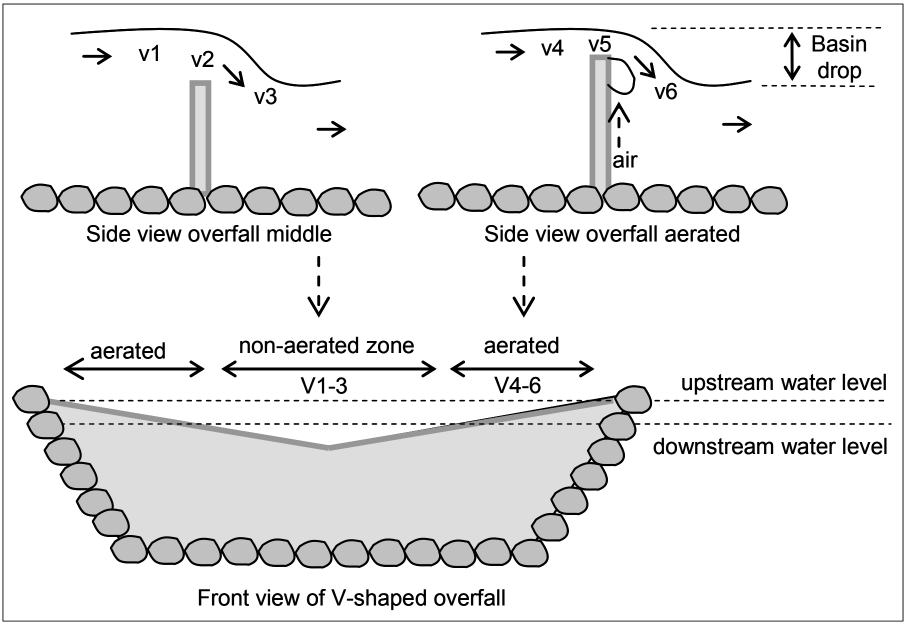


Figure 3.2 *Schematic cross-section overview of the V-shaped overfall (slope 1:7) separating each basin in the V-stepped fishways. Positions of water velocity measurements at overfalls are indicated (V1-V6), the bottom and shores of the basins are reinforced with riprap, arrows in side views indicate flow direction.*

Table 3.1 *Characteristics of the V-stepped fishways that bypass the weirs in the River Vecht (F1-F6) and tributary Regge (F7)*

Fishways Nr.	Locationname	Distance to source (km)	Year of Constuction	Fishway Length (m)	Fishway Gradient %	Number of basins	Basin length Median (range) (m)	Distance to weir Outflow (m)	Distance to weir Inflow (m)
F1	Vechterweerd	166	1987	96	1.6	8	10 (9-10)	45	32
F2	Vilsteren	156	1989	113	1.2	9	10 (10-15)	25	67
F3	Junne	144	1991	125	1.6	12	9 (8-18)	40	71
F4	Mariënberg	137	1994	209	0.7	7	20 (20-52)	53	13
F5	Hardenberg	130	1991	135	1.4	11	11 (9-19)	40	56
F6	De Haandrik	120	1992	172	1.4	14	10 (10-23)	64	45
F7	Archem	152*	1990	96	1.5	10	9 (9)	60	15

* Distance from Regge-Vecht confluence to the source of the Vecht is 152 km, distance from the confluence to the first weir in the Regge is 8 km

Monitoring fish passage through the fishways

Upstream ascent of fish through these fishways in the River Vecht and Regge was monitored in 1991, 1996, 1997 and 1998 (Table 3.2). Because the fish fauna is dominated by cyprinids performing mostly pre-spawning migrations in spring (Lucas & Baras 2001), these recordings were restricted to February-June. Starting dates varied for logistic reasons (Table 3.2). Upstream migrating fish were trapped with fykenets (length 10 m, stretched mesh size 20 mm) covering the entire upstream inflow overfall of a fishway. Catches were recorded each day, only rarely per two days. After measuring total length, all fish (n=51 528 in total) were released in the main channel directly upstream of the fishway. The fraction of juveniles was indicated from the length frequency for the six most abundant species by using a length at maturity of 8 cm for bleak, 15 cm for roach, white bream and perch and 30 for ide and bream (based on unpublished local maturity data of IMARES). Due to high discharge events and much debris flowing downstream after these floods, recording with fykenets was impossible during two periods in 1998 (Table 3.2). In addition, one overfall in F1 was videotaped for three hours during a migration peak in May 1998 to get an impression of the different pathways used by fish ascending the overfalls.

Table 3.2 *Periods when fish passage through V-stepped fishways in the River Vecht and the tributary Regge was recorded during 1991-1998. For fishway numbers see Fig. 3.1 and Table 3.1.*

	1991		1996				1997	1998		
Fishway no.	F1	F7	F1	F3	F5	F6	F1	F1	F5	F7
Start date (day-month)	27-3	3-4	26-3	4-4	25-4	25-4	1-4	20-2	20-2	12-3
End date (day-month)	6-6	5-6	31-5	24-5	23-5	23-5	10-4	4-6	8-6	21-5
Number of days recorded	26	58	66	50	28	28	4	72	82	78
% of period recorded	36	94*	100	100	100	100	36	69*	75*	96*

* Recording was impossible during part of the period, due to high flood events and flowing debris or broken nets

Electrofishing surveys

Electric fishing surveys (direct-current, 6 A, 350 V) were performed on 27 days during spring (between 19 February-12 May) in the years 1989, 1996, 1997 and 1998 along the entire Dutch section of the River Vecht, subdivided into three strata; 1) within 100 m downstream a weir, 2) in the fishway below the most downstream overfall (i.e. the entrance of the fishway) and 3) on randomly selected river stretches. In total, 6 818 fish were caught: 1 566 in stratum 1; 2 477 in stratum 2; 2 779 in stratum 3, and total lengths were measured.

Environmental parameters

Water temperature was recorded daily during each of the fykenet monitoring and electrofishing surveys. Daily river discharge at the German border (Fig. 3.1), and water level downstream and upstream each weir were available for the entire period (1989-1998). During fish passage monitoring in spring 1991 no free-flowing events took place. Discharge during spring 1996 was extremely low (minimum of the period 1970-1998) and no free-flowing conditions occurred for any weir. Discharge during spring 1998 was relatively high (78 percentile of 1970-1998) and two high discharge events resulted in free-flowing conditions (5-12 March and 9-12 April at F1; and 8-11 March and 10-11 April at F5).

Suitability of hydraulic conditions in the fishways for upstream passage
Hydraulic conditions in the fishways may constrain fish passage. Based on hydraulic models and field observations in many pool-type fishways in France, Larinier (1992) proposes a pool drop of 0.30-0.60 m for salmonids and 0.15-0.30 m for non-salmonids. Criteria for pool volume are related to the dissipated power per unit volume P_v (W.m^{-3}), calculated as:

$$P_v = \rho \cdot g \cdot Q \cdot \frac{dH}{V} \qquad (1)$$

where: ρ=density (1000 kg.m^{-3}), g=gravity constant (9.81 m.s^{-2}), Q=discharge (m^3.s^{-1}), dH=pool drop (m), V=pool volume (m^3). Maximum values for P_v suitable for fish passage are 200 W.m^{-3} for salmonids, 150 for shads and cyprinids, and 100 for northern pike and pikeperch (Larinier 1998). This was used to evaluate the fishways in the River Vecht.

Water velocities were measured using an Ott current meter in four fishways in the River Vecht (F1, F2, F3 and F5) and the Regge (F7) during 1990-1992. Water velocities were measured at three points in the middle of overfalls (V1-V3; Fig. 2) and three points at the side of the non-aerated zone of overfalls (V4-V6). Observations were grouped for all fishways because differences between individual fishways and years were negligible.

To assess whether the measured water velocities were potentially constraining fish passage, we compared observed minimum size of fish passing for each day during the monitoring with the modelled minimum size that physically should be able to ascend these water velocities. For this, we used the relationship as found by Videler and Wardle (1991) between burst swimming speed, body size and temperature, and burst swimming data of dace *Leuciscus leuciscus* and gibel carp *Carassius auratus* (Bainbridge 1960) according to Winter and van Densen (2001). Dace, a fast sprinter, and gibel carp, a poor sprinter, probably represent the entire range of sprinting capacities for the fish species present (Winter & Van Densen 2001). We modelled the minimum size of these two species that could ascend the mean minus SD of the water velocity at the crest at side of the overfalls (V5), as a conservative estimate for the water velocities that at least had to be conquered in relation to temperature. Because high velocities were restricted to a stretch of about 0.5 m at the crest of an overfall, endurance was not taken into account. In fact, the large basins provide suitable resting areas to recover from burst speed swimming.

Hydraulic conditions in the fishways are constant for most river discharge rates. However, at extremely high river flow when both weirs and fishways are free-flowing, and at extreme low river flow when discharge through the fishways drops to suboptimal, the hydraulic conditions change and as a result suitability may become different. To measure the hydraulics under exceptional conditions, first extremely low water flow was induced at 19 July 1990 in F2, by adjusting the upstream overfall to generate a suboptimal flow of 0.6 m^3.s^{-1} and basin drops, water layer at the crest and water velocities at all overfalls were measured. Second, during an extremely high discharge event on 11 March 1998, water velocities in weir-gaps of the most downstream weir and in the inflow-gap of F1 were measured (Winter & Van Densen 2001).

Identifying possible species-specific bottlenecks for upstream passage

As an indication of passage suitability by species, we compared abundance from the electrofishing surveys in three strata to abundance in fishway passage. Because gear selectivity will affect estimates of both size composition and abundance per species, and because determining the total numbers of fish that are motivated to move upstream and present in the hydraulic complex habitats directly downstream weirs and fishways proves extremely difficult (Baumgartner 2006), a truly unbiased comparison between catches downstream weirs and fish passing fishways was not feasible. As an indication of abundance in each of the electrofishing strata during spring and the fishway monitoring, we classified the relative abundance of each species as absent, rare (< 0.5 %), common (0.5-5 %), or abundant (> 5 %). A distinction was made between the river section downstream F1 that was free accessible for the downstream situated lakes and upstream F1 where all river sections and fishways were grouped.

Results

Hydraulic conditions in V-stepped fishways

The water velocities at the overfalls were highest directly downstream the crest, slightly smaller at the crest and smallest directly upstream the crest (Table 3.3). The design criteria of 1 $m.s^{-1}$ was exceeded in all measurements at the crest (V2, V5) and just below the crest (V3, V6) in both the aerated and non-aerated sections of the overflow. Average basin drop was 0.19 m (maximum 0.24 m), close to the design basin drop of 0.18 m. Maximum P_v for all basins was 39 $W.m^{-3}$ (using equation 1, Tables 3.1 and 3.3) and therefore well below the limits proposed by Larinier (1998).

Table 3.3 *Hydraulic measurements of in total 40 overfalls in five different V-stepped fishways (F1, F2, F3, F5 and F7; see Fig. 3.1 and Table 3.1), discharge through the fishways ranged from 0.8-1.2 m3.s-1. The results were grouped, because differences between fishways were negligible.*

n=32	Middle of overfall				Side of non-aerated zone overfall			
	Loc*	Mean ± SD	Min	Max	Loc*	Mean ± SD	Min	Max
Velocity above crest ($m.s^{-1}$) †	V1	0.90 ± 0.23	0.4	1.4	V4	0.61 ± 0.18	0.2	1.1
Velocity crest overfall ($m.s^{-1}$) †	V2	1.48 ± 0.21	1	1.9	V5	1.39 ± 0.20	1	2.1
Velocity below crest ($m.s^{-1}$) †	V3	1.87 ± 0.26	1.1	2.5	V6	1.66 ± 0.28	1	2.2
Water layer crest overfall (m)		0.29 ± 0.05	0.1	0.4		0.16 ± 0.05	0.1	0.3
Basin drop (m)		0.19 ± 0.03	0.1	0.2				

* Location of measurement-point see Fig. 3.2

† Distance between measurements were about 0.3 m

Table 3.4 *Monitoring of fish passage through V-stepped fishways in the River Vecht and tributary Regge during spring 1991-1998. For scientific names of the species see Table 3.5.*

Fishway no.	F1	F1	F1	F1	F3	F5	F5	F6	F7	F7	Total	Length
Year	1991	1996	1997	1998	1996	1996	1998	1996	1991	1998	all	range
Roach	2,746	19,233	359	1,279	4,027	82	1,037	2	6,183	3,614	38,562	4-42
Bream	257	2,702	33	315	61	13	19	-	848	70	4,318	9-58
Ide	122	2,196	61	75	237	7	79	-	50	32	2,859	9-55
Perch	91	761	1	298	103	88	182	69	16	46	1,655	4-41
White bream	179	276	2	401	64	1	25	-	26	238	1,212	8-41
Bleak	222	464	7	39	108	33	157	-	-	172	1,202	5-20
Eel	18	11	-	7	10	16	373	7	385	357	1,184	11-95
Gudgeon	1	113	3	3	63	-	2	-	17	46	248	8-19
Pike	-	32	-	18	12	-	15	-	4	5	86	30-109
Ruffe	-	12	-	-	-	1	-	61	-	7	81	4-16
Am. crayfish	-	1	-	-	-	3	-	28	-	-	32	
Rudd	6	10	-	4	1	1	5	-	-	5	32	11-30
Hybrid cypr.	-	23	-	1	-	-	-	-	-	-	24	12-37
Carp	-	-	-	2	-	-	-	-	5	2	9	60-75
Dace	-	6	-	-	-	-	-	-	-	-	6	14-21
Tench	-	-	-	1	-	1	2	-	-	1	5	4-43
Chub	1	-	-	-	-	-	-	-	1	2	4	38-44
Barbel	-	1	-	-	-	-	1	-	-	-	2	36-58
Grass carp	-	-	-	-	-	-	-	-	-	2	2	
Brown trout	1	-	-	-	-	-	-	-	-	-	1	31
Bullhead	-	-	-	-	1	-	-	-	-	-	1	5
Nase	-	-	1	-	-	-	-	-	-	-	1	17
Rainbow trout	-	-	-	1	-	-	-	-	-	-	1	34
River lamprey	-	-	-	-	-	-	-	-	-	1	1	19
Total	3,644	25,841	467	2,444	4,687	246	1,897	167	7,535	4,600	51,528	4-109

During an extreme high discharge event (11 march 1998) the mean velocity at the inflow of F1 was 0.67 $m.s^{-1}$ (SD 0.46, n=10), whereas the mean velocity in the free-flowing weir-gaps adjacent to F1 were 1.79 $m.s^{-1}$ in the middle (SD 0.12, n=47) and 1.65 $m.s^{-1}$ at 0.2 m from the edges (SD 0.30, n=20).

Measurements in F2 under a suboptimal flow of 0.6 $m^3.s^{-1}$ on 19 July 1990, showed a maximum basin drop of 0.28 m, where V2 was 2.0 $m.s^{-1}$ and V3 was 2.1 $m.s^{-1}$. The extremely low river flow during May 1996 resulted in suboptimal discharge (< 0.6 $m^3.s^{-1}$) over the upstream fishways F5 and F6 throughout the recording period (apart from 3-5 May 1996; when discharge was ca. 1 $m^3.s^{-1}$).

Fish passage

Upstream migration of fish through the fishways in the River Vecht and Regge during spring was dominated by cyprinids (14 out of 22 fish species recorded in total, Table 3.4). Roach was by far the most abundant species followed by bream and ide. Perch was the most abundant non-cyprinid species. In the more upstream fishways, roach became less abundant, whereas especially eel increased in relative abundance. Seven species use the fishways in substantial numbers and the remaining 15 species used the fishways in relatively small numbers during spring. Besides fish, a small number of crayfish managed to ascend. Numbers of fish passing per spring period were highest for the downstream F1 in 1996. Considerably lower numbers were recorded for other fishways and years. Numbers of fish ascending per fishway per day varied from 0 to 2 109.

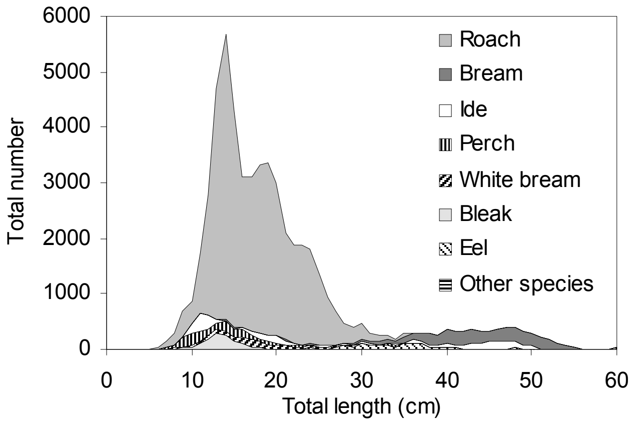


Figure 3.3 Length frequency and species composition of fish passing through V-stepped fishways during 1991-1998 in the River Vecht and tributary Regge.

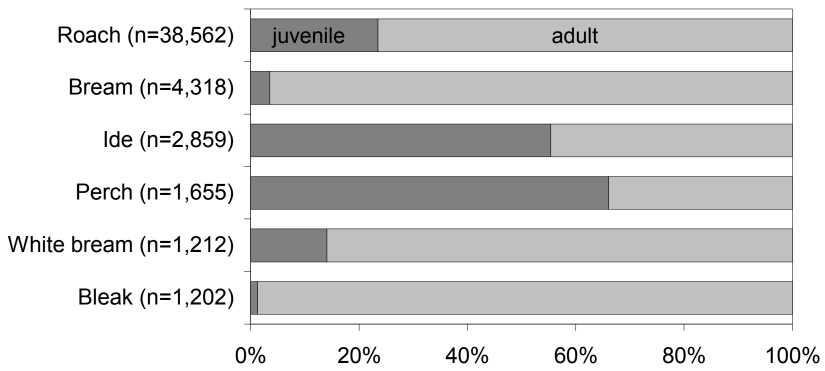


Figure 3.4 *Fraction of juveniles for the six most abundant species passing the fishways (all recordings during 1991-1998 combined)*

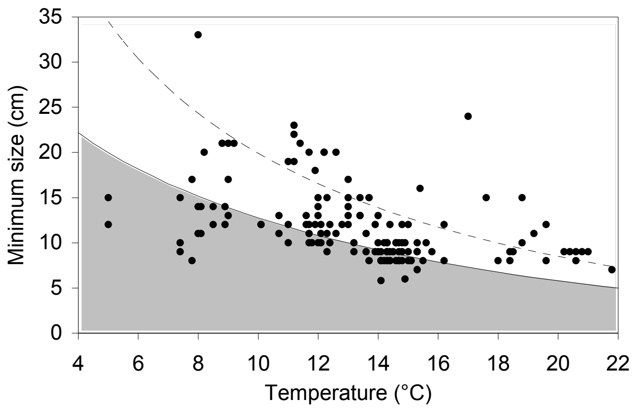


Figure 3.5 *Minimum size per daily recording of fish passing the fishways in relation to water temperature. The modelled minimum size of dace, a fast sprinter (solid line) and gibel carp, a slow sprinter (hair line), that should physically be able to ascend a water velocity of 1.2 m.s-1 (see text) is given in relation to water temperature. If the water velocity at the crest of the overfalls is the true constraint, no observations are expected in the shaded area.*

Fish with a wide range of sizes (4-109 cm) were caught ascending the fishways (Table 3.4). Medium-sized individuals (10-25 cm) were most frequently caught ascending (Fig. 3.3). For the six most abundant species, the fraction of juveniles varied from 1 % in bleak to 66 % in perch (Fig. 3.4). Observed minimum size relative to temperature was well below the modelled minimum size of dace that should physically be able to ascend the water velocities at the crest of overfalls (Fig. 3.5). As the critical flow that fish encounter we used 1.2 m.s-1 (mean minus SD), which is conservative because mostly at least one of the overfalls had minimum water velocities > 1.4 m.s-1. Thus, the minimum size of dace capable in passing is often somewhat larger than as represented in Fig. 3.5.

During the extremely low flow in May 1996, when discharge in F5 and F6 was suboptimal throughout most of the recording period, numbers of migrants through these passes were extremely low also (Table 3.4), except for F5 during 3-5 May 1996, when discharge was close to the design flow, and 40 % of the total numbers ascended during only 11 % of the total period.

Video observations in May 1998 showed that small fish, mainly roach, used the side edges of the overfalls (aerated zone, Fig. 3.2), where they jumped to the upstream basin from a small standing wave. Only part of the jumps was successful and some fish landed on the edge of the fishway or rip-rap shore. Larger fish, mainly bream, used burst swimming with high tail beat frequencies to overcome the water velocities in the middle of the overfall, where the overflowing water layer was at maximum.

During the recordings it was noticed that relatively few debris accumulated in the fishways and that most floating debris flows over the V-shaped overfalls. Another observation was that grey herons *Ardea cinerea* were often seen hunting near the overfalls.

Abundance downstream weirs and fishways compared to fish passage through fishways

In general, for most species the abundance of fish on downstream river stretches, below weirs and at the fishway entrance was in accordance with the relative abundance in fishway passage (Table 3.5). Of the species that were observed to use the fishways, perch, pike and ruffe appeared more abundant on the different river stretches than in fishway passage. Eel passed the upstream fishways in larger relative abundance than through F1.

In total, eight species were observed in the electrofishing surveys but absent in the fish passage recordings in the fishways. Of these, Smelt, three-spined stickleback and flounder were only observed downstream the most downstream fishway F1 and never upstream. Smelt was the only species for which large aggregations were found directly downstream the weir and fishway F1. Sunbleak, ten-spined stickleback and pikeperch were observed along the entire Dutch river course. Crusian carp and stone loach were only present in the river stretches upstream F1, without ever being recorded passing any fishway.

Table 3.5 *Catches of all electrofishing surveys, subdivided in three river sections: 1) river stretch, 2) directly below the weirs and 3) at the entrance of the fishways, and catches in all monitorings of fish passage through the fishways, during 1989-1998 combined. A distinction is made between the part of the river downstream the first fishway F1 (Fig. 3.1) and the upstream part, where the different stretches and fishways were grouped. Numbers per species were classified as abundant (xxx), common (xx), rare (x) or absent (-) for each of the river sections (see text).*

	Downstream from F1			F1	Upstream from F1 (F2-F7 combined)			
	Electrofishing surveys			Fykenet	Electrofishing surveys			Fykenet
Species	River Stretch	Below Weir	Fishway Entrance	Fishway passage	River Stretch	Below Weirs	Fishway Entrance	Fishway passage
Roach *Rutilus rutilus*	xx	xx	xxx	xxx	xxx	xx	xxx	xxx
Bream *Abramis brama*	xx	xxx	xxx	xxx	xxx	xxx	xx	xxx
Ide *Leuciscus idus*	xx	xxx	xxx	xxx	xx	xx	xx	xx
Perch *Perca fluviatilis*	xxx	xx	xx	xx	xxx	x	xx	xx
White bream *Abramis bjoerkna*	x	-	x	xx	xx	x	xx	xx
Bleak *Alburnus alburnus*	x	xx	xx	xx	x	-	xx	xx
Gudgeon *Gobio gobio*	x	-	xx	x	x	-	xx	xx
Pike *Esox lucius*	xx	xx	x	x	xx	xx	xx	x
Eel *Anguilla anguilla*	xx	-	xx	x	xx	-	xx	xxx
Rudd *Scardinius erythrophthalmus*	xx	-	x	x	xx	-		x
Ruffe *Gymnochehalus cernuus*	xx	-	xx	x	xx	-	x	x
Dace *Leuciscus leuciscus*	-	-	x	x	-	-	-	-
Carp *Cyprinus carpio*	-	-	-	x	x	-	x	x
Brown trout *Salmo trutta*	-	x	-	x	-	-	-	-
Chub *Leuciscus cephalus*	-	x	-	x	-	-	-	x
Rainbow trout *Oncorynchus mykiss*	-	-	-	x	-	-	-	-
Tench *Tinca tinca*	-	-	-	x	xx	-	x	x
Barbel *Barbus barbus*	-	-	-	x	-	-	-	x
Nase *Chondrostoma nasus*	-	-	-	x	-	-	-	-
Orconectus limosus *	-	-	-	x	-	-	x	x
Grass carp *Ctenopharyngodon idella*	-	-	-	-	-	-	-	x
River lamprey *Lampetra fluviatilis*	-	x	-	-	-	-	-	x
Bullhead *Cottus gobio*	x	-	-	-	-	x	-	x
Smelt *Osmerus eperlanus*	-	xxx	xxx	-	-	-	-	-
3sp.stickleback *Gastereus aculatus*	x	x	xx	-	-	-	-	-
Sunbleak *Leucaspius delineatus*	-	-	x	-	xx	-	x	-
10sp.stickleback *Pungitius pungitius*	-	x	x	-	x	-	-	-
Flounder *Platichthys flesus*	-	xx	-	-	-	-	-	-
Pikeperch *Stizostedion lucioperca*	-	x	-	-	x	xx	x	-
Crusian carp *Carassius carassius*	-	-	-	-	x	-	-	-
Stone loach *Barbatula barbatula*	-	-	-	-	xx	x	xx	-

* North American crayfish species

Discussion

Suitability of the hydraulic conditions in V-stepped fishways for upstream passage

V-stepped fishways obviously allow passage of a broad range of fish species and sizes, even including crayfish (Table 3.4). Passage of individuals smaller than 10 cm were recorded for 10 different species. Even though the measured water velocities at the crest and just below were higher than the design criteria of 1 $m.s^{-1}$, observed minimum sizes relative to temperature were considerably smaller than could be expected from the burst swimming capacity of even the fast-swimming dace (Fig. 3.5). This may be explained by the temporal presence of pathways with lower water velocities than were measured. An alternative explanation is that some small fish leap over the sides of overfalls (as was recorded by video), and thus pass the small stretch with too high water velocities. Although it could be argued that the smallest individuals may have penetrated the fykenets from an upstream direction (e.g. perch of 6.7 cm has a girth that equals the perimeter of 20 mm stretched meshes; Mous et al. 2000), it is more likely that ascent of small fish was underestimated by escapement of trapped fish through the meshes than overestimated by voluntarily penetrating the gear from an upstream direction. In fact, none of the observed meshed fish had entered the net from an outside direction.

The low numbers of fish passing at F5 and F6 in May 1996 (Table 3.4), when discharge through the fishways was suboptimal, and the relatively high numbers of fish ascending F5 on the three days with optimal discharge (40 % of total catch in 11 % of total period), supports a decreased suitability for these fishways with flows < 0.6 $m^3.s^{-1}$.

Water velocities as measured in F1 at an extremely high discharge event at 11 March 1998 averaged 0.7 $m.s^{-1}$ at the upstream inflow-gap, where the wet cross-section of the fishway is smallest and consequently velocities are higher than in the rest of the fishway. In the adjacent free-flowing weir-gaps the water velocities were much higher (1.8 $m.s^{-1}$). Thus, even though fish with sufficient swimming capacity may pass through the weir-gaps, the fishways provide a more suitable passage pathway. Moreover, free-flowing conditions at high discharge events result in hydraulic conditions within the fishways that are more suitable for upstream passage than during non free-flowing conditions (cf. Table 3.3). However, recording during high discharge events with fykenets was impossible and data on fish passage during these events were not available. Given the higher suitability of the hydraulic conditions in the fishways during free-flowing events, missing substantial numbers of fish passing under these conditions might at least partly explain the relatively low numbers passing in 1998 when compared to 1996 when a continuous recording was possible.

Possible remaining bottlenecks for upstream passage

Eight fish species were caught during the electrofishing surveys in spring but never recorded to have passed the fishways, despite the much lower fishing effort. Several explanations may account for this: 1) they might have been constrained by the water velocities in the fishways exceeding their swimming or leaping capacities, 2) they might have passed the fishways undetected, when individuals had lengths that were too small to effectively been caught by a 20 mm stretched meshed fykenet, 3) they might have passed the fishways in different seasons outside the recording periods and fishway use was therefore missed, 4) they might have been motivated to move upstream but rejected this type of fishway as a suitable pathway and 5) they might not have been motivated to move upstream. We will subsequently discuss these explanations per species.

Smelt (7-11 cm) and three-spined stickleback (5-6 cm) were frequently observed downstream the weir at F1 (Table 5) and were even crowding in the entrance of the fishway, but no passage was ever recorded. Since both species exhibit anadromous migratory strategies during early spring (Lucas and Baras 2001), motivation to move upstream were presumably present. It may be that ascent of the small-sized smelt (individuals of 9.6 cm have girths that equal the perimeter of 20 mm meshes; Mous et al. 2000) and three-spined stickleback remained undetected owing to escapement through the meshes. However, if ascending had taken place in considerable numbers, at least some individuals would have been detected (as observed for other species). Furthermore, both species migrate in February-March under low temperature conditions (Lucas & Baras 2001), when swimming capacities are lowest (Videler and Wardle 1991). Therefore, it is most likely that hydraulic conditions within the passes were unsuitable for upstream movement of these small-sized early spring migrants, either by too high water velocities at the crest (Castro-Santos 2004) or failure to leap over the overfall at the sides. For the other small-sized species sunbleak, ten-spined stickleback and stone loach, the water velocities were probably too high as well, although the other explanations might be equally true. For pikeperch and flounder, swimming capacity is sufficiently high to be able to pass these fishways. Therefore it is likely that behavioural decisions lead to the absence in the upstream passage recordings, either because they refuse these fishways as a possible pathway, or are not motivated to migrate or migrate upstream exclusively outside the recorded spring period. A radio-telemetry study in the weir-regulated Marfeldkanal, a side-channel of River Danube in Austria, showed that the entrances of bypass-channels with surface overflows were frequently visited by pikeperch and long distances were covered, but none ever passed these fishways (Schmutz et al. 1998). On the other hand, upstream migration of pikeperch through a fish elevator in the River Dordogne, monitored year-round, did occur during spring, although motivation for upstream migration was apparently less strong than during autumn (Travade et al. 1998). Therefore, if these fishways were acceptable for pikeperch the passing of at least a few individuals was expected. For flounder, a catadromous migrant (Lucas and Baras 2001), motivation strong enough to accept these fishways for further upstream dispersion may not be expected for the observed size-range (24-30 cm), because only juveniles move upstream to the lower reaches of rivers, whereas adults move downstream in autumn to spawn in the sea (Jager 1999). There is little or no evidence that adults move back into freshwater after spawning. Thus, less intense motivation might have lead to a reduced acceptance of the fishway (i.e. most probably at the most downstream overfall) as a possible pathway to disperse further upstream. It is likely that bottom-dwelling species like pikeperch and flounder might not be willing to pass through a relatively small layer of water at the surface.

Besides the above mentioned hydraulic or behavioural constraints, other possible bottlenecks might have occurred, such as malfunctioning due to maintenance problems, which is often mentioned to be a critical factor in fishway functioning (Larinier 1998). In the V-stepped fishways, however this appeared of only minor importance since most debris flowed though the fishways fairly easily without accumulating, probably due to the smooth V-shaped structure of the overfall. This appears to be a clear benefit over other fishway types. In addition, ascending the fishways may lead to an increased mortality risk. When passing through a small layer of water at the surface, fish is more vulnerable to predation by birds, e.g. the grey herons which were often observed to hunt in the fishways. Moreover, small fish leaping to an upstream basin at the sides sometimes landed on the riprap shore, which may inflict injury or extra mortality as well. To what degree these factors reduce the success rate of fish passing these fishways should be subject of future studies.

Improving longitudinal connectivity by V-stepped fishways

Facilitating the weirs in the River Vecht and tributary Regge with V-stepped fishways have clearly improved migratory opportunities for upstream migration, when compared to the previous period in which migration was only possible through the weir-gaps under free-flowing conditions (Winter & Van Densen 2001). This is especially true for small species, juveniles and late-spring or summer migrants, because opportunities for these were close to zero before the fishways were constructed.

High suitability of the fishway itself, however, does not ensure high improvement of migratory opportunities, because other factors might be limiting also. For instance searching behaviour downstream weirs and the ability to locate the entrance of fishways (Larinier 1998, Lucas & Baras, 2001, Katopodis 2005). To determine whether fish approaching weirs are motivated to move upstream is still very challenging. Also the role that migration plays in the life history is still unknown for many riverine species, although the numbers of studies on this are increasing where most is known on adult migrations or downstream larval drift (Lucas & Baras 2001). Upstream movement of juveniles was observed for many species in the River Vecht, such as perch, ide and roach, but its role in population biology is still unclear. For instance, high numbers of juveniles were also found to pass fishways in the Marchfeldkanal along the Danube in Austria (Mader et al. 1998).

Longitudinal connectivity in rivers is of course best restored by removing obstructions, but if this is not feasible, the best solution for mitigation is probably the construction of fishways that provide a wide variety of water velocities and water depths, so that each species at different life-stages is able to select suitable pathways. In conclusion, the V-stepped fishways proved to be suitable for upstream passage of a wide variety of species including early life stages and require relatively low maintenance with regards to debris.

Acknowledgements

We thank the many recreational and commercial fishermen for assistance with recording fish passage; G. Schmidt of Waterschap Regge & Dinkel and J. Kemper of VisAdvies for providing passage data of the Regge during spring 1998; J. Heinen of RWS for discharge data; H. Stolwijk, W. Heermans, H. Wiegerinck, D.J. de Vries and W. Boiten for hydraulic measurements and evaluation, and J.J. de Leeuw, N. Daan and E.A. Huisman for valuable comments and discussion. This research was funded by the Dutch Ministry of Agriculture, Nature and Food Quality.

Fishway (F3) at low river discharge / Vistrap Junne bij lage rivierafvoer

Fishway (F3) at high discharge event / Vistrap Junne bij hoogwater

References

- Bainbridge, R. 1960. Speed and stamina in three fish. Journal of Experimental Biology 37: 129-153.
- Baumgartner, L.J., 2006. Population estimation methods to quantify temporal variation in fish accumulations downstream of a weir. Fisheries Management and Ecology 13: 355-364.
- Boiten, W. 1991. Hydraulic design of the pool-type fishway with V-shaped overfalls. In: Proceedings of the International Symposium on Fishways, Gifu, Japan, 8-10 October 1990. pp. 483-490.
- Castro-Santos, T., 2004. Quantifying the combined effects of attempt rate and swimming capacity on passage through velocity barriers. Canadian Journal of Fisheries and Aquatic Sciences. 61: 1602-1615.
- Cazemier, W.G. and W.J.M. Muyres, 1981. On the functionality of an experimental fishway in the Neerbeek. RIVO-report ZS 81-1, IMARES, IJmuiden, The Netherlands (in Dutch).
- Clay, C.H., 1995. Design of fishways and other fish facilities. Lewis Publishers, London, UK.
- Cowx, I.G. and R.L. Welcomme (Editors), 1998. Rehabilitation of Rivers for Fish. FAO, Fishing News Books, Blackwell Science Ltd., Oxford, UK.
- Gebler, R.J., 1998. Examples of near-natural fish passes in Germany: Drop structure conversions, fish ramps and bypass-channels. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 403-419.
- Jager, Z., 1999. Floundering: processes of tidal transport and accumulation of larval flounder (*Platichthys flesus* L.) in the Ems-Dollard nursery. PhD thesis, University of Amsterdam. 192 pp.
- Jungwirth, M., 1996. Bypass channels at weirs as appropriate aids for fish migration in rithral rivers. Regulated Rivers: Research and Management 12: 483-492.
- Larinier, M., 1992. Passes à bassins successifs, prébarrages et rivières artificielles. Bull. Français de La Pêche et de la Pisciculture 326: 45-72.
- Larinier, M., 1998. Upstream and downstream fish passage experience in France. *In* Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 127-145.
- Lucas, M.C. and E. Baras, 2001. Migration of Freshwater Fishes. Blackwell Science, Oxford, UK.
- Katopodis, C., 2005. Developing a toolkit for fish passage, ecological flow management and fish habitat works. Journal of Hydraulic Research 43: 451-467.
- Knaepkens, G., K. Baekelandt, and M. Eens, 2006. Fish pass effectiveness for bullhead (*Cottus gobio*), perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) in a regulated lowland River. Ecology of Freshwater Fish 15: 20-29.

- Mader, H., C. Unfer, and S. Schmutz, 1998. The effectiveness of nature-like bypass channels in a lowland river, the Marchfeldkanal. *In* Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 384-402.
- Mous, P.J., W.L.T. van Densen and M.A.M. Machiels, 2000. The efffect of smaller mesh sizes on catching larger fish with trawls. *In* Interactions between fisheries and birds in IJsselmeer, The Netherlands, Mous, P.J., PhD-thesis, Wageningen University, The Netherlands.
- Naughton, G.P., C.C. Caudill, C.A. Peery, T.S. Clabough, M.A. Jepson, T.C. Bjornn and L.C. Stuehrenberg, 2007. Experimental evaluation of fishway modifications on the passage behaviour of adult Chinook salmon and steelhead at Lower Granite Dam, Snake River, USA. River Research and. Applications 23: 99-111.
- Peake, S., F.W.H. Beamish, R.S. McKinley, D.A. Scruton and C. Katopodis, 1997. Relating swimming performances of lake sturgeon, *Acipenser fulvescens*, to fishway design. Canadian Journal of Fisheries and Aquatic Sciences 54: 1361-1366.
- Schmutz, S., C. Giefing and C. Wiesner, 1998. The efficiency of a nature-like bypass channel for pike-perch (*Stizostedion lucioperca*) in the Marchfeldkanalsystem. Hydrobiologia 371: 355-360
- Schwalme, K., W.C. McKay and D. Lindner, 1985. Suitability of vertical slot and Denil fishways for passing north-temperate, non-salmonid fish. Canadian Journal of Fisheries and Aquatic Sciences 42: 1815-1822
- Travade, F., M. Larinier, S. Boyer-Bernard and J. Dartiguelongue, 1998. Performance of four fish pass installations recently built on two rivers in south-west France. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 146-170.
- Videler, J.J. and Wardle, C.S., 1991. Fish swimming stride by stride: speed limits and endurance. Reviews in Fish Biology and Fisheries 1: 23-40.
- Winter, H.V. and van Densen, W.L.T., 2001. Assessing the opportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.

Passeerbare vistrappen

Om de optrek van vis in de Vecht te verbeteren zijn tussen 1987 en 1994 alle stuwen voorzien van een 'bekken-vistrap met V-vormige overlaten'. Dit type vistrap is begin jaren 80 in Nederland ontwikkeld. Inmiddels zijn deze op tal van plaatsen aangelegd, waaronder ook in de Regge (zijrivier van de Vecht). In de Vecht ligt elke vistrap in een omleiding om de stuw heen. Het waterhoogteverschil bij de stuw wordt verdeeld over een serie ruim bemeten water bassins (gemiddeld 10 m per bekken). Elk bekken wordt gescheiden door een V-vormige overlaat (drempel) waarover het water met een hoogteverschil van 15-20 cm in het volgende bekken stroomt. De stromende waterlaag is boven het midden van de overlaat het grootst, maar ook de stroomsnelheid die overwonnen moet worden. Aan de zijkanten is de stroomsnelheid lager, maar is ook een geringere waterlaag beschikbaar om vis door te laten. Gemiddeld gaat er 1 m^3/s door de vistrap, de rest van de rivierafvoer gaat over de stuw. Maar hoe goed zijn deze vistrappen voor de verschillende vissoorten passeerbaar?

Om dat te onderzoeken hebben we gedurende een aantal jaren tijdens het voorjaar, wanneer de meeste soorten stroomopwaarts trekken om te paaien, per soort het tijdstip van optrek en het aantal individuen gemeten in de vistrap. Er zijn grote fuiken geplaatst die de hele bovenstroomse uitzwemopening van de vistrap afsloten. Om de invloed van de bemonstering op de vismigratie zo klein mogelijk te houden, hebben vrijwilligers van hengelsportverenigingen en enkele beroepsvissers dagelijks de fuikvangsten doorgemeten. Deze bemonsteringen vonden plaats bij vier van de zes vrijwel identiek aangelegde vistrappen. De gemeten vis werd voorzichtig behandeld en boven de vistrap weer teruggezet om hun migratie voort te kunnen zetten. Om een indruk te krijgen van het aanbod aan vis benedenstrooms van de stuwen, hebben we bemonsteringen uitgevoerd met elektrovisserij. Dit klinkt erger dan het is, vis kan met deze methode vrijwel altijd weer onbeschadigd worden teruggezet na meting. Verder zijn er op verschillende plaatsen in de overlaat waterstroomsnelheden gemeten om te kunnen bepalen of alle vis fysiek in staat is om de vistrappen te kunnen passeren.

In totaal zijn 22 verschillende vissoorten waargenomen die in de periode februari-juni optrekken via de vistrappen in de Vecht (inclusief de eerste vistrap in de Regge). Ook veel kleine vis wist de vistrappen te passeren: van 10 soorten zijn exemplaren kleiner dan

10 cm opgetrokken. De meest talrijke soort was blankvoorn, gevolgd door brasem en winde. Opvallend was het feit dat niet alleen volwassen paairijpe vissen optrokken maar ook veel jonge onvolwassen vis. Voor winde en baars betrof dit meer dan 50% van de totale aantallen. De reden waarom die jonge vis ook de rivier optrekt is nog onbekend. Vis wist de vistrap vaak beter te passeren dan we op grond van de stroomsnelheden, watertemperatuur en het sprint-model (box 8.1, blz 155) zouden inschatten. Bijvoorbeeld door springend langs de zijkanten van de overlaten naar het volgende bekken te trekken (zoals vaak is gezien).

De soortsamenstelling van de vis die de hindernis via de vistrap genomen heeft, kwam over het algemeen behoorlijk overeen met de samenstelling benedenstrooms van de stuw en ook bij de ingang van de vistrap. Er waren echter een paar belangrijke verschillen: met name spiering, driedoornige stekelbaars, snoekbaars en bot zijn wel benedenstrooms van de eerste stuw gezien, maar er is nooit waargenomen dat ze via een vistrap verder optrokken. Van spiering en driedoornige stekelbaars is bekend dat ze trekgedrag kunnen vertonen, maar beiden zijn kleine soorten die ook nog eens heel vroeg in het voorjaar optrekken als het water koud is en de sprintcapaciteit minimaal. Hierdoor konden ze de vistrap waarschijnlijk niet passeren. Voor bot en snoekbaars ligt dit anders: ze kunnen het theoretisch wel, maar doen het blijkbaar niet.

De bekken-vistrap met V-vormige overlaten lijkt weliswaar passeer-baar voor de meeste soorten en maten, maar het functioneren van vistrappen hangt niet alleen af van de passeerbaarheid van de vistrap zelf. Dit is namelijk ook afhankelijk van het deel van de vissen die naar boven willen dat er in slaagt om de ingang van de vistrappen te vinden. Hierover meer in hoofdstuk 7.

Bream and roach / Brasem en blankvoorn

4

Rehabilitating fish communities in the River Vecht: an evaluation of the effect of fishways

Erwin Winter

(Submitted for publication)

Abstract

The ultimate goal of restoring fish passage along barriers in rivers is to rehabilitate fish communities, but assessments of the effectiveness of fishways are still scarce. The River Vecht is a weir-regulated lowland river flowing through Germany and the Netherlands. Since 1914, six weirs have severely limited upstream movements of most fish species present (mainly cyprinids), until fishways were constructed along each of the weirs in 1987-1994. These V-shaped stepped passes consist of large basins separated by overfalls with surface overflow and drops of 0.2 m. The objective is to determine whether these fishways have resulted in changes in fish communities. The potential benefit of fishways by species was estimated by integrating 1) an assessment of the species-specific degree of obstruction posed by the weirs before fishways were built, 2) monitoring fish passage through the fishways during spring 1996-1998, and 3) electrofishing surveys at river stretches in between weirs during 1995-1998. It is hypothesized that species that were severely obstructed before fishways were built, and that were abundant in fishways relative to their abundance in the river, have benefited most from their construction. To test this hypothesis, data from the 1990s were compared to historical electrofishing data from 1975, when large aggregations of fish directly downstream of three different weirs were sampled. The minor shifts in relative abundances observed between the pre-fishway period (1970s) and the fishway-period (1990s) were in agreement with the expected benefit by species. This applies especially for bleak *Alburnus alburnus*, bream *Abramis brama* and ide *Leuciscus idus*, which probably passed series of fishways. However, no major shifts in fish communities were observed. It is argued that the highly regulated state and degraded habitats of the River Vecht still poses severe bottlenecks on riverine fish populations even though the, formerly disrupted, longitudinal connectivity has been greatly improved.

Introduction

Globally many rivers are regulated with dams or weirs posing severe obstructions to fish movements. These barriers often have had a greater impact on riverine fish than any other anthropogenic factors (Petts 1984). To facilitate upstream migration, these barriers are increasingly equipped with fishways or bypass channels of inventive designs (reviewed in Clay 1995 and Katopodis 2005). Most studies evaluating fishways primarily assess their functioning, e.g. whether the hydraulics within a fishway are suitable for the ascent of target species and which numbers of these fish actually succeed in passing (Larinier 1998). Where in the past most attention was paid to anadromous species (Beach 1984), more recently focus has been shifted to design fishways suitable for a wider range of species and sizes (Lucas & Baras 2001, Katopodis 2005). The ultimate goal of restoring fish passage is to rehabilitate fish communities upstream and downstream barriers, but assessment studies of the effectiveness of fishways in achieving this goal are mostly lacking (Gehrke et al. 2002).

In The Netherlands, a widely used type of fish pass is the V-stepped fishway, with large basins subdivided by V-shaped overfalls with surface overflow and small drops between basins (Boiten 1991, Cowx & Welcomme 1998). These fishways are designed to facilitate the ascent of fish with relatively poor swimming capacity (Cazemier & Muyres 1981). The River Vecht was the first river in The Netherlands where all six weirs were bypassed with such fishways. Before their construction, upstream movements over the weirs were severely constrained, because passage of weirs was restricted to periods of floods when the weirs were lowered, allowing only strong swimmers to ascend through the free-flowing weir-gaps (Winter & van Densen 2001).

To evaluate whether fishways have resulted in measurable changes in the fish community in the River Vecht, electrofishing data from the 1970s and 1990s and fishway passage data from the 1990s were used. In particular, the question arises whether there is evidence for an increase in abundance of fish species that use the fishways when compared to the period before these were built. Only the actual use of the fishways by each species is taken into account, not their optimal functioning for each of the species separately. Thus the species-specific suitability of these fishways is beyond the scope of this study.

It is hypothesized that species that are abundant in fishway passage relative to their abundance in the river ('*relative fishway use*') and that suffered a high degree of obstruction to migrate in the past have increased in relative abundance, as opposed to species with a low relative fishway use or a low degree of obstruction. Specifically, the question is addressed whether species that may pass multiple fishways have benefited more than others, because they should have been more constrained in the past than species that passed only single weirs (Winter & van Densen 2001).

Material and methods

Study area

The rain-fed River Vecht (52°30'N, 6°30'E; Fig. 4.1) has an average discharge of 32 $m^3.s^{-1}$ at the most downstream weir Vechterweerd (Weir 1) and drains a catchment area of 3,800 km^2, of which 1,800 km^2 is located in Germany (Parmet & Raak 1997). The downstream Dutch part of the river is on average 50 m wide and discharges into Lake Zwarte Meer and finally into Lake IJsselmeer. Both are shallow eutrophic lakes that are remainders of a former brackish estuary that was closed off when a 32 km dam (Afsluitdijk) was built in 1932. As in many rivers, different factors of human impact may have affected the fish communities in the River Vecht. The most important factors and their development during 1970-1998 will subsequently be described below.

1) *Migration barriers*: Main regulatory works in the river took place between 1850 and 1914, when many meanders were cut off and weirs were constructed to maintain target water levels at low discharge rates. At these weirs, upstream water levels are kept close to the target. At low discharge rates, these weirs cause abrupt differences in water level, ranging up to 3 m. At high discharge rates, weirs are lowered and water is '*free flowing*' through the weir-gaps (Winter & van Densen 2001).

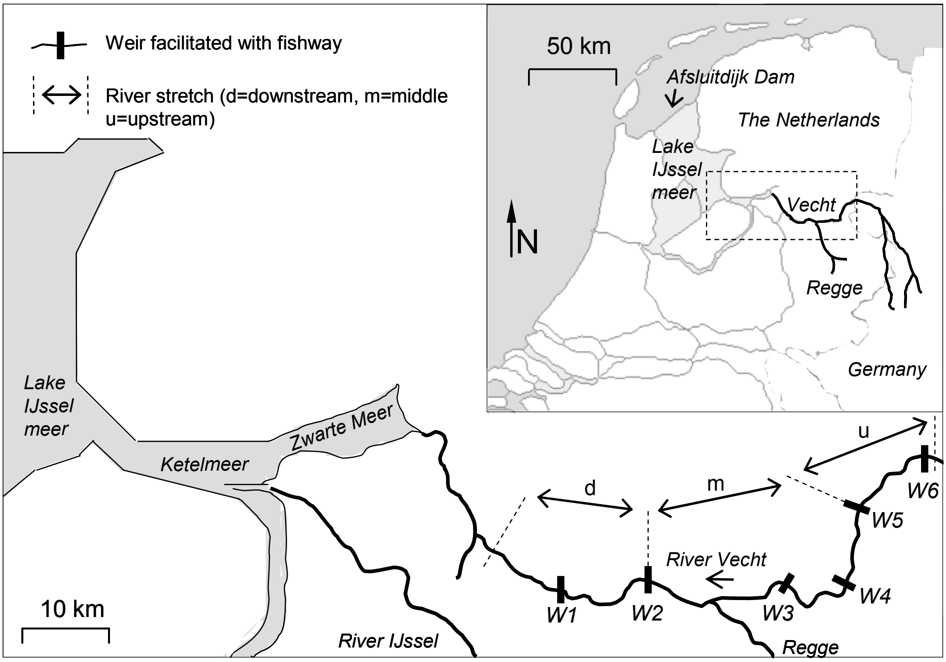


Figure 4.1 *Map of the study area with the location of the six weirs in the River Vecht and subdivision in stretches d, m and u. Weirs with fishways are numbered W1-W6 in the order that upstream migrating fish encounter them.*

2) *Habitat degradation*. Compared to the original freely meandering state, the highly canalized river shows little habitat heterogeneity (Wolfert et al. 1996) and most of the shorelines are protected against erosion by riprap. During 1970-1998, hardly any morphological changes have occurred and almost all regulatory measures took place long before those years.

3) *Water pollution*. In the absence of large-scale industries and urbanisation in the Vecht catchment area, water quality has never been as poor as in many other West-European rivers, such as in the River Rhine (Hellmann 1994, Beurskens et al. 1994). Since 1973, an increasing number of water quality parameters have been measured monthly (Fig. 4.2). Mean concentrations of oxygen and total nitrogen remained constant during the last three decades, whereas total phosphorus showed a clear decline, as a consequence of reduced loads in wastewater effluents. Despite this improvement, the River Vecht is still considered as a eutrophic river, where algal blooms, as indicated by chlorophyll-a concentrations above 0.1 mg. l^{-1}, occur especially during summers with low discharge (Figure 3.2). Submerged plants are still scarce. Micropollutants show various trends since 1988, but for most parameters, concentrations are considered not to be problematic by the local authorities.

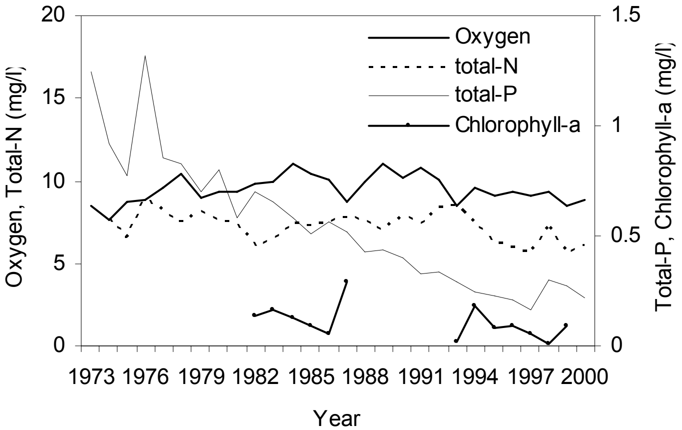


Figure 4.2. Trends in water quality parameters; oxygen, nitrate, phosphorus and chlorophyll-a, in the River Vecht during 1973-1999. For each year the mean of monthly measurements is given.

4) *Fisheries*. Commercial fisheries in the river are restricted to eel *Anguilla anguilla* and fishing pressure has remained constant at a relatively low level during the 1970-1998. Recreational fisheries (catch and release) were intensive throughout 1970-1998 and mainly focussed on cyprinid species. Stocking of fish has not occurred in the river stretches studied.

V-stepped fishways

To mitigate the barriers that the weirs pose to fish migration, a series of V-stepped fishways (Cowx & Welcomme 1998) was constructed alongside each of the six weirs between 1987 and 1994 (Fig. 4.1). All fishways are similar in construction, flow and their position relative to the weir. The large basins (on average 10 by 9 m) are separated by V-shaped overfalls with a basin drop of 0.15-0.20 m (Boiten 1991). At most discharge rates, upstream water levels at each weir remain close to the target and as a consequence flow through the fishways is constant at c. 1 $m^3.s^{-1}$ for all fishways. Only at high discharge rates when the water over the weirs is free-flowing, flow over the fishways is increasing with rising upstream water levels.

Fish sampling

Upstream ascent of fish through the fishways was monitored in 1996 (fishways 1, 3, 5 and 6) and 1998 (fishways 1 and 5, Fig. 4.1). Because the fish fauna is dominated by cyprinids (Cazemier 1978) performing generally pre-spawning migrations in spring (Mills 1991, Smith 1991, Prignon et al. 1998, Travade et al. 1998), recordings were restricted to February-June (Table 4.1). Fish moving upstream were trapped in fykenets (length 10 m, stretched mesh size 20 mm) covering the entire upstream inflow overfall of a fishway. Catches were recorded daily including numbers and total length (measured to the nearest cm below). All fish were released in the main channel directly upstream of the fishway. During spring 1996, floods did not occur and monitoring could be continued during the entire spring period. In spring 1998, two floods occurred during which overspilling gates were opened completely and recording was impossible owing to much floating debris, resulting in two breaks in the monitoring.

Electrofishing surveys were performed during March/April 1996 and 1997; during August 1996, 1997 and 1998; and during October/November 1995, 1996 and 1997. Along the entire shoreline of the Dutch river course, random stretches of about 300 m were sampled by electric fishing (direct-current, 6 A, 350 V) for each 3 km mainstream stretch and in each connected backwater during each survey.

During the pre-fishway period, large fish aggregations could be found directly downstream of these weirs during spring (Cazemier 1978). Such aggregations are related to 'crowding effects' of barriers (Eberstaller et al. 1998, Baumgartner 2006). Large aggregations of fish directly downstream weir 1, weir 3 and weir 6 were sampled on 20-22 May in 1975 with similar electric fishing equipment as used in the 1990s surveys, but further information on effort and other specifications were not available. In all electric fishing surveys, total length to the nearest cm below was measured for samples of all species.

Potential benefit of facilitating fishways

The potential benefit of the construction of fishways for each species is supposedly dependent on 1) the fraction of each population that uses the fishway, 2) the degree of obstruction before their construction, and 3) the number of weirs that have to be passed to reach the target habitat.

As a measure for the fraction of the population that uses the fishway, for each species the ratio between the relative abundance recorded in the fishway and the relative abundance on the river stretches in between weirs was calculated (i.e. species specific '*relative fishway use*'). The composition of the 0-group fish assemblage in the August surveys was considered to be the best available approximation for the relative abundance in the river stretches in between weirs because: 1) during summer 0-group fish of almost all riverine fish are confined to the littoral zone (Schiemer & Zalewski 1992), whereas older fish use a much wider range of habitats, all of which could not be sampled by electric fishing, 2) differences in catch efficiency of electric fishing among species are smallest when variation in fish length is smallest (Regis et al. 1981), as in 0-group fish, and 3) 0-group fish represent both resident and migrant species, because most migrant species present in the River Vecht are either potamodromous or anadromous using the river for spawning and nursing (Winter & van Densen 2001). Two catadromous species, flounder *Platichtys flesus* and eel, migrate into the river as juveniles. From the length-distributions of both species the numbers of 0-group fish (flounder) or of the first cohort (eel) was used.

The degree of obstruction for upstream movement before fishways were constructed has been assessed by Winter & van Densen (2001) for each species for the period of 1960-1983. The percentage of years that upstream movement at weirs 1-4 was completely obstructed per species was used as a measure for the species specific 'degree of obstruction' during the pre-fishway period.

Table 4.1 Relative abundance per species in the samplings of aggregations in 1975 and river stretches in 1995-1998 by electrofishing, and in fishway passage by fykenets. Per stretch (d=downstream; m=middle; u=upstream, see Figure 4.1), the relative abundance in 1975 was compared to relative abundance in fishway passage in 1996-1998 and by including relative abundance of electrofishing in stretches also (+1=increase since 1975; 0=unchanged; -1=decrease, see also text).

Sampling:	Passage	0+fish	Aggregations before			Fishway passage			Electrofishing river			Aggregation vs.			Aggregation vs.		
Period:	96/98	96-98	May 1975			May 1996/1998			Winter 1995-1998			fishway passage[1]			passage/elec.fish[2]		
Species *Stretch:*	all	all	d	m	u	d	m	u	d	m	u	d	m	u	d	m	u
Eel, *Anguilla anguilla* (L.)	1.1	0.3*	1.1	2.3	4.7	0.1	0.8	20.0	5.6	5.5	3.6	-1	-1	+1	0	0	+1
Pike, *Esox lucius* (L.)	0.2	0.6	0.0	0.6	1.4	0.0		0.2	2.4	2.7	2.8	0	(-1)	-1	0	0	0
Smelt, *Osmerus eperlanus* (L.)			0.2														
Brown trout, *Salmo trutta* (L.)									0.1								
Bream, *Abramis brama* (L.)	8.9	16.3	7.4	2.2	0.4	16.8	5.1	1.7	9.1	0.4	0.7	+1	+1	+1	+1	+1	+1
Bleak, *Alburnus alburnus* (L.)	2.2	0.0	0.5	0.7	0.1	1.7	6.2	7.1	0.0			+1	+1	+1	+1	+1	+1
Barbel, *Barbus barbus* (L.)	0.0																
White bream, *Blicca bjoerkna* (L.)	2.2	0.5	0.0	4.8	1.2	4.2	3.6	1.1	0.3	0.1	0.8	+1	0	0	+1	-1	-1
Crusian carp, *Carassius carassius* (L.)					0.1												
Carp, *Cyprinus carpio* (L.)	0.0			0.1		0.0				0.1							
Gudgeon, *Gobio gobio* (L.)	0.5	11.2	0.2	8.3	3.8	0.1	2.0	0.1	0.5	1.6	1.1	-1	-1	-1	0	-1	-1
Sunbleak, *Leucaspius delineatus* (L.)		1.7							0.0	0.0	0.7						
Chub, *Leuciscus cephalus* (L.)		0.0															
Ide, *Leuciscus idus* (L.)	7.4	8.4	3.5	0.9	1.3	4.6	3.8	3.4	2.0	1.0	0.5	+1	+1	+1	0	+1	+1
Dace, *Leuciscus leuciscus* (L.)	0.0	0.5	0.3	1.4	2.6	0.0				0.0	0.1	-1	(-1)	(-1)	-1	-1	-1
Bitterling, *Rhodeus sericeus* (L.)										0.0							
Roach, *Rutilus rutilus* (L.)	73.4	41.9	84.4	57.6	71.0	66.2	73.0	52.3	1.6	2.9	1.0	-1	+1	-1	-1	0	-1
Rudd, *Scardinius erythrophthalmus* (L.)	0.1	0.4				0.1		0.1	0.3	0.5	0.6						
Tench, *Tinca tinca* (L.)	0.0	0.1	0.0	0.3	0.1	0.0		0.2	0.5	2.1	0.9	0	(-1)	0	0	0	+1
Stone loach, *Barbatula barbatula* (L.)		0.4							0.7	2.9	7.7						
Spined loach, *Cobitis taenia* (L.)		0.1	0.0														
Weatherfish, *Misgurnus fossilis* (L.)			0.1														
3-sp. Stickleback, *Gasterosteus aculeatus* (L.)		0.0							0.1								
10-sp. Stickleback, *Pungitius pungitius* (L.)		0.0							0.1	0.1	0.3						
Ruffe, *Gymnocephalus cernuus* (L.)	0.0	0.2	0.0	4.7	0.7	0.1		3.9	9.3	1.8	1.0	0	(-1)	+1	+1	-1	+1
Perch, *Perca fluviatilis* (L.)	3.9	17.3	1.6	11.8	12.5	6.1	5.3	9.9	66.7	78.0	78.1	+1	-1	0	+1	0	0
Pikeperch, *Stizostedion lucioperca* (L.)		0.0	0.5	4.2					0.3	0.1		(-1)	(-1)	(0)	-1	-1	0
Bullhead, *Cottus gobio* (L.)	0.0	0.0					0.1		0.4	0.1							
Flounder, *Platichthys flesus* (L.)									0.1								
Total numbers of fish caught	34880	9032	2584	1114	835	14640	1109	3488	3519	4699	2063						

* For eel the smallest cohort in the LF distribution in the river was treated as 0-group; [1] method 1; [2] method 2

The timing of the passage at fishways 1 and 3 was used to get an indication whether fish species predominantly pass a single fishway or a series of fishways. If the timing of 'first appearance' or the 'peak' of migration for a species coincides in fishways 1 and 3, the two groups were considered to consist of predominantly different individuals (Fig. 4.3). If the start and peak at fishway 3 was later than in fishway 1, the majority might consist of one cohort passing a series of fishways. The assumption made here is that the onset of migration coincides along the river course. Onset of migration is mostly triggered by water temperature, photoperiod or flow (Smith, 1985; Jonsson, 1991) and spatial variation in these factors along the course investigated is insignificant. If timing of first start or peak of migration coincides with, or is even earlier than at a downstream fishway, the majority of the upstream migrants observed could not have passed a series of fishways, at best only a minor part. By species a distinction between adults and juveniles was made, because motivation and timing for upstream movement might differ between these life stages. By fishway, the date at which 5% of the total number during the entire period had passed was used as time of first appearance, and the date at which 50% had passed as time of the migration peak. As a prerequisite for this approach, the spring monitoring needs to be continuous and therefore these parameters were only calculated for fishways 1 and 3 in 1996 during 4 April-24 May. Moreover, all species showed one dominant migration peak and only species of which more than 50 individuals were caught at each fishway were considered.

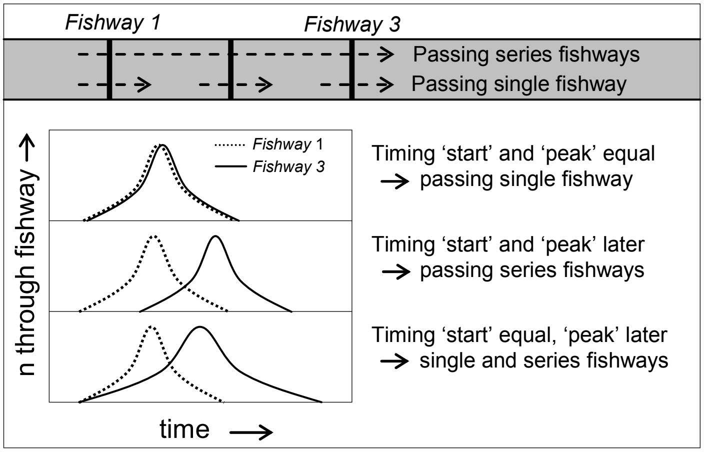


Figure 4.3. *Hypothesized scale of fishway use, i.e. single or series, for each fish species as derived from the timing of 'start' (first appearance) and 'peak' of passage through the fishways 1 and 3, under assumption that the triggering of upstream migration occurs simultaneously along the river course.*

Evaluation of changes in abundance before and after fishways were constructed

Aggregations of fish directly downstream of the weirs sampled in 1975 were likely to consist primarily of fish motivated to move upstream. Many cyprinids perform pre-spawning migrations during spring (Mills 1991, Smith 1991, Prignon et al. 1998, Travade et al. 1998, Lucas & Baras 2001). Because the weirs posed a complete obstruction during the four weeks prior to sampling (the last free-flowing event in spring 1975 occurred on 16 April), these aggregations may be expected to have built up during these weeks. To compare the relative abundance of the aggregations in 1975 to the relative abundance in the fish passage for each species from 1996-1998, the river was divided in 3 stretches, downstream (d), middle (m) and upstream (u) (Figure 4.1). For each species and stretch the relative abundance in 1975 was tested against the relative abundance in each fishway in 1996-1998 by 2x2 G-test ($p < 0.05$, df=1) using William's correction factor (Sokal & Rohlf 1995).

Even though most fish in the 1975 aggregations may represent fish motivated to move upstream, it can not be ruled out that part consisted of fish that were not motivated, i.e. fish using the area below the weir as a target habitat. Therefore, a second more conservative approach was used to compare the relative abundance of the aggregations in 1975 to both the relative abundance in the fishway and the relative abundance in the river stretches during the winter half year prior to spring migration. The latter should be more representative of the 'resident' fraction. When for a species and stretch the value for 1975 fell within the range between the value for the fishway and the average value of the river stretch and fishway combined, the relative abundance was considered unchanged. When the value for 1975 was higher than this range it was considered to have decreased, when lower to have increased.

In both approaches only those species representing more than 1 % of the catch in at least one of the samplings ('aggregations 1975', 'fishways 1990s' or 'river stretch 1990s') were taken into account, which was the case for 13 species. Change per stretch was expressed as −1, 0 or +1 for a decrease, no change or increase, respectively. The mean change of the three stretches combined for each species and each approach was then compared to the expected potential benefit.

Results

Expected benefit of fishways

Based on the relative fishway use, as determined from the relative abundance in fishways and along river stretches (Table 4.1, which contains all scientific names of the species mentioned) and the degree of obstruction before the fishways were built, the expected benefit of fishways is highest for bleak, white bream, eel and roach, and lowest for pikeperch, chub, dace and gudgeon (Table 4.2).

Table 4.2. The 'relative fishway use' (i.e. the ratio between relative abundance in fishway passage and on river stretches) and the percentage of years when migration was obstructed during the period before fishways were constructed (Winter & van Densen 2001) are shown for the 13 most abundant species. The 'potential benefit' of facilitating fishways was hypothesized to be highest for species with high 'relative fishway use' and high 'degree of obstruction' before fishways were present.

Species	Relative fishway use during 1996/1998	Percentage of years when migration was obstructed during 1960-1984	
	all fishways	weirs 1-4	weirs 5-6
Bleak	50	82	98
White bream	4.5	89	100
Eel	3.8	100	100
Roach	1.8	71	98
Ide	0.9	16	61
Bream	0.5	61	98
Pike	0.4	54	91
Perch	0.2	32	76
Ruffe	0.2	98	100
Tench	0.2	80	98
Gudgeon	0.05	87	98
Dace	0.04	38	85
Pikeperch	< 0.01	33	70

Of the fish species passing the upstream fishway 3 in spring 1996, indications were found for bleak, bream and juvenile ide that the majority might have passed series of fishways. White bream and gudgeon might have partly passed series of fishways and single fishways. The majority of roach, adult ide and perch were likely to have passed only a single fishway (Fig. 4.4). Timing of the onset of passage in 1996 showed that six of these species started migration during late April, while adult ide started two weeks earlier. Before the recording started in 1996, water temperatures were below 5°C and hardly any fish were caught downstream of weir 1 by recreational fishermen. Migration peaks occurred during the last week of April for most species, except for adult ide (one week earlier) and adult bream (one week later).

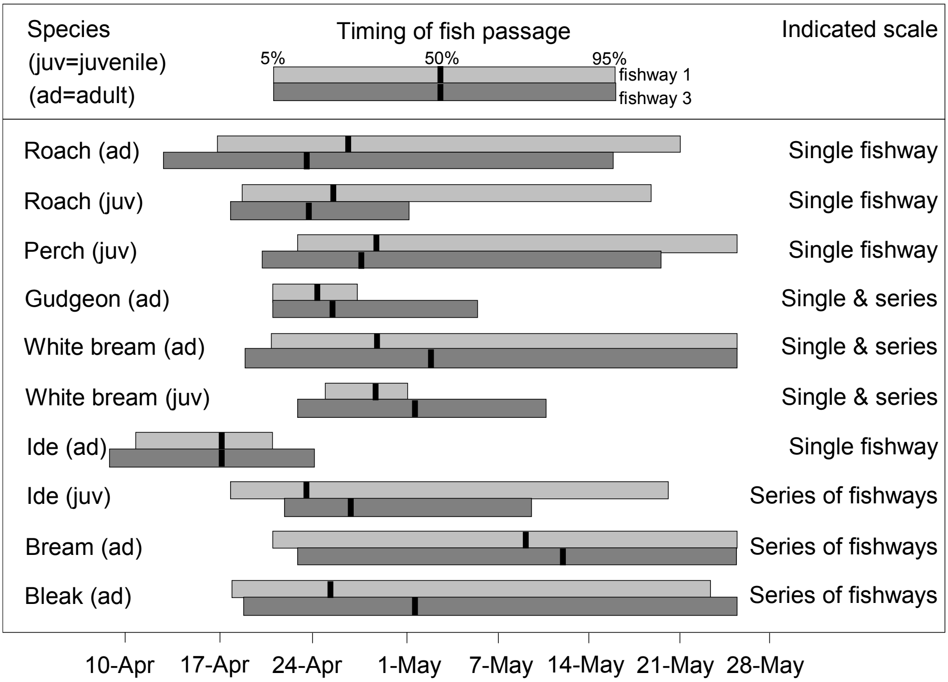


Figure 4.4 *Observed timing of fishway passage in fishway 1 (light grey bars) and fishway 3 (dark grey bars) in spring 1996 for the most abundant species, indicating the date when 5 % has passed as the 'start' and when 50 % has passed as 'peak' of migration. For each species subdivided in juveniles and adults, the scale of fishway use is indicated as derived according to Figure 4.3.*

Community changes after fishway construction

Roach was by far the dominant species in the 1975 aggregations and in the fishways in 1996-1998, whereas perch was dominant along river stretches during the winter half year in 1995-1998 (Table 4.1). For each stretch and species, changes in relative abundance was examined using two approaches. When comparing relative species composition, roach has remained dominant and no major shifts were found. However, a few species show clear changes. Bleak, bream and ide have increased in relative abundance in all stretches, whereas gudgeon, dace and pikeperch have decreased in nearly all stretches. The size composition by species in 1975 and in 1996-1998 were largely similar for most species, except for bream where the fishway recordings showed hardly any juveniles in contrast to the aggregations in 1975 (Fig. 4.5).

Changes in relative abundance in relation to expected potential benefit of the fishways

Decreases in relative abundance were found for the species with the lowest relative fishway use, whereas increases in relative abundance were only found for species with a higher than average fishway use (Fig. 4.6). However, no change or a slight decrease was found for roach, eel and white bream.

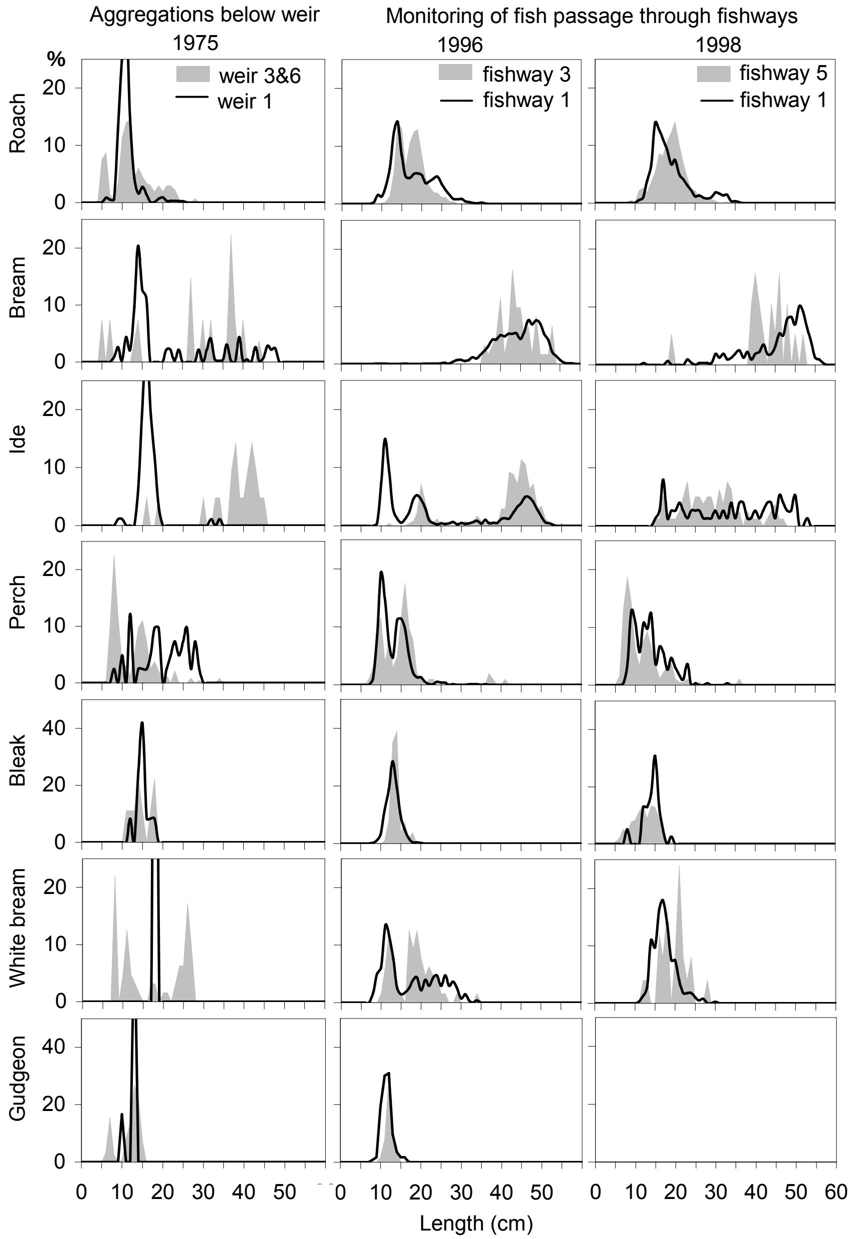


Figure 4.5 *Length-frequency distributions per species for the 1975 electrofishing surveys and the 1996 and 1998 fishway passage recordings are given for a downstream location (solid line) and upstream location (shaded area) in each panel.*

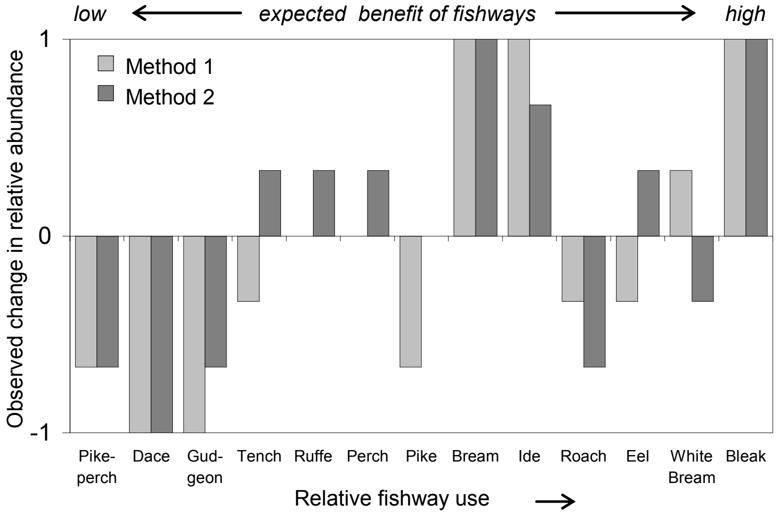


Figure 4.6. *The 13 most abundant species were ranked in increasing relative fishway use (see Table 4.2). Changes in relative abundance between 1975 and 1996-1998 (1 denotes an increase and -1 denotes a decrease in all three stretches) are given for two different methods of comparison: method 1) aggregations 1975 vs. fishway passage (light grey bars, 2x2 G-test, p>0.05) and method 2) aggregations 1975 vs. fishway passage and river abundance 1996-1998 (dark grey bars, see text and Table 4.1).*

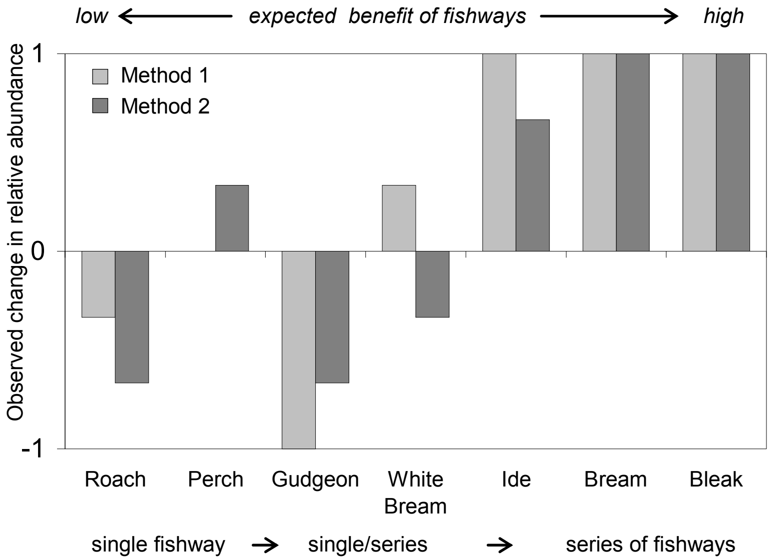


Figure 4.7. *The 7 most abundant species in fishway passage, were ranked in increasing scale of fishway use from indications for predominantly single fishway use to series of fishways (see Fig. 4.4). Changes in relative abundance between 1975 and 1996-1998 (1 denotes an increase and -1 denotes a decrease in all three stretches) are given for two different methods of comparison: method 1) aggregations 1975 vs. fishway passage (light grey bars, 2x2 G-test, p>0.05) and method 2) aggregations 1975 vs. fishway passage and river abundance 1996-1998 (dark grey bars, see text and Table 4.1).*

Changes in relative abundance were higher for those species (bleak, bream and ide; Fig. 4.4) that may pass series of fishways, either as juveniles or adults, than for those (white bream, gudgeon, roach and perch) that appear to pass predominantly or partly one single fishway (Fig. 4.7).

Discussion

For most species, the observed changes in relative abundance between the period before and after the construction of fishways are in agreement with their expected benefit, as derived from both relative fishway use (Fig. 4.6) as well as from evidence for passage of series of fishways (Fig. 4.7). The observed changes, however, were relatively minor for most species and major shifts in species composition as a result of building fishways along the weirs have not been observed. Observed changes in relative abundance, even if in accordance with the hypothetic direction, may have been caused by other (both methodological and ecological) factors than fishway construction, such as: 1) relative abundance in the samples may be biased, so that the observed changes do not reflect actual changes; 2) year-to-year variations in relative abundance can be large and a single year observation for 1975 may not provide an accurate estimate for the pre-construction situation; 3) main upstream migration may occur at other times of the year than represented by the samples, resulting in an underestimation of relative fishway use; and 4) other changes in ecosystem functioning between 1970s and 1990s have caused the observed differences in relative abundance. All these explanations are discussed below.

1) An obvious potential bias may be caused by differences in species-specific and/or size-specific catch efficiency between the two sampling methods used. However, the observed similarity of the size compositions of the catches obtained by electrofishing in 1975 and the fykenet catches in 1996-1998 for almost all species (Fig. 4.5) suggests that differences in catch efficiency have played a minor role. For example, the size composition of ide showed large differences among sites both in 1975 and in 1996-1998, whereas the size compositions by year and site were almost the same for the two methods. The largest differences refer to the lack of juvenile bream in the fishway sampling and the absence of white bream juveniles in 1975 at the most downstream weir. Because in both cases the method of sampling was the same (electrofishing) and both species are likely to have a similar catchability, the differences in size composition are unlikely to be caused by differences in catch efficiency.

2) Year-class strength variation can be high in riverine populations (Mills & Mann 1985). Size compositions by species in 1975 and 1996-1998 shows that in most cases several year-classes are present. This should reduce the effect of year-class strength variation on total abundance. Moreover, when comparing the size compositions of the catches in fishway 1 in 1996 and 1998 (Fig. 4.5), most species show little differences, indicating that year-class strength variation is relatively small, except perhaps for ide.

3) If the timing of main upstream migration of a species falls outside the spring season, the expected change should be positive because relative fishway use is underestimated, and more so in the conservative 'fishway/river' approach than in

the tested 'fishway' approach. However, a positive change has not been observed for any of the species with a low relative fishway use. Anadromous brown trout and lampern migrate upstream mainly in autumn (McDowall 1988), but these species were not recorded as 0-group fish. Therefore, even if changes in these populations have occurred, they did not alter the relative abundance of the other species considered.

4) Other ecological factors than fishway construction affecting fish communities might also have changed from the 1970s to the 1990s simultaneously and thus causing the observed changes in relative abundance. Because the different human impact factors on River Vecht started long before the 1970s (e.g. habitat degradation, water pollution and fisheries) and remained at a relatively constant level throughout the 1970s to 1990s, the only likely candidate factor might be the observed decline of phosphorus (Fig. 4.2) . Especially for bream (Pinder *et al*, 1997) and pikeperch less eutrophication would be expected to affect abundance negatively, whereas positive effects might be expected for more critical species like dace, gudgeon, tench, pike and bleak. Overall, the observed changes for these species are inconsistent with this alternative hypothesis because trends appear to vary independently of the expected sign of the relationship. Moreover, algal blooms occurred not only in the 1970s but also in the 1990s, despite the lower level of phosphate. Nevertheless, an effect of the decline in P-concentration on individual species cannot be ruled out. The data available do not allow a causal proof between effect and factors for any of the species. The possibility is left open that other changes in the river ecosystem have caused the observed changes in some species.

For roach, white bream and eel, in contrast to the high potential benefit of facilitating fishways based on relative fishway use, no increase in relative abundance between 1970s and 1990s was observed (Fig. 4.6). Even though longitudinal migration has been improved, population size of these species might have been restricted by other factors than longitudinal connectivity. Roach and white bream are eurytopic species that are capable of completing their life-cycle in relatively small watersystems such as ponds or river stretches. Therefore, barriers might not have been the true bottleneck for population sizes of roach and white bream. Numbers of glass eel immigrating Lake IJsselmeer have drastically declined since the 1970s (Dekker 2004). Nevertheless, overall relative abundance of eel has remained unchanged in the River Vecht. Thus, the beneficial effect of improved migratory opportunities for this species may be obscured by decreasing numbers of upstream migrating juveniles. Indeed, relative abundance of eel appears to have decreased in the downstream part while the upstream part showed an increasing trend. This lends further support to improved migratory opportunities.

The construction of fishways in the River Vecht appears to have resulted in a shift in the fish community in favour of species that use fishways, especially ide, bleak and bream. Bleak perform upstream passage through fishways in large numbers in other rivers (Prignon et al. 1998, Travade et al 1998). Also for bream longer distance migrations were found e.g. up to 59 km in an Irish river (Whelan, 1983). Individual ide may use rivers at a scale varying from a few km to over 100 km year-round (Winter & Fredrich 2003). For many riverine species, only anecdotical information on migration exist, i.e. that it occurs, but the role that migration plays in population biology and on what scales these appear are largely unknown although such knowledge is increasing rapidly with the fast development of new tagging and telemetric methods (Lucas & Baras 2001).

Because the available data allow only for relative changes in the fish community to be determined, it remains uncertain how the observed increase of 'migratory' species relates to absolute changes in the different components. For instance, the construction of fishways may have left the populations of 'resident' species unaffected, or the migratory species may have increased at the expense of resident species.

The approach used to determine the potential effect of fishways from the 'relative fishway use' and the 'degree of obstruction before' their construction is widely applicable to other rivers and independent on assumptions or a priori knowledge on migratory behaviour of fish. Evaluation of the effects could be greatly improved, however, if upstream migration patterns had been determined and long-term monitoring had allowed density estimates to be made before and after the construction of fishways. However, evaluation studies will be hampered by the absence of comparable historical data, as is the case here. Ideally, measuring the pre-fishway conditions should start during the planning phase rather than after the construction phase.

Of course, fishways represent only one possible measure to rehabilitate riverine fish communities in regulated rivers. The net effect of restoring longitudinal connectivity on fish communities will largely depend on the degree of degradation of other essential features such as morphology, flow dynamics, habitat quality, pollution and fisheries. For the River Vecht, the changes observed in the fish community after the construction of bypasses around all six weirs, although in agreement with the expected potential benefit of providing fishways, have remained relatively minor. This can be attributed to the still highly regulated state of the river. A full rehabilitation of the riverine fish community may only be achieved with further measures to restore the morphology and habitat quality of the river system.

Acknowledgements

I thank the many recreational fishermen for assistance with daily recording fish passage, W.G. Cazemier for providing the data from 1975 and B. Kreunen from Waterschap Groot-Salland for providing the water quality data. N. Daan, E.A. Huisman and R.E. Grift provided valuable comments and suggestions on an earlier draft. This research was funded by the Dutch Ministry of Agriculture, Nature and Food Quality.

References

- Baumgartner, L.J., 2006. Population estimation methods to quantify temporal variation in fish accumulations downstream of a weir. Fisheries Management and Ecology 13: 355-364.
- Beach, M.H., 1984. Fish Pass Design. Fisheries Research Technical Report 78. Ministry of Agriculture, Fisheries and Food, Directorate Fisheries Research: Lowestoft, UK.
- Beurskens, J.E.M., H.J. Winkels, J. de Wolf and C.G.C. Dekker, 1994. Trends of priority pollutants in the Rhine during the last fifty years. Water Science and Technology 29: 77-85.
- Boiten, W., 1991. Hydraulic design of the pool-type fishway with V-shaped overfalls. Proceedings International Symposium on Fishways. Gifu, Japan. pp. 483-490.
- Cazemier, W.G., 1978. Study on the necessity of fishways in the River Vecht. RIVO-report ZS 78-03, IMARES, IJmuiden, The Netherlands. (in Dutch)
- Cazemier, W.G. and W.J.M. Muyres, 1981. On the functionality of an experimental fishway in the Neerbeek. RIVO-report ZS 81-1, IMARES, IJmuiden, the Netherlands. (in Dutch)
- Clay, C.H., 1995. Design of Fishways and other Fish Facilities. 2nd edition. Lewis Publishers: Boca Raton.
- Cowx, I.G. and R.L. Welcomme (Editors). 1998. Rehabilitation of Rivers for Fish. FAO, Fishing News Books, Blackwell Science Ltd.: Oxford, UK.
- Dekker, W., 2004. *Slipping* through our hands: Population dynamics of the European eel. PhD-thesis, University of Amsterdam, the Netherlands.
- Eberstaller, J., M. Hinterhofer and P. Parasiewicz, 1998. The effectiveness of two nature-like bypass channels in an upland Austrian river. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK pp. 363-383.
- Gehrke, P.C., D.M. Gilligan and M. Barwick, 2002. Changes in fish communities of the Shoalhaven River 20 years after construction of Tallowa Dam, Australia. River Research and Applications 18: 265-286.
- Hellmann, H., 1994. Load trends of selected chemical parameters of water quality and trace substances in the River Rhine between 1955 and 1988. Water Science and Technology 29: 69-76.
- Jonsson, N., 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nordic Journal of Freshwater Research 66: 20-35.
- Katopodis, C., 2005. Developing a toolkit for fish passage, ecological flow management and fish habitat works. Journal of Hydraulic Research 43: 451-467.
- Larinier, M., 1998. Upstream and downstream fish passage experience in France. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK. pp. 3-18.

- Lucas, M.C. and E. Baras, 2001. Migration of freshwater fishes. Blackwell Science Ltd: Oxford, UK.
- McDowall, R.M., 1988. Diadromy in Fishes: Migrations between Freshwater and Marine Environments. Croom Helm: London, UK.
- Mills, C.A., 1991. Reproduction and life history. In: Cyprinid fishes: Systematics, biology and exploitation. I.J. Winfield and J.S. Nelson (Editors), Chapman and Hall: London, UK. pp. 483-508.
- Mills, C.A. and R.H.K. Mann, 1985. Environmentally-induced fluctuations in year-class strength and their implications for management. Journal of Fish Biology 27 (suppl. A): 209-226.
- Northcote, T.G., 1998. Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK. pp. 3-18.
- Parmet, B and M. Raak, 1997. Impact of climate change on the discharge of the river Rhine. A case study for a sub-basin in the lowland part of the Rhine system, the Overijsselsche Vecht. RIZA Report 97.049, Lelystad, The Netherlands.
- Petts, G.E., 1984. Impounded Rivers: perspectives for Ecological Management. John Wiley and Sons: Chichester, UK.
- Pinder, L.C.V., A.F.H. Marker, R.H.K. Mann, J.A. Bass and G.H. Copp, 1997. The River Great Ouse, a highly eutrophic, slow-flowing, regulated. Lowland river in Eastern England. Regulated Rivers: Research and Management 13: 203-218.
- Prignon, C., J.C. Micha and A. Gillet, 1998. Biological and environmental characteristics of fish passage at the Tailfer Dam on the Meuse River, Belgium. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK. pp. 69-84.
- Regis, J, E. Pattee and J.D. Lebreton. 1981. A new method for evaluating the efficiency of electric fishing. Archiv für Hydrobiologie 93: 68-82.
- Schiemer, F. and M. Zalewski, 1992. The importance of riparian ecotones for diversity and productivity of riverine fish communities. Netherlands Journal of Zoology 42: 323-335.
- Smith, R.J.F., 1985. The Control of Fish Migration. Springer-Verlag: Berlin, Germany.
- Smith, R.J.F., 1991, Social behaviour, homing and migration. In: Cyprinid fishes: Systematics, biology and exploitation. I.J. Winfield and J.S. Nelson (Editors), Chapman and Hall: London, UK. pp. 509-529.
- Sokal, R.R. and F.J. Rohlf, 1995. Biometry: the principles and Practice of Statistics in biological Research. Third Edition. WH Freeman and Company: New York, USA.
- Travade, F., M. Larinier, S. Boyer-Bernard and J. Dartiguelongue, 1998. Performance of four fish pass installations recently built on two rivers in south-west France. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK. pp. 146-170.

- Whelan, K.F., 1983. Migratory patterns in bream *Abramis brama*, L. shoals in the River Suck system. Irish Fisheries Investigations, Series A 23: 11-15.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing migratory opportunities for non-salmonid fish in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.
- Winter, H.V. and F. Fredrich, 2003. Migratory behaviour of ide: a comparison between the lowland rivers Elbe, Germany, and Vecht, The Netherlands. Journal of Fish Biology 63: 871-880.
- Wolfert, H.P., G.J. Maas and G.H.P. Dirkx,1996. Het meandergedrag van de Overijsselse Vecht; historische morfodynamiek en kansrijkdom voor natuurontwikkeling. DLO Staring Report 408. Alterra: Wageningen, The Netherlands. (in Dutch)

Effect van vistrappen geëvalueerd

Vistrappen worden aangelegd om herstel van populaties migrerende vissen mogelijk te maken. Indien de migratiebelemmering veroorzaakt door stuwen een belangrijk knelpunt vormt, is de verwachting dat vooral díe soorten die veel gebruik maken van de vistrappen toenemen en een groter aandeel in de visgemeenschap gaan uitmaken. In dit hoofdstuk vindt een evaluatie plaats van de veranderingen in de visgemeenschap in de periode vóór en ná de aanleg van de serie vistrappen in de Vecht in 1987-1994. Daarnaast is bekeken in hoeverre deze veranderingen aan toegenomen migratiemogelijkheden kunnen worden toegeschreven.

Idealiter wordt hierbij de samenstelling van de visgemeenschap en de grootte van de vispopulaties in rivieren vóór en ná de aanleg van vistrappen onderzocht en vergeleken. Dit soort evaluatie-studies is wereldwijd echter nog erg schaars. Veelal blijven de metingen beperkt tot wat er door de vistrappen trekt (hfst. 3). In de Vecht ligt dit iets gunstiger, al is het geen vooropgezette vóór-ná studie: In de jaren 70, voor de aanleg van vistrappen, zijn oriënterende visonderzoeken uitgevoerd en in de jaren 90 zijn er (in het kader van dit promotieonderzoek) na de aanleg uitgebreide visstands-bemonsteringen uitgevoerd.

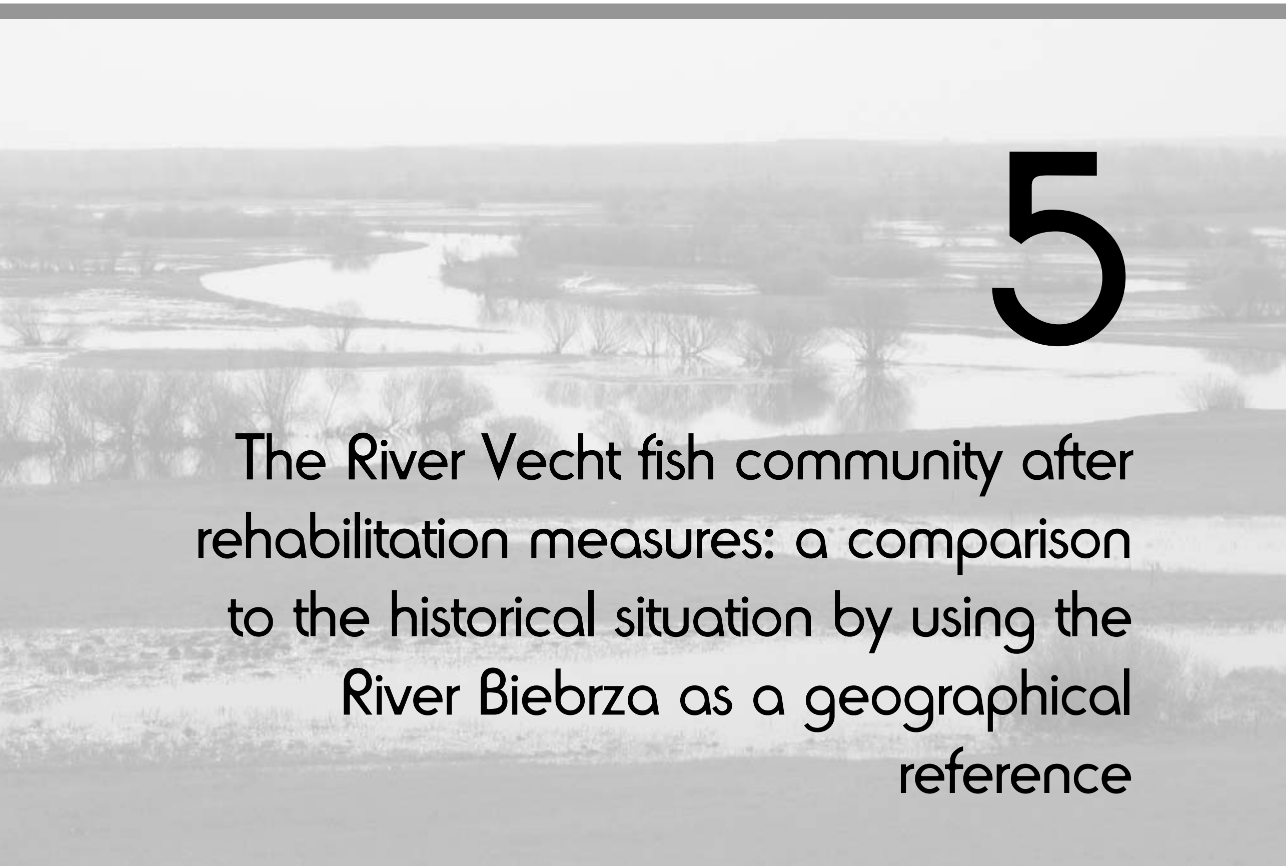
Om eventuele veranderingen in de visgemeenschap te kunnen relateren aan een toename in migratiemogelijkheden is er ook gekeken of er andere factoren van mogelijk belang zijn veranderd tussen de jaren 70 en 90. De leefomgeving (habitat) in de Vecht is voor de jaren 70 drastisch veranderd maar daarna niet veel meer. Gedurende de laatste decennia was de visserijdruk van beroepsvissers en hengelaars naar schatting vrij constant. De waterkwaliteit is met name in de jaren 60 verbeterd, de Vecht is echter nooit zo sterk vervuild geweest als bijvoorbeeld de Rijn. Veel waterkwaliteits-parameters zijn vanaf 1970 constant gebleven, alleen het fosfaatgehalte is flink gedaald. Maar de Vecht is momenteel nog steeds een eutrofe (voedselrijke) rivier.

Daarnaast is getest of juist díe soorten zijn toegenomen die relatief veel gebruik maken van de vistrap. Het is moeilijk om te bepalen welk deel van de totale populatie gebruik maakt van de vistrappen. Als maat hiervoor is het ‘relatieve vistrap gebruik’ genomen: de verhouding tussen het aandeel dat een soort inneemt in aantallen die via de vistrappen optrokken, en het aandeel dat de soort inneemt in de aantallen 0-jarige vis in bemonsteringen op de rivier zelf.

In de jaren 70 bevonden zich in het voorjaar grote concentraties vis benedenstrooms van de stuwen. Het merendeel van deze vis wilde waarschijnlijk verder stroomopwaarts trekken, maar werd hierin belemmerd door de stuwen waardoor de aantallen zich ophoopten. In 1975 zijn deze concentraties bemonsterd bij drie stuwen. Na de aanleg van vistrappen in de jaren 90 werden nauwelijks nog concentraties vis waargenomen. Dit is op zich al een duidelijk teken van verbeterde migratiemogelijkheden, maar een directe vergelijking tussen de bemonsteringen vóór en ná was hierdoor niet goed meer mogelijk. Om te onderzoeken of er verschuivingen in de visgemeenschap zijn opgetreden voor en na de aanleg van vistrappen, zijn er twee vergelijkingen gemaakt: 1) tussen de samenstelling van de jaren 70 concentraties met de samenstelling van vis die via de vistrappen optrok in de jaren 90, ervan uitgaande dat alle vis in de jaren 70 concentraties verder wilde trekken, en 2) tussen de samenstelling van de jaren 70 concentraties met de samenstelling van vis via de vistrappen gecombineerd met de samenstelling op de rivier zelf in de jaren 90, ervan uitgaande dat een deel van de vis in de jaren 70 verder wilde trekken en een deel ter plekke wilde blijven.

Volgens beide methoden was er een relatieve toename voor alver, winde en brasem (inderdaad allen met een bovengemiddeld ‘relatieve vistrap gebruik’), terwijl snoekbaars, serpeling en riviergrondel (allen een laag ‘relatieve vistrap gebruik’) afnamen. Of de toename van de eerstgenoemde drie soorten ten koste van laatstgenoemde is gegaan of dat deze toename daar bovenop heeft plaatsgevonden was met de beschikbare gegevens niet te bepalen. De gevonden verschuivingen zijn weliswaar in lijn met de toegenomen migratiemogelijkheden, maar de visgemeenschap is niet drastisch veranderd sinds de aanleg van de vistrappen.

River Biebrza, Poland / Rivier de Bierbza in Polen



5

The River Vecht fish community after rehabilitation measures: a comparison to the historical situation by using the River Biebrza as a geographical reference

Erwin Winter
Malgorzata Lapinska
Joep de Leeuw

Published as:
Winter, H.V., Lapinska, M. & J.J. de Leeuw. The River Vecht fish community after rehabilitation measures: a comparison to the historical situation by using the River Biebrza as a geographical reference. River Research and Applications 23: 1-13.

Abstract

Setting ecological goals for restoring fish communities in larger rivers is hampered by a lack of knowledge of the natural reference conditions. The lowland river Vecht has become highly-regulated since 1850. Since the 1970s, measures have been taken to improve water quality followed by the construction of fishways along weirs in the 1990s to rehabilitate migration. We aim to assess the degree of deviation of the current fish community in the river from its pre-regulation state. The assessment is based on a comparison with the less impacted river Biebrza in Poland as a geographical reference, involving a semi-quantitative stepwise reconstruction based on available historic evidence. Electrofishing was used to describe the current quantitative species compositions of the fish communities in the rivers Vecht and Biebrza and historical records of the Vecht region were used to cross-check the reconstructed fish community around 1850 after correcting for zoogeographical differences. Despite various rehabilitation measures, the deviation from the natural reference is still large. Currently, perch *Perca fluviatilis* and bream *Abramis brama* are much more abundant, and bleak *Alburnus alburnus*, white bream *Blicca bjoerkna* and most rheophilic species are far less abundant, than before. The main reasons for this deviation appears to be the present quality of the habitats and, for some species, the poor connectivity with the sea as well as with small tributaries. The approach used should be widely applicable to derive natural references, assess rehabilitation success or aiding the ecological assessment of integrity as imposed by the European Water Framework Directive.

Introduction

Rivers are among the ecosystems most heavily affected by man, especially in the temperate zone (Dynesius & Nilsson 1994, Malmqvist & Rundle 2002). A long history of utilization of rivers as well as their catchment areas has resulted in morphological and hydrological changes that have affected the living conditions for the riverine fauna severely. Impact includes flow regulation for safety, shipping and agricultural purposes, land reclamation in floodplains, loss of original habitat, reduced heterogeneity, disrupted connectivity caused by dams and weirs, poor water quality owing to urban, industrial and agricultural waste water disposal and subsequent delivery of nutrients, changed temperature regimes through use as cooling water, overfishing and introductions of exotic species. All effects combined have changed riverine fish communities drastically (Lelek 1987, Bayley & Li 1992, Waidbacher & Haidvogl 1998, De Groot 2002, De Leeuw et al., 2005).

In recent years, an increasing effort is made to restore riverine ecosystems. The initial goals largely referred to improving water quality, but rehabilitation schemes increasingly include measures to enhance longitudinal and lateral connectivity by constructing fishways along barriers and removing levees (Buijse et al. 2005). A common problem in setting realistic ecological goals for restoration is the lack of knowledge on the natural situation and absence of appropriate reference conditions, especially for larger lowland rivers (Wolter et al. 2005). In guiding restoration programmes, the European Water Framework Directive (2000/60/EG) specifically requires an assessment of the current state of the fish community in relation to the natural reference. Two methods to derive such a reference can be distinguished (Dussling *et al.*, 2004; Wolter et al. 2005): 1) reconstruction of the original fish community by modeling or expert judgement based on historical information from periods when impact was much less (e.g., catch records or habitat descriptions from archives and maps); and 2) geographical comparisons with fish assemblages in rivers (or river stretches) where human disturbance is still limited. So far, reconstructions of natural references for European lowland rivers are few and usually restricted to one of these approaches (Carrel 2002, Dussling et al. 2004, Wolter et al. 2005).

The River Vecht is a highly regulated lowland river in the Netherlands (Winter & Van Densen 2001) where rehabilitation plans are being carried out (Werkgroep Vechtvisie 1997, Duursema 2004). Starting in the 1850s, and especially since the 1890s, many meanders have been cut off, a series of weirs have been constructed to control water level at low flow and shores have been reinforced with riprap against erosion. Moreover, untreated waste-water discharges from urban areas and a potato-processing industry led to hypoxic events during the 1950s and 1960s. As a first rehabilitation measure, these emissions were terminated and waste-water plants have been built. Subsequently, water quality has improved (chapter 4) and hypoxic events ceased to occur since the 1970s. During 1987-1994, a series of V-stepped fishways were constructed along all weirs present in the Netherlands to enhance longitudinal connectivity (Winter & van Densen 2001). Although shifts in the fish community after these rehabilitation measures have been documented (chapter 4), it remains unclear to what extent the current community deviates from the one originally present. Intended, more ambitious rehabilitation plans include the (partial) recreation of conditions that allow for a natural meandering process (Werkgroep Vechtvisie 1997). To guide the direction of these further plans, a reconstruction has been made of the historical morphology and meandering dynamics of the Vecht (Wolfert et al. 1996). The relatively undisturbed river Biebrza in Poland has been selected as a geographical reference for comparison of ecological features (Duursema 2004).

The reconstruction of the fish community likely to have been present in the second half of the 19th century before the main regulation measures were taken is based on recent electrofishing surveys to describe the current fish communities in the two rivers, as well as on a review of the available historical information on the pre-regulated state of the Vecht.

Material and methods

River characteristics

The Vecht (52°30'N and 6°30'E) flows through Germany and the Netherlands, discharging through the shallow eutrophic freshwater lake Zwarte Meer. This lake is in open connection with another lake (Ketelmeer), which receives also the water from the river IJssel and is connected directly to the IJsselmeer. This last (fresh water) lake came into existence after the construction of a large dam in 1932 that closed off the downstream area from the North Sea (Fig. 5.1). Before 1932, the river directly discharged into the (brackish) Zuiderzee Estuary.

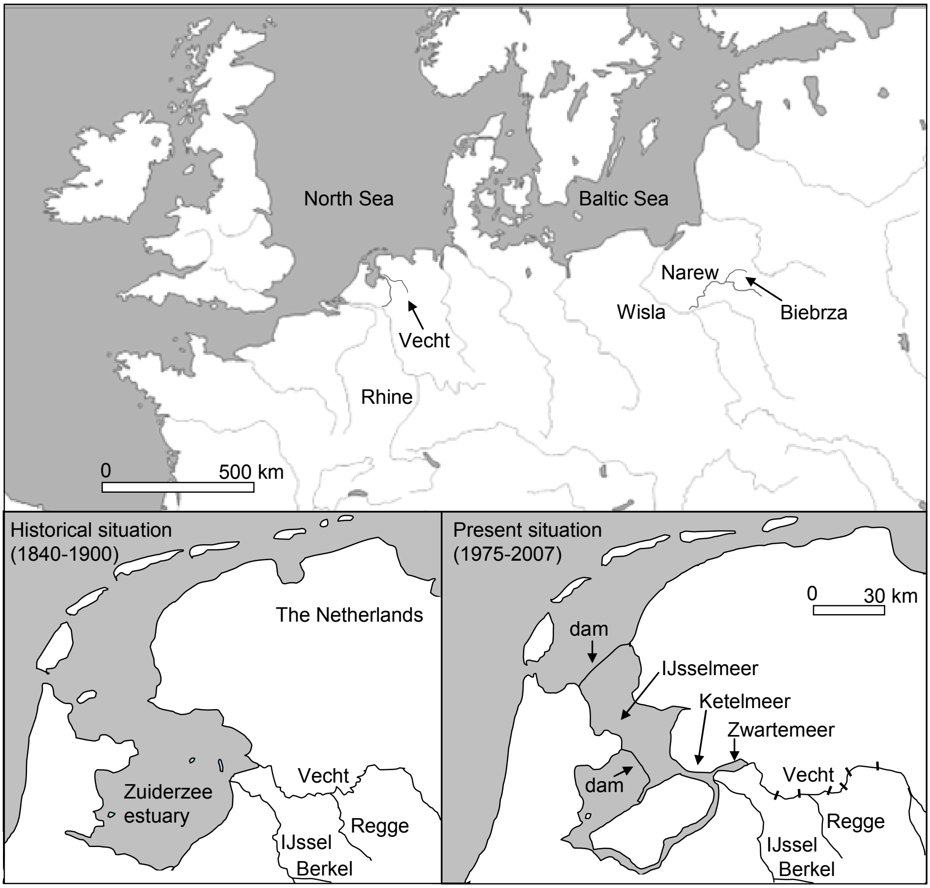


Figure 5.1. *Situation of the River Vecht catchment and the River Biebrza (top panel) and the historical situation (bottom left panel) and present situation (bottom right panel, where the bars in the River Vecht represent the six weirs and fishways) of the River Vecht.*

Originally, the Vecht was a freely meandering lowland river (Wolfert et al. 1996). Although deforestation and the consequent loss of large woody debris in the River Vecht (TAUW 1992) started much earlier, the main regulatory works started in 1850 when two weirs were constructed. During 1896-1914, many meanders where cut off, which reduced the length of the Dutch part of the river by 30 km and five more weirs were constructed (TAUW 1992, Wolfert et al. 1996, Winter & van Densen 2001). Because the geomorphologic situation in 1847 is relatively well described, we selected the period just before 1850 as the historical reference condition. For this we used hydrological data discharge patterns throughout the year, water bottom elevations and water velocities collected during 1847, 1860-1866 and 1878-1887 (Staring & Stieltjes 1848, Deking Dura 1889, van Hezel 1992, TAUW 1992, Wolfert et al. 1996).

Table 5.1. *Characteristics of the River Vecht, the Netherlands, in the current regulated state, compared to the pre-regulated state in 1847 as a historical reference and to the River Biebrza, Poland, as a geographical reference.*

	Vecht at present	Vecht in 1847	Biebrza at present
River basin features			
Catchment area	3785 km^2	3785 km^2	7062 km^2
Climate: annual rainfall, Jan/Jul temperatures	758 mm, 2 / 17 °C	750 mm, 1 /16 °C	583 mm, -3 / 17 °C
Mean river discharge at the mouth	29 $m^3.s^{-1}$	ca. 30-35 $m^3.s^{-1}$	30 $m^3.s^{-1}$
Total river length from source	177 km, Dutch section 60 km	>207 km, Dutch section 90 km	164 km
Morphology in downstream 60 km section			
River slope	0.17 ‰	0.11 ‰	0.10-0.15 ‰
Mean river width, upstream - river mouth	35-59 m	26-155 m	30 m
Average water depth (range) in mainstream	2.7 (2.0-3.5) m	2.4 (0.7-7.6) m	2.5 m
Flood plain area and land use	32.1 km^2 (mainly grasslands)	51.4 km^2 (grass- and wetlands)	> 50 km^2 (grass- and wetlands)
Flood plain width	50-1500 m	84-1700 m	Mostly > 1000 m
Flood protection	Winter dikes, some levees	Locally some small levees	Locally some small levees
Flood plain inundation frequency / duration	Many, short lasting, winter	Few, long lasting, mainly winter	Few, long lasting, winter/spring
Mainstream substrate	Course sand	Course to fine sand	Course to fine sand
Channel morphology*	Rarely channel side bars	Points bars, few islands	Point bars, some braiding
Lateral channel activity*	None	Progression and cutoffs	Mainly cutoffs
Meandering dynamics	Non-meandering (fixed banks)	Strongly meandering	Strongly meandering
Shore slopes	Steep, reinforced with riprap	Very shallow + steep (erosion)	Very shallow + steep (erosion)
Occurrence of macrophytes	Few macrophytes	Many macrophytes	Many macrophytes
Shore vegetation	Helophytes, herbs	Helophytes	Helophytes, trees e.g. willows
Additional human impact factors			
Flow regulation	6 weirs with fishways	Hardly any, only very locally	Hardly any
Downstream barriers, connectivity from sea	Large dam at sea	Free access	2 dams in Wisla/Narew
Upstream barriers, connectivity to tributaries	Regge good, others upstream poor	Good, except some small brooks	Many barriers present upstream
Navigation	Extensive upstream to 3th weir	Extensive with shallow boats	Hardly none
Water quality (eutrophication)	Nutrient rich (decrease since 1970)	Moderate nutrient rich	Moderate to poor nutrient rich
Water quality (micropollutants)	Some metals and herbicides critical	Low levels	Moderate levels
Commercial fisheries	Extensive, severe in downstr. lakes	Extensive	None (severe in downstr. rivers)
Recreational fisheries	Intensive catch and release angling	None	Extensive
Fish stocking and introductions	Hardly, some trout and grass carp	None	Hardly any

River Vecht based on: Staring & Stieltjes 1848, Deking Dura 1889, Lambrechtsen 1918, Schutten 1981, Goutbeek & Verlinde 1989, Janssens 1990a, 1990b, Szappanos 1991, TAUW 1992, van Hezel 1992a, 1992b, Wolfert et al. 1996, Werkgroep Vechtvisie 1997, Duursema 2004.

River Biebrza based on: Backiel 1985; Succow & Jeschke 1986, Okruzko 1990, 1991, 2005, Van der Perk & Bierkens 1997, Wassen et al. 2003.

* Based on Kellerhals & Church 1989.

Duursema (2004) proposed the Biebrza in N.E. Poland (22°30'– 23°60'E and 53°30'– 53°75'N) as an appropriate geographical reference for the natural situation of the Vecht. The Biebrza is one of the last extensive undrained non-reclaimed valley mires in Central Europe (Succow & Jeschke 1986, Okruszko 1990, 1991) and has been used as an ecological reference for conditions in Dutch waters before (e.g. Van der Perk & Bierkens 1997, Wassen et al. 2003). The Biebrza is relatively undisturbed but the rivers Narew and Wisla through which the Biebrza discharges to sea are more regulated. There are two dams situated in the Wisla and Narew with poorly functioning fishways (Backiel 1985).

Table 5.1 summarizes various characteristics of the Vecht in its current regulated state and its pre-regulated state and of the River Biebrza in its current state. For a comparison of the fish communities in the two rivers, we focus on their lower sections: the Dutch section of the Vecht (i.e. 60 km from the mouth at present and 90 km from the mouth historically) and the lower 90 km of the Biebrza.

Current fish communities

Fish in the two rivers were sampled by electrofishing by boat. In the Vecht, surveys were performed during March-April 1996 and 1997; August 1996, 1997 and 1998; and October-November 1995, 1996 and 1997. Along the entire 60 km shoreline and during each survey, random stretches of 300 m were sampled by electric fishing (direct-current, 6 A, 350 V) for each 3 km of mainstream and in each connected backwater (chapter 4) and about 38,000 fish were caught. In the Biebrza, electrofishing (direct- current, 5-6 A, 220 V) was performed in the years 1978-1980 from spring till late autumn, when about 50,000 fish were caught from 48 sites (Witkowski 1984a, 1984b). The overall average relative abundances by species were calculated and differences between the two rivers were tested by 2x2 G-test ($p<0.05$, df=1) using William's correction factor (Sokal & Rohlf 1995).

Historical evidence for the River Vecht

For the River Vecht, historical records are scarce as in many rivers (Wolter et al. 2005). The few written documents available mostly originate from municipal archives encompassing the period 1500-1900, especially from Hardenberg and Zwolle. Redeke (1941) provides anecdotic information and reviews historical sources on the occurrence of species in the area between 1845 and 1940. For the adjacent IJssel and its tributary Berkel (Fig. 5.1), data have been collected by the 'Society on Advancing Inland Ichthyology' during 1847-1849 (Van den Ende 1847a, 1847b, 1849), including lists of all fish species encountered. Because the discharge of the Vecht falls within the range of the IJssel (ca. 300 $m^3.s^{-1}$) and Berkel (ca. 8 $m^3.s^{-1}$), has comparable geomorphologic features and free exchange between fish populations in these rivers was possible at least during part of the year, extrapolation of these data from adjacent rivers to the Vecht seemed appropriate. Historical fishing methods were mainly fykenets and seines.

Historical records may be incomplete and not be comparable quantitatively, because catches were taken with different gears. Interpretation of the information is also hampered by altered taxonomy. For instance, the sunbleak *Leucaspius delineatus* was not yet recognized as a species in 1850. Furthermore, the tendency of listing aberrant specimens as new species was widespread in the 18th and 19th century (Wolter et al. 2005). Subsequently, many of the preserved specimens have proven to represent hybrids among cyprinids. This is supposed to apply to *Cyprinus alburnoides* and *Cyprinus dolabratus* mentioned by Van den Ende (1847a, 1847b), and therefore, these species were excluded. Archeological data on fish remains, which might be another source for reconstructing historical fish occurrence (Wolter et al. 2005) have not been found so far in the region.

Reconstruction of the historical fish communities

For the reconstruction we used a semi-quantitative stepwise approach. Firstly, the recent fish communities of the two rivers were characterized by using the electrofishing data, supplemented with additional records from other sources with reference to the less common species (Vecht: chapter 4, de Nie 1996, Biebrza and adjacent rivers Pisa, Gwda and Narew: Backiel 1985, unpublished data). Based on all available information, species were classified as being dominant (relative abundance > 25 %), abundant (5-25 %), common (0.5-5 %), rare (0.01-0.5 %), or sporadic (> 0.01 %). Sporadic species were assumed not to represent viable populations within the river itself, but rather vagrants from distant populations, either from upstream sections or brooks or from downstream areas.

Secondly, some corrections were made to reflect changes in the Biebrza fish community related to human impact, such as the introduction of new species, effects of fisheries and the construction of dams in the downstream rivers Narew and Wisla resulting in a fall in migratory species (Backiel, 1985). Given the still undisturbed character of the Biebrza valley (Table 5.1), historical changes in the fish community were assumed to be restricted to declines in abundance of diadromous species and the introduction of carp and gibel carp (see Table 5.2 for scientific names). Based on Backiel (1985), we assigned the relative abundance of the following diadromous species one class higher than at present: river lamprey, houting, sea-run brown trout, vimba and eel.

Thirdly, the historical Vecht community was assessed, using the historical Biebrza community as a starting point. To this end, the species composition was corrected for regional distribution patterns by species across Europe (Lelek 1987). Pikeperch, asp, sabrefish, blue bream and vimba have been found in Poland from way back, but not so in the Netherlands. They were considered to have been absent in the Vecht. Differences in environmental conditions between the two rivers were also incorporated. One main difference is the distance to the estuary. Because the Vecht discharged directly into a brackish estuary, we expect a higher relative abundance of diadromous species that do not move far upstream: smelt, flounder, twaite shad, three-spined stickleback and houting.

Finally, the classifications derived after the consecutive steps described above were compared to the available historical information on abundance or occurrence of fish in the Vecht region, and adjusted where appropriate.

Results

Hydrology

Discharge patterns throughout the year in the River Vecht have changed marginally when compared to the historical situation (Fig. 5.2), although the peak flow appears to have shifted from February/March to January. The main difference is that discharge in June-August has become 40-60 % lower than in historic times. Discharge of the Biebrza peaks later than in the River Vecht owing to melting snow in late winter/early spring. Water velocities during winter have become considerable higher in the Vecht and much lower during summer (Fig. 5.2), reflecting a stagnant character owing to the impoundment.

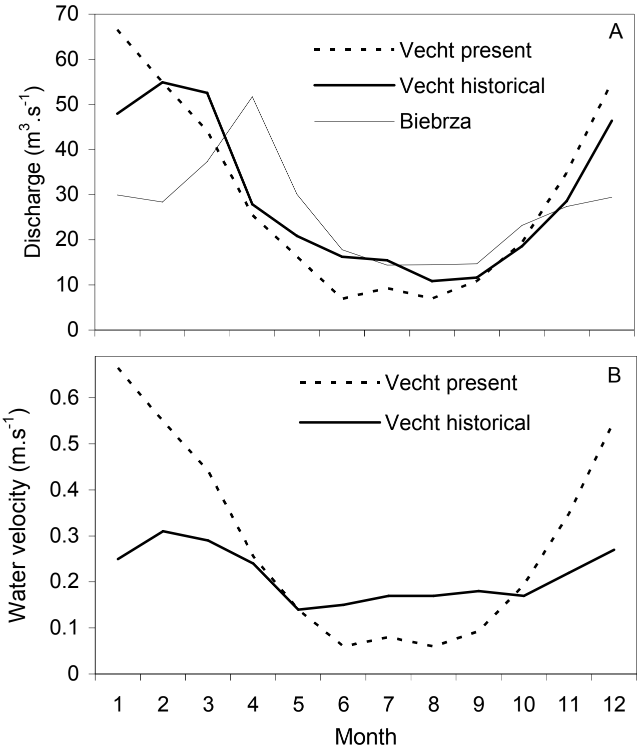


Figure 5.2 *Monthly discharge (A) and water velocities (B) in the river Vecht at present (1987-2000) and historically (1860-1866) and in the River Biebrza at present (1970-1995), (based on Deking Dura, 1889; van Hezel, 1992a; 1992b; TAUW 1992; Okruszko, 2005).*

The impounded Vecht shows much less variation in water depth along the longitudinal axis compared to the free-flowing river in 1847 (Fig. 5.3). Moreover, mean water levels nowadays hardly vary between summer and winter, whereas they used to be on average 2 m higher during winter than during summer. Also, inundations now last only for short periods, whereas historically the floodplains might be inundated for long periods. Furthermore, the bottom profile shows a marked effect of erosion caused by the higher water velocities during winter and the straightening of the river by cutting off many of the meanders, which resulted in a lowering of the water bottom up to 2 m in 150 years.

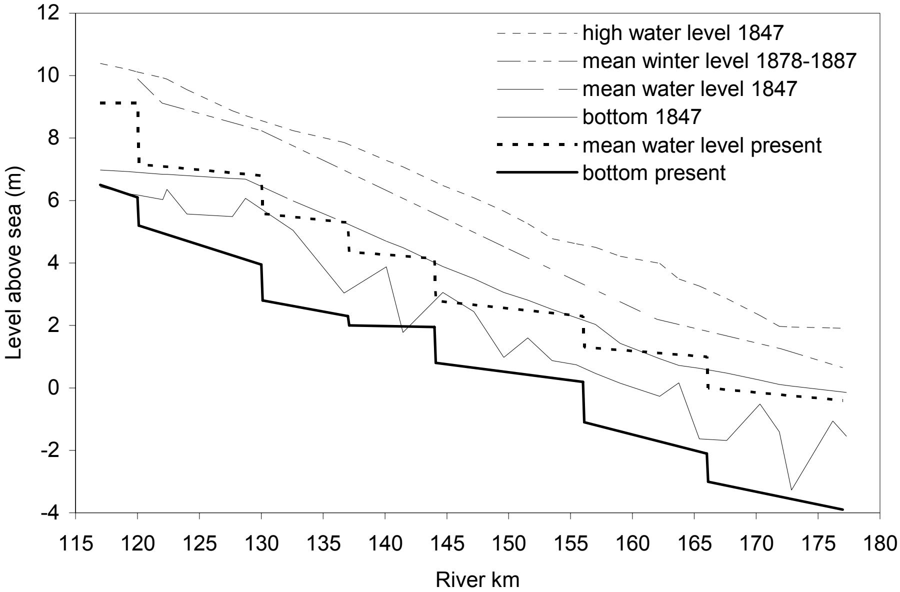


Figure 5.3 *Comparison of the water depth at mean water level and high winter level in 1847 and mean winter level during 1878-1887 along the Dutch part of the river Vecht compared to the present situation with six weirs (after TAUW 1992, van Hezel 1992a, 1992b). River km refers to the current situation (60 km from the German border): locations in 1847 (when the meandering river length of the Dutch section was 90 km) are plotted at the nearest current river km.*

Contemporary fish communities in the two rivers

Relative abundance as determined directly from electrofishing surveys differs significantly between the two rivers for all species (Fig. 5.4). The most striking features are the much higher abundances of perch, and to a lesser extent eel, bream and gudgeon, and the much lower abundances of burbot, bleak (both virtually lacking), and to a lesser extent pike, ide and white bream, in the Vecht than in the Biebrza. Roach is abundant in both rivers, but more so in the Biebrza. Diadromous species are rare or absent in the samples from both rivers, as are non-native species.

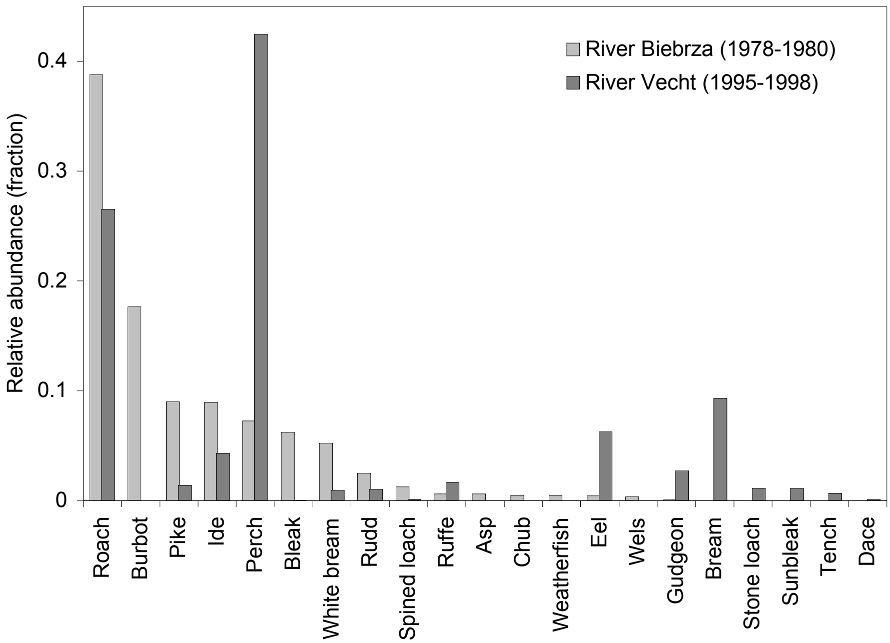


Figure 5.4 *Comparison of the relative abundances by species between the regulated river Vecht and the more natural river Biebrza as determined by electrofishing surveys (differences for all species are significant, 2x2 G-test: $p<0.05$).*

Comparing current and historic fish communities

Table 5.2 lists the species compositions classified in terms of relative abundance in the two rivers, both in recent years and historically, based on the data presented in Fig. 5.4 and the adjustments discussed in the methods section. Based on written historical evidence, further adjustments for the historic Vecht community were made as follows:

The burbot was found in the tributary Dinkel (Ruting 1958), common in the nearby Rivers IJssel and Berkel (van den Ende 1947a, 1847b) and was regularly caught together with pike, eel and perch with hook and line baited with prey fish (van den Ende 1849). However, it appeared to be less abundant than in the River Biebrza and was therefore classified as being common around 1850 in stead of abundant.

Chub was rarely observed in the Vecht region (van den Ende 1948a, 1847b, Redeke 1941) and was therefore presumably less abundant than in the Biebrza and was classified as rare instead of common.

The higher abundance of three diadromous species (smelt, flounder and three-spined stickleback) in the Vecht around 1850 as assumed from its direct discharge into the estuary was confirmed by van den Ende (1847) with regard to smelt and by Redeke (1941) with regard to flounder. Redeke (1941) mentions also the occurrence of houting in the IJssel-Vecht area. Catches of salmon in the area around 1850 were reported as being 'very rare' (POZC 1857a).

In 1873, the most abundant species taken by fisheries in the Vecht at Hardenberg were pike, eel, roach, white bream, perch and ide (Anonymous 1873), confirming the high abundance of these species. In the lower section of the river near Zwolle, sometimes large amounts of breams and white breams were caught (PODZ 1857b).

Discussion

Reconstructed fish community

The reconstructed fish community of the Vecht differs profoundly from the current community (Table 5.2). However, the semi-quantitative stepwise approach followed might have led to bias owing either to fundamental differences between the two rivers (i.e., related to the use of a geographical reference) or by the incompleteness or incorrectness of historical records (i.e., related to the long time-lag between pre-regulated and present state).

The geomorphology of the two rivers in their original state seems largely comparable (Table 5.1), suggesting that the available habitats were similar. Climate, however, differs to some extent, winters in Poland being colder and discharge peaks occurring later, which might have consequences for the role of floodplains as nurseries (Grift 2001). Although zoogeographical differences exist, these seem to be limited because only five Biebrza species did not belong to the Dutch fauna and of these, only asp is classified as common. The other four were classified as rare or sporadic. Omitting these from the Vecht therefore should not require an adjustment in the abundance classes of the remaining species. One important difference between the two rivers is that the Vecht originally discharged directly into an estuary, whereas the Biebrza tributes to the rivers Narew and Wisla before flowing out into the Baltic. Even though abundance of some migratory species was presumably higher in the Vecht, the available evidence suggests that they were relatively rare compared to the potamodromous and 'resident' species completing their entire life-cycle in freshwater. Given the scarcity of undisturbed larger lowland rivers in Europe and the high degree of similarity between the two rivers (Table 5.1), the use of the Biebrza as a geographical reference for the Vecht seems justified.

The validity of the historical records is another issue. When comparing the species potentially occurring in the Vecht region based on distribution maps (Lelek 1987), the actual lists established around 1850 for the adjacent IJssel and Berkel seem fairly complete. The species lacking might be expected to be rare in lowland rivers (twaite shad, minnow, brook lamprey, grayling, wels), or represent small-sized species that could have easily been missed by the fishing techniques then used (stone loach, spined loach and bitterling) or were unknown to science at that time (sunbleak). Nevertheless, three species were expected to have been mentioned: sea lamprey, especially in the IJssel, anadromous brown (sea) trout (which might have been mistaken for Atlantic salmon: de Groot 2002), and Crucian carp (maybe its favoured habitats were not often fished). The historical records on the most abundant species caught in fisheries around Hardenberg (Anonymous 1873) lists all species classified as abundant or dominant for the Biebrza, except bleak. The latter species is a small, pelagic species that might be either underestimated in the catches, or underrated because of its low consumption value.

Table 5.2 *Fish community composition in the rivers Vecht and Biebrza in the present situation and as reconstructed for the historical, more natural state. Relative abundance by species is classified as dominant (++++), abundant (+++), common (++), rare (+), sporadic (.) or absent (-), see text.*

Species per ecological guild*			River Vecht		River Biebrza	
Common name	Scientific name	Migr.**	Present	Historical	Present	Historical
Rheophilic *(at least one life-stage requires flowing freshwater)*						
Ide	*Leuciscus idus*		++	+++[1,2]	+++	+++
Burbot	*Lota lota*		.	++[1,2]	+++	+++
Gudgeon	*Gobio gobio*		++	++[1,2]	++	++
Flounder	*Platichthys flesus*	D	.	1	-	.
Dace	*Leuciscus leuciscus*		+	++[1,2]	+	++
Chub	*Leuciscus cephalus*		.	+[1,2]	++	++
Stone loach	*Barbatula barbatula*		++	+	+	+
Bullhead	*Cottus gobio*		+	2	+	+
River lamprey	*Lampetra fluviatilis*	D	.	+[1,2]	.	+
Barbel	*Barbus barbus*		.	1	+	+
Brown trout	*Salmo trutta*	pD	.	+	.	+
Houting	*Coregonus oxyrinchus*	D	-	1	-	.
Smelt	*Osmerus eperlanus*	pD	.	1	-	.
Sea lamprey	*Petromyzon marinus*	D	-	.	-	.
Twaite shad	*Alosa fallax*	D	-	.	-	-
Nase	*Chondrostoma nasus*		.	.[1]	.	.
Minnow	*Phoxinus phoxinus*		-	.	-	.
Brook lamprey	*Lampetra planeri*		.	.	.	.
Spirlin	*Alburnoides bipunctatus*		-	.[1]	-	.
Grayling	*Thymallus thymallus*		-	.	.	.
Allis shad	*Alosa alosa*	D	-	.[1]	-	-
Atlantic salmon	*Salmo salar*	D	-	.[1]	-	.
Atlantic sturgeon	*Acipenser sturio*	D	-	.[1]	-	.
Asp	*Aspius aspius*		.	-	++	++

Vimba	*Vimba vimba*	D	-	-	.	+
Sabrefish	*Pelecus cultratus*		-	-	.	.
Blue bream	*Abramis ballerus*		-	-	.	.
Non-specific / eurytopic *(all life-stages can be completed in both flowing and stagnant freshwater)*						
Roach	*Rutilus rutilus*		++++	++++[1,2]	++++	++++
Perch	*Perca fluviatilis*		++++	+++[1,2]	+++	+++
White bream	*Blicca bjoerkna*		++	+++[1,2]	+++	+++
Bleak	*Alburnus alburnus*		+	+++[1,2]	+++	+++
Pike	*Esox lucius*		++	+++[1,2]	+++	+++
European eel	*Anguilla anguilla*	D	+++	+++[1,2]	+	++
Bream	*Abramis brama*		+++	++[1,2]	+	+
3-spined stickleback	*Gasterosteus aculeatus*	pD	.	++[1,2]	.	.
Ruffe	*Gymnocephalus cernuus*		++	++[1,2]	++	++
Spined loach	*Cobitis taenia*		+	++	++	++
Wels	*Silurus glanis*		.	.	+	+
Carp	*Cyprinus carpio*		+	.[1,2]	.	.
Pikeperch	*Stizostedion lucioperca*		++	-	.	.
Gibel carp	*Carassius auratus*		.	-	.	-
Limnophilic *(several life-stages require stagnant water with macrophytes)*						
Rudd	*Scardinius erythrophthalmus*		++	++[1,2]	++	++
Tench	*Tinca tinca*		++		2 +	+
Weatherfish	*Misgurnus fossilis*		.	++[1,2]	++	++
Sunbleak	*Leucaspius delineatus*		++	+	+	+
10-spined stickleback	*Pungitius pungitius*		+	+[1,2]	+	+
Crucian carp	*Carassius carassius*		+	+	+	+
Bitterling	*Rhodeus sericeus*		.	+	+	+

* Ecological guilds based on Schiemer & Waidbacher (1992)

** Migratory behaviour: D=diadromous, pD=part of the population shows diadromous behaviour.

[1] recorded for the River IJssel in 1847 (Van den Ende 1847a)

[2] recorded for the River Berkel in 1847 (Van den Ende 1847b)

Of course, relative abundance by species may change throughout the year, and vary among years, owing to population dynamic processes (recruitment) and behavioural responses (migrations). A mean species composition can never capture such features. However, an approach with abundance classes is more robust to temporal changes in relative abundance and given the above uncertainties, this may be the highest level of accuracy feasible.

Overall, bias caused by using a distant geographical reference, supported with the scarce information available from the historical reference itself appears to be low and the conclusion seems justified that the current fish community of the Vecht, after the various rehabilitation programs, still deviates markedly from its historical potential, as exemplified by the 1850 reference. Of course, even 1850 does not represent the pristine situation, because humans settled in the area long before the Middle Ages and probably have always had an impact on rivers that brought them important services. However, compared to the severe measures introduced after 1850, the pristine situation may not have been that different from the historical reference.

Some species have become much more abundant and are seemingly favoured by the environmental conditions created by man. Most obvious is the much higher abundance of perch, which has been related to the construction of riprap structures along the shores (Wolter & Vilcinskas 1997). To a lesser extent, this may apply also to the stone loach. The third species favoured is bream, which may be related to the impoundment and the stagnant character of the river during most of the time. Roach is still abundant but presumably less dominant than in the historical situation.

Other eurytopic species that are generally more common in flowing waters than in stagnant waters (i.e., species closer to the rheophilic section on the continuum of ecological guilds: bleak and white bream) are relatively less abundant than in the historical reference. Moreover, most rheophilic species (e.g., ide, burbot, chub and dace) are less abundant at present. For all these species the impounded character, with low water velocities during summer may be an important factor, perhaps in combination with the low connectivity with small tributaries (particularly for dace: Clough et al. 1998). Burbot is virtually absent at present, but should have been at least common in the 1850s. This species exhibits different migration strategies and may effectively develop resident population (Fredrich & Arzbach 2002). However, next to habitat loss and loss of migration windows, changes in winter temperature may also have taken its toll. The burbot requires low winter temperatures of 0-2 °C for successful spawning (McPhail 1997). Because the Netherlands are already on the border of its distribution limits, the recorded increase of 1.5 °C in winter temperatures during the period 1880-2004 (www.knmi.nl) may have contributed to the decline.

All diadromous species were assessed to have been more abundant in the historical reference. Despite the improvements in the longitudinal connectivity through the construction of a series of fishways , these species are still hampered by the large dam (Fig. 5.1), separating the estuarine tidal zone from the large freshwater lake. However, of all the diadromous species that collapsed in Dutch rivers during the last 150 years (de Groot 2002), sea lamprey, Atlantic sturgeon, salmon and allis shad probably never formed viable populations in the Vecht, but catches merely represented strayers from the nearby IJssel and Rhine populations, given the scarcity of suitable upstream habitats for spawning and early life stage development for these species, also historically. A small population of brown trout exists in the upstream sections to date, resulting in sea-run individuals, but this population was probably never large owing to the limited areas of gravel available. River lamprey may also use coarse sand for spawning and should have been much more abundant historically. Immigration of diadromous species that need well-functioning estuaries for at least some life-stages (houting, flounder and anadromous populations of three-spined sticklebacks and smelt) is severely limited by the sharp transition from salt to fresh water created by the dam. The panmictic eel population faces many bottlenecks (Dekker 2004) and hence the decline in both rivers.

Pike appears to have become much less common. On the continuum of ecological guilds, pike is situated closer to the limnophilic species than most eurytopic species. The presence of macrophytes in the main channel and along the shores is much lower than in 1850 and this must have affected most limnophilic species. A complicating factor, however, is that the number of connected backwaters has increased after many meanders were cutoff on purpose (Table 5.1). Because a natural succession from water to land is proceeding in all these backwaters and no new ones will be formed because the meandering process has been stopped, the relatively high abundance of some limnophilic species (sunbleak, rudd and tench) must be regarded a temporary phenomenon. In contrast, bitterling, Crucian carp and weatherfish are virtually absent at present, while at least the weatherfish appeared to be common before 1850 (van den Ende 1849). These differences within the limnophilic guild might be related to the water or habitat quality of the backwaters and differences in habitat requirements of the different species.

Management implications

The deviation of the current fish community from the historical reference is still large, despite all the measures taken to rehabilitate water quality and connectivity. Water quality has never been as poor as in the adjacent river Rhine because of the absence of large industries. The main problem was related to nutrient enrichment, which led sometimes to hypoxia in the 1950s and 1960s, whereas contaminants were considered to be less problematic (Duursema 2004). These problems have been largely resolved, although agricultural use of fertilizers continues. The construction of a series of V-shaped fishways along the six weirs has led only to minor shifts in the fish community (Winter, chapter 4). Especially bleak, ide and bream have increased to some extent in relative abundance, whereas pikeperch, dace and gudgeon have decreased when compared to the pre-fishway state. Not all these shifts point in the direction towards a rehabilitation of the historical fish community. The increase in bream and decrease in dace make the deviations for these species even larger. Bream arguably have profited from the availability of suitable impounded habitats during summer and an increased accessibility from the downstream lakes by the construction of fishways. During winter, the uniform channel and high water velocities (Fig. 5.2) provides unsuitable habitat for bream, and therefore this species is supposed to leave the river partly downstream to the lakes and partly to the few deep backwaters after the feeding season. For dace, other population bottlenecks, such as habitat quality and connectivity with tributaries (Clough et al. 1998), may still prevail.

Comparison of the features of the current and the historical Vecht suggests that the main differences are quality of the mainstream channel habitat, lack of an adjacent estuary and the connectivity to the sea as well as to upstream tributaries. In the Biebrza, the mainstream habitats are nearly intact, supporting a fish community with higher relative abundances of especially the rheophilic species as well as pike, bleak and white bream.

Because the river is hardly used for navigation, at least above the third weir (see Table 5.1), and the main management concern is the safety of urban areas against flooding, there are many opportunities to improve the mainstream habitats (Duursema 2004). The riprap shores represent a totally unnatural feature and might be removed over at least some stretches. This would re-establish the natural meandering processes, and consequently the formation of sand banks and shallow sloping shores where macrophytes can make a comeback. Restoring the connection of existing backwaters to the main stream would further enhance this process. Such additional measures are expected to enhance the benefit of the measures already taken such as providing fishways along the weirs, but would also enhance the self-cleaning capacity of the river. A return to a more natural fish community appears feasible, especially because, as in the Biebrza, exotic species play only a minor role at present. Some populations may need measures on larger scales to recover. Several of the diadromous species present originally suffer from the absence of a properly functioning estuary, but it is unrealistic to assume that the original conditions may be recreated. In addition, anadromous species and some rheophilic species might have population bottlenecks owing to the poor connectivity with small tributaries, which should be easier to address.

The approach applied here could help to derive reference fish communities for other river systems and might aid the assessment of rehabilitation success of different measures taken in temperate river systems. In addition, the approach may be useful for determining Indexes of Biological Integrity, which are developed for the ecological assessment of water bodies imposed by the European Water Framework Directive.

Acknowledgements

We thank Gerrit van Hezel for his large efforts to make historical data on the River Vecht available, Gerhard Duursema for valuable information on river management and future rehabilitation plans. Fish data in Polish rivers were collected within the EU-project FAME: 'the Development, Evaluation and Implementation of a Standardized Fish based Assessment Method for the Ecological Status of European Rivers. A Contribution to the European Water Framework Directive.'

Straightened main channel of the river Vecht / Recht getrokken hoofdstroom van de Vecht

Cut-off meander / Afgesneden rivierbocht

References

- Anonymous, 1873. Letter from the Municipal Hardenberg to the County Aldermen 'Gedeputeerde Staten' on 12-09-1873, no. 254 in the municipal archives of Hardenberg, the Netherlands.
- Backiel, T., 1985. Fall of the migratory fish populations and changes in commercial fisheries in impounded rivers in Poland. In: Habitat modification and freshwater fisheries. Alabaster, J.S. (Editor). Proceedings of EIFAC symposium.
- Buijse, A.D., F. Klijn, R.S.E.W. Leuven, H. Middelkoop, F. Schiemer, J.H. Thorp and H.P. Wolfert , 2005. Rehabilitation of large rivers: references, achievements and integration into river management. Large Rivers Vol. 15 No. 1-4, Archiv für Hydrobiologie Suppl. Vol. 155/1-4: 715-738.
- Carrel, G., 2002. Prospecting for historical fish data from the Rhone River Basin: a contribution to the assessment of reference conditions. Archives for Hydrobiology 155: 273-290.
- Clough, S., P. Garner, D. Deans and M. Ladle, 1998. Post spawning movements and habitat selection of dace in the River Frome, Dorset, southern England. Journal of Fish Biology 53 (5): 1060-1070
- De Groot, S.J., 2002. A review of the past and present status of anadromous fish species in the Netherlands: is restocking the Rhine feasible? Hydrobiologia 478 (1-3): 205-218.
- De Leeuw, J.J., A.D. Buijse, R.E. Grift and H.V. Winter, 2005. Management and monitoring of the return of riverine fish species following rehabilitation of Dutch rivers. Large Rivers Vol. 15 No. 1-4, Archiv für Hydrobiologie Suppl. 155/1-4: 391-411.
- De Nie, H.W., 1996. Atlas van de Nederlandse Zoetwatervissen. Media Publishing, Doetichem, the Netherlands.
- Deking Dura, A., 1889. Het regime van de kleine rivieren in Overijssel. Zwolle, the Netherlands.
- Dekker, W., 2004. Slipping through our hands: population dynamics of the European eel. PhD-thesis, University of Amsterdam, the Netherlands.
- Dussling, U., R. Berg, H. Klinger and C. Wolter, 2004. Assessing the Ecological Status of River Systems Using Fish assemblages. Handbuch Angewandte Limnologie 20, 1-84.
- Duursema, G., 2004. Leidraad voor ecologisch herstel van de Overijsselse Vecht. Waterschap Velt en Vecht, Coevorden, the Netherlands.
- Dynesius, M. and C. Nilsson, 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266: 753-762.
- Fredrich, F. And H.H. Arzbach, 2002. Migrations and bank structure use of burbot *Lota lota* in the River Elbe, Germany. Zeitschrfit für Fischkunde, suppl 1: 159-178.
- Grift, G.E., 2001. How fish benefit from floodplain restoration along the lower River Rhine. PhD-thesis Wageningen University, the Netherlands.

- Goutbeek, A. and A.D. Verlinde, 1989. Dalfsen in de prehistorie. In: Uit de geschiedenis van Dalfsen. J. Ten Hove, F. Pereboom and H.A. Stalknecht (Editors). IJsselakademie, Kampen, the Netherlands.
- Haidvogl, G., S. Hohensinner, S. Schmutz and H. Waidbacher, 2003. Description of reference conditions of the Austrian Danube based on historical data with special emphasis on hydromorphology and fish fauna. Guidance paper within the scope of the UNDP-GEF Danube Regional Project. Project Document Activity 1.1.6 - Typology and Definition of Reference Conditions for the Danube River; United Nations Office for Project Services, New York, USA.
- Janssens, M.H.M., 1990a. Naar een hoogwatermodel Vecht. Deel 1. Systeem beschrijving. Ministerie van verkeer en Waterstaat, Rijkswaterstaat RIZA-Report 90.055, the Netherlands.
- Janssens, M.H.M., 1990b. Naar een hoogwatermodel Vecht. Deel 2. Gegevensanalyse. Ministerie van verkeer en Waterstaat, Rijkswaterstaat RIZA-Report 90.055, the Netherlands.
- Janssens, M.H.M., 1992. Naar een hoogwatermodel Vecht. H_2O 25, No. 10: 263-268.
- Kellerhals, R. and M. Church M. 1989. The morphology of large rivers: characterization and management. In: Dodge, P. (Editor). Proceedings of the Large Rivers Symposium, Special Publication of Fisheries and Aquatic Sciences, 106, 31-48.
- Lambrechtsen, N.C., 1918. De verbetering van de Overijsselsche Vecht. Nummer 24: 428-442.
- Lelek, A., 1987. The Freshwater Fishes of EuropeVol.9. Threatened Fishes of Europe. AULA-Verlag Wiesbaden, Germany.
- Malmqvist, B. and S. Rundle, 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29: 134-153.
- McPhail, J.D., 1997. A review of burbot (*Lota lota*) life history and habitat use in relation to compensation and improvement opportunities. Can. Man. Rep. Fish. Aquat. Sci. 2397: viii: 37 pp.
- Okruszko, T., 1990. Wetlands of the Biebrza valley. Their value and Future Management. Polish Academy of Sciences, Warsaw, Poland.
- Okruszko, T., 1991. Bagna Biebrzanski. Zeszyty Problemowe Postepow Nauk Rolniczych. In: Issue Papers of Progress in Agricultural Sciences. Polish Scientific Publishers, Warsaw, Poland. pp.163–184.
- Okruszko, T., 2005. Hydrological critera in wetlands protection, Warsaw Agricultural University monography, Warsaw, Poland.
- POZC, 1857a. Article in the local newspaper 'Provinciale Overijsselsche en Zwolsche Courant' on 8-9-1857 about the catch of a salmon of 22 pound in the River Zwarte Water at Zwartsluis. Available in archives of 'Overijsselsche Vereeniging tot Ontwikkeling van Provinciale Welvaart' at the Historisch Centrum Overijssel at Zwolle, the Netherlands.

- POZC, 1857b. Article in the local newspaper 'Provinciale Overijsselsche en Zwolsche Courant' on 2-10-1857 about the catch of 3-4000 pound of bream and white bream in River Vecht at Zwolle. Available in archives of 'Overijsselsche Vereeniging tot Ontwikkeling van Provinciale Welvaart' at the Historisch Centrum Overijssel at Zwolle, the Netherlands.
- Redeke, H.C., 1941. Fauna van Nederland X (Pisces). Sijthoff's, Leiden, the Netherlands.
- Ruting, J., 1958. Welke vis is dat? Thieme, Zutphen, the Netherlands.
- Schiemer, F. and H. Waidbacher, 1992. Strategies for conservation of a Danubian fish fauna. In: River Conservation and Management. P.J. Boon, P. Calow and G.E. Petts (Editors). Wiley & Sons, pp 363-382.
- Schutten, G.J., 1981. Varen waar geen water is. Reconstructie van een verdwenen wereld. Geschiedenis van de scheepvaart ten oosten van de IJssel van 1300 tot 1930. Broekhuis, Hengelo, the Netherlands.
- Staring, W. and T.J. Stieltjes, 1848. De Overijsselse wateren. Zwolle, the Netherlands.
- Succow, M. and L. Jeschke, 1986. Moore in der Landschaft. Urania. Verlag, Leipzig, Germany.
- Szappanos, P., 1991. River Basisn Management of the Rivers Drag (Hungary) and Overijsselse Vecht (The Netherlands). RBA-centre. Centre for Comparative Studies on River Basin Administration. Delft University of Technology, the Netherlands.
- TAUW, 1992. Bouwstenen voor een natuurontwikkelingsvisie voor de Overijsselse Vecht. Minstery of LNV, Directie Nature, Forrest, Landscape and Fauna, the Netherlands.
- Van Hezel, G., 1992a. Overijsselse Vecht: waterkwantiteit en oeverbeleid en – beheer. RWS-Overijssel, Zwolle, the Netherlands.
- Van Hezel, G., 1992b. De dynamiek van de Overijsselse Vecht na 1800. RWS-Overijssel, Zwolle, the Netherlands.
- Van den Ende, W.P., 1847a. Lijst van eenige vischsoorten, die in den IJssel bij Zutphen worden gevangen. Verslag der werkzaamheden Vereeniging tot Bevordering der Inlandsche Ichtyologie: eerste deel. An. Nijhoff, Arnhem, the Netherlands. pp 11-15.
- Van den Ende, W.P., 1847b. Opnoeming van eenige vischsoorten, die in de Berkel, bij Warnsveld, worden waargenomen. Verslag der werkzaamheden Vereeniging tot Bevordering der Inlandsche Ichtyologie: eerste deel. An. Nijhoff, Arnhem, the Netherlands. pp 30-32.
- Van den Ende, W.P., 1849. Verslag der werkzaamheden: tweede deel. Vereeniging tot Bevordering der Inlandsche Ichtyologie. An. Nijhoff, Arnhem, the Netherlands.
- Van der Perk, M. and M.F.P. Bierkens, 1997. The identifiability of parameters in a water quality model of the Biebrza River, Poland. Journal of Hydrology 200: 307-322.

- Waidbacher, H. and G. Haidvogl, 1998. Fish migration and fish bypass facilities in the Danube: past and present. In: Fish migration and fish bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fishing News Books, Oxford, UK. pp 85-89.
- Wassen, M.J., W.H.M. Peeters and H.O. Venterink, 2003. Patterns in vegetation, hydrology, and nutrient availability in an undisturbed river floodplain in Poland. Plant Ecology 165 (1): 27-43.
- Werkgroep Vechtvisie, 1997. De Vechtvisie: stap voor stap naar een duurzame Vecht. Arcadis Heidemij Advies-Rapport 634/OA97/7108/45545/djm, Deventer, the Netherlands.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing the opportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8, 513-532.
- Witkowski, A., 1984a. Structure of communities and biomass of ichthyofauna in the Biebrza River, its old river beds and affluents. Polish Ecological Studies 10, 447-474.
- Witkowski, A., 1984b. Analiza ichtiofauny basenu Biebrzy. Część II. Materiały do znajomośći rybostanu i przegląd gatunków. Fragmenta Faunistica 28 (6),137-184.
- Wolfert, H.P., G.J. Maas and G.H.P. Dirkx. 1996. Het meandergedrag van de Overijsselse Vecht; historische morfodynamiek en kansrijkdom voor natuurontwikkeling. DLO-Staring Centrum Rapport 408, Wageningen, the Netherlands.
- Wolter, C. and A. Vilcinskas, 1997. Perch (*Perca fluviatilis*) as an indicator species for structural degradation in regulated rivers and canals in the lowlands of Germany. Ecology of Freshwater Fish 6 (3): 174-181.
- Wolter, C., A. Bischoff and K. Wysujack, 2005. The use of historical data to assess fishfaunistic reference conditions for large lowland rivers in northern Germany. Large Rivers Vol. 15 No. 1-4, Archiv für Hydrobiologie Suppl. Vol. 155/1-4: 37-47.

Huidige visstand van zaken versus vroeger

De Vecht is de afgelopen eeuwen enorm van karakter veranderd. Vóór 1850 was het een natuurlijke sterk meanderende rivier met veel ondiepe zandbanken. Vis kon zich vrij bewegen tussen de Zuiderzee en de bovenstroomse beken. Maar vooral tussen 1890-1914 zijn er veel regulerende werken uitgevoerd in de Vecht. De rivier werd rechtgetrokken door veel bochten af te snijden en werd daarmee met 30 km ingekort. Hoogwater kon nu snel worden afgevoerd, maar dit gaf wel een flinke uitslijting van de waterbodem (tot 2 m in 100 jaar). Om het water op een constant streefpeil te houden werden er stuwen gebouwd. Hierdoor is de gemiddelde waterdiepte in de rivier sterk toegenomen en in tijden van minder rivierafvoer heeft de rivier zijn stromende karakter volledig verloren. Tenslotte zijn veel oevers met stortsteen beschermd tegen erosie.

Intussen zijn er maatregelen genomen om de rivier te herstellen. Allereerst werd de waterkwaliteit sinds de jaren 60 een stuk beter. Vervolgens zijn er in de jaren 90 vistrappen aangelegd om de vismigratie te vergroten. Dit heeft geleid tot een beperkte verschuiving in de samenstelling van de visgemeenschap (hfst. 4). Maar hoever de huidige visstand nog verwijderd is van de visstand zoals die vroeger in de natuurlijke situatie aanwezig was is onbekend. Uiteraard zijn er geen visstandbemonsteringen beschikbaar van de situatie voor 1850. Het enige dat beschikbaar is, zijn beschrijvingen over het voorkomen van vis in archieven en oude boeken. Daarnaast zijn er wel veel gegevens en oude kaarten beschikbaar over de historische rivierbeddingen van de Vecht vóór 1850. De oorspronkelijke meander-dynamiek van de Vecht is goed onderzocht en beschreven.

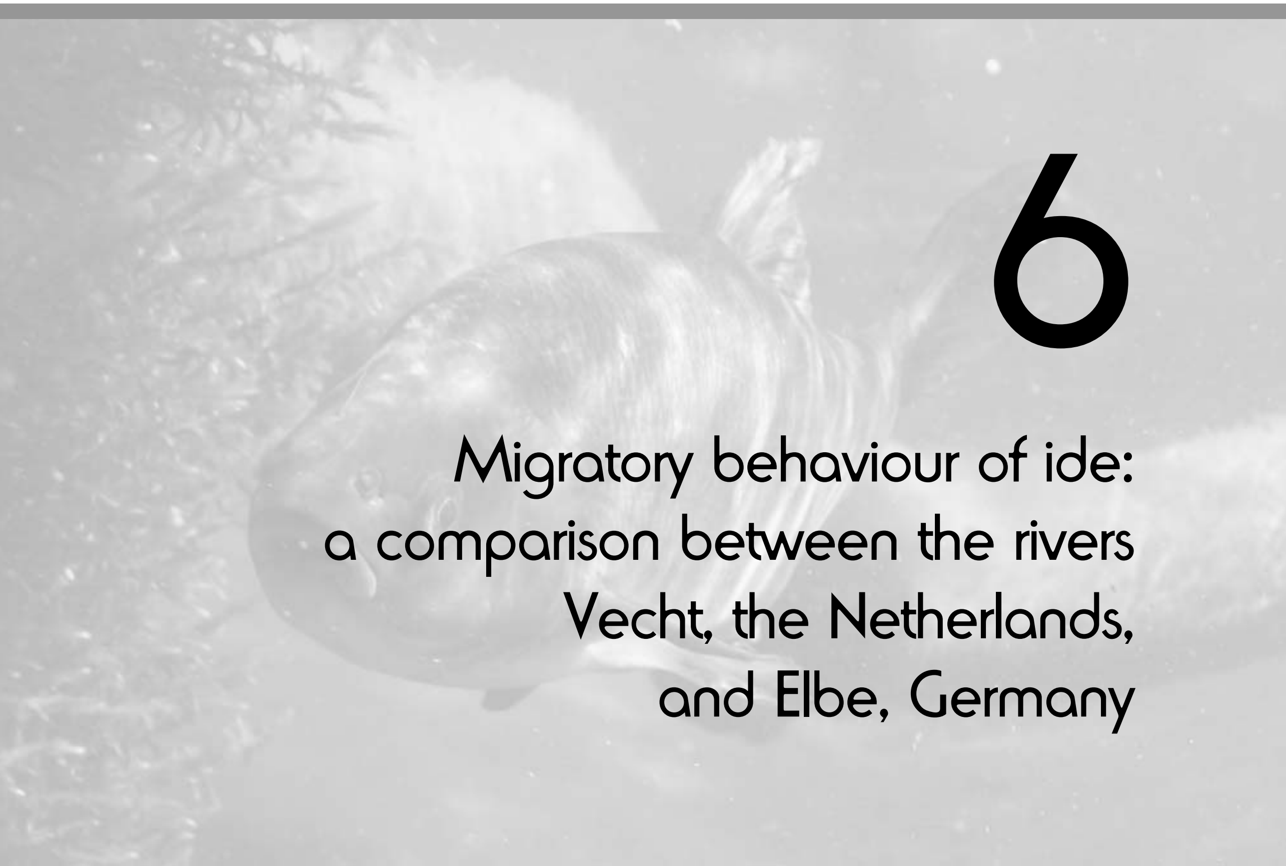
Om een idee te krijgen van de oorspronkelijke samenstelling van de visstand, is er gezocht naar een rivier elders in Europa (een ‘geografische’ referentie situatie) die goed overeenkomt met de natuurlijke situatie van de Vecht uit het verleden (de ‘historische’ referentie situatie). De Biebrza is nog een vrijwel volledig natuurlijke rivier in Polen die in veel aspecten sterk lijkt op hoe de Vecht vroeger was. Bovendien zijn in deze Poolse rivier visbemonsteringen uitgevoerd met elektrovisserij op een manier die vergelijkbaar is met de bemonsteringen in de jaren 90 in de Vecht. De huidige visstand van de Biebrza is mogelijk een goede afspiegeling voor de visstand in de Vecht vroeger.

Bij het maken van een reconstructie van de visstand zoals die vroeger in de Vecht voorkwam, is de visstand in de huidige Biebrza als uitgangspunt genomen. Vervolgens is deze gecorrigeerd voor een paar (relatief zeldzame) soorten die wel in Polen maar vroeger niet in Nederland voorkwamen. Daarnaast is een inschatting gemaakt welke lange-afstandstrekkers ondervertegenwoordigd zijn in de huidige situatie in de Biebrza doordat er door barrières op de rivieren Wisla en Narew, waar de Biebrza in uitmondt, tegenwoordig een slechte verbinding met zee is. Vervolgens is deze reconstructie geijkt met de visgegevens die uit historische bronnen beschikbaar waren. Het bleek dat deze vaak zeer goed overeenkwamen.. Zo is de kwabaal een talrijk voorkomende soort in de Biebrza en werd deze rond 1850 ook veelvuldig aangetroffen in de Vecht. Tegenwoordig is de kwabaal vrijwel verdwenen uit de Vecht. Van de zeven als meest algemeen geclassificeerde soorten in de reconstructie, noemt een bron uit 1873 er zes als meest algemeen voorkomend in de visserij in de Vecht bij Hardenberg.

De huidige visstand in de Vecht wijkt echter sterk af van de visstand in de Biebrza en de gereconstrueerde historische visstand in de Vecht rond 1850. Zo is baars in de huidige situatie veel talrijker. Dit is gerelateerd aan de vele steenstort oevers waarlangs deze soort erg goed gedijt. Ook brasem komt nu veel meer voor dan in de referentiesituaties (zowel historisch als geografisch). Andere soorten komen daarentegen tegenwoordig veel minder voor: kwabaal, snoek, alver, winde en kolblei.

Dus ondanks de verbeterde mogelijkheden voor migratie door de aanleg van vistrappen in de Vecht, is de visgemeenschap nog steeds ver verwijderd van wat als natuurlijk kan worden beschouwd. De meest aannemelijke verklaring hiervoor is het feit dat de leefomgeving voor vis in de huidige gestuwde en gereguleerde situatie nog sterk afwijkt van de natuurlijke situatie.

Adult ide / Volwassen winde



6

Migratory behaviour of ide: a comparison between the rivers Vecht, the Netherlands, and Elbe, Germany

Erwin Winter
Frank Fredrich

Published as:
Winter, H.V. & Fredrich, F. 2003. Migratory behaviour of ide, Leuciscus idus: a comparison between the lowland rivers Elbe, Germany, and Vecht, The Netherlands
Journal of Fish Biology 63: 1-10

Abstract

Individual movement patterns of adult ide *Leuciscus idus*, a Eurasian river-dwelling cyprinid, in two lowland rivers were measured year-round during 1997-2000 to assess migratory behaviour and variation between and within these populations. In River Elbe, a 1091 km long lowland river with a free flowing stretch of 590 km, 24 ide were implanted with radio transmitters. Fish were hand-tracked year-round once a week in the main study area (75 km), and once per six weeks in a larger area (321 km). In the River Vecht, a 190 km long highly regulated river with six weirs and fishways in the Dutch section, 25 ide were implanted with transponders. An array of three automatic detection stations covering the entire river width, registered each individual passage continuously. Within population variation in year-round movement patterns was very high. In both rivers a similar continuum was found from individuals using a river stretch of only a few km for spawning, feeding and wintering, to individuals migrating more than 100 km. The population in the two rivers differed, however, in spawning site fidelity. In the River Vecht spawning site fidelity was observed in all individuals and appeared much stronger than in River Elbe, where individuals moving downstream further than 60-90 km tended to adopt new spawning sites in the next year. Moreover, some ide in River Vecht migrated upstream to wintering habitats in autumn, whereas this was not observed in River Elbe. Our results suggest that ide are a flexible species capable of using a wide variety of movement pattern and scales.

Introduction

Cyprinid species form a large proportion of fish communities in lowland rivers in Europe, but relatively little is known about their migratory behaviour (Lucas et al. 2000, Lucas & Baras 2001). To disentangle the various anthropogenic impacts of habitat loss, habitat fragmentation, pollution and overfishing on fish populations, especially regarding rheophilic cyprinids of which many are endangered (Lelek 1987, Schiemer & Spindler 1989), more insight is required in their movement patterns. Migration occurs in many cyprinid species, but on what scale and how important it is in population biology remains largely unclear (Smith 1991). Recent developments in telemetry have enabled an increased use in behavioural studies on medium-sized to small cyprinids (Clough & Beaumont 1998, Baade & Fredrich 1998, Lucas & Baras 2001), providing evidence that migration plays an important role in at least some species, such as barbel *Barbus barbus* (L.) (Baras & Cherry 1990, Lucas & Batley 1996) and dace *Leuciscus leuciscus* (L.) (Clough & Ladle 1997, Clough et al. 1998). Most telemetric studies have so far been confined to a few individuals during a relatively short period up to several months in a particular water system. In this study, year-round migratory behaviour of adult ide *Leuciscus idus* (L.) based on telemetric studies in two lowland rivers, the Elbe in Germany and the Vecht in the Netherlands, were compared to assess intra- and interpopulation variation in individual movement pattern and the scale of the areas used year-round. Ide are widely distributed in the lower reaches of large river systems from Central Europe to Siberia and has been classified as 'vulnerable to endangered' in Europe (Lelek 1987, Schiemer & Spindler 1989). It is a lithophytophilous spawner (Balon 1975) that requires running water for the eggs to develop (Pliszka 1953). This rheophilic cyprinid is considered to be potamodromous, performing upstream prespawning migrations in early spring followed by downstream movements directly after spawning (Cala 1970).

Material and methods

Study areas

The River Elbe has a length of 1091 km and flows into the North Sea (Fig. 6.1).
The downstream German section (725 km in length) is highly regulated with poor shallow sloping banks dominated by groynes and sandy beaches and one weir at Geesthacht (river km 586 from Czech border), with a lock and a fish pass. The weir separates the downstream section influenced by tide from the free-flowing upstream stretch. Tracking was carried out between river km 287 and 608. The average discharge at these two locations were 315 $m^3.s^{-1}$ and 720 $m^3.s^{-1}$ respectively. River width normally varied between 200 and 500 m, but may increase up to 1000 m during flooding. Water levels fluctuated up to 4,5 m during 1997-2000. High flows occurred in March each year (varying from 2.8 to 4.5 m above minimum water level). There are many permanently or temporarily connected stagnant floodplain water bodies as well as some tributaries.

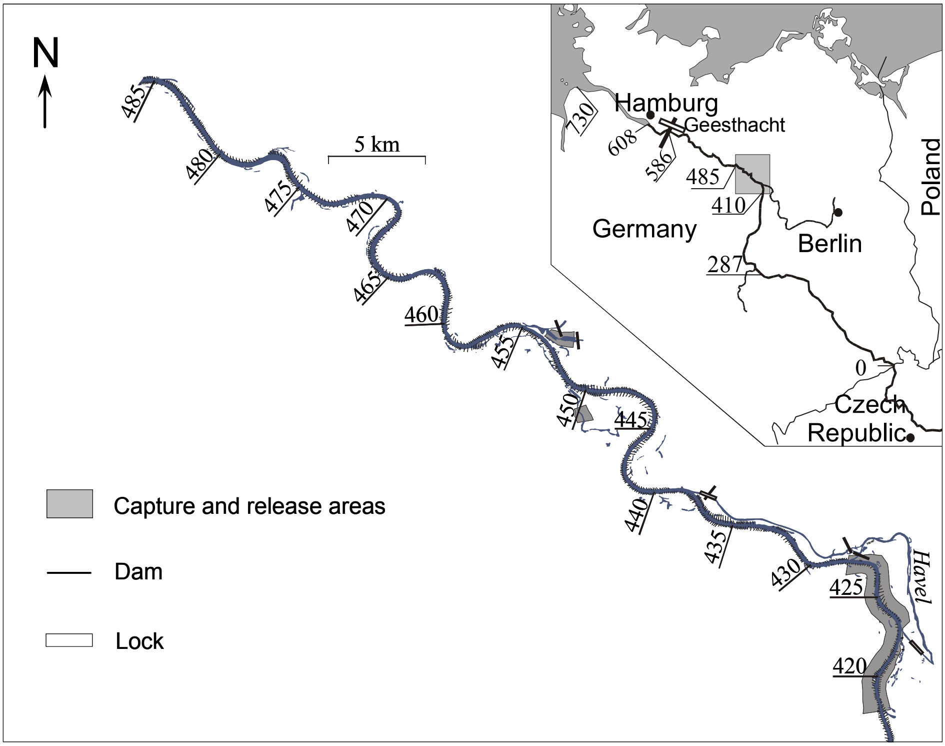


Figure 6.1 *Map of the study area in the River Elbe. Distances shown are from the border between Germany and Czech Republic.*

The River Vecht has a total length of 190 km and discharges into the eutrophic lakes Zwarte Meer, Ketelmeer and eventually IJsselmeer (Fig. 6.2). The river is highly regulated with six weirs in the downstream Dutch part. Along each weir, fishways that are passable for a wide range of fish species and sizes are present (chapter 3). Banks are steep and most of these are reinforced with riprap. There are only few sandy banks and submerged water plants are scarce. Discharge averages 32 $m^3.s^{-1}$. River width varies from 30 to 60 m, but may increase up to 1000 m during flooding events, which rarely exceed more than a few days (Winter & van Densen 2001). Water level is kept constant by weir regulation with only short lasting rises in water level up to 2 m during 1997-2000. In the Dutch section, there are about fifteen permanently connected water bodies, mainly oxbow lakes and sandpits, and one tributary that is accessible to fish (Fig. 6.2).

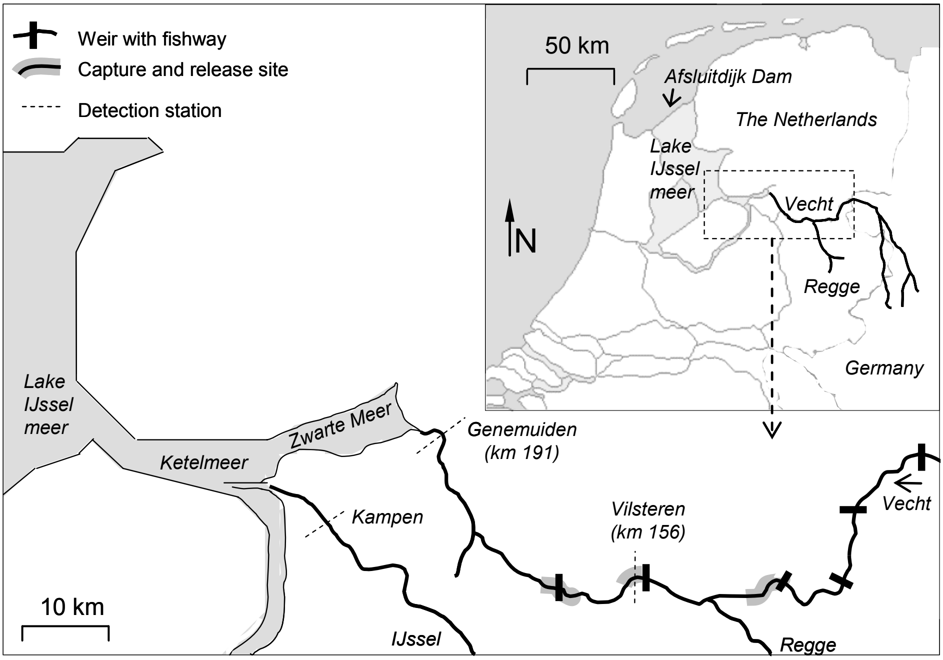


Figure 6.2 *Map of the study area in River Vecht, the Netherlands. Distances shown are km downstream from its origin in Germany.*

Telemetric experiments

In River Elbe and River Vecht, 24 respectively 25 adult ide were caught for telemetric experiments (Elbe: with electrofishing, weir-baskets or seine nets at the main channel River km 423-437 and backwaters at River km 450-455; Vecht: with electrofishing or fykenets at the main channel River km 144-168). Fish were anaesthetised (Elbe: 0.1 $g.l^{-1}$MS-222; Vecht: 0.5 $ml.l^{-1}$ 2-phenoxy-ethanol), total length was measured (Elbe: 35.5-51.0 cm; Vecht: 40.0-52.2 cm), weighed (Elbe: 550-1585 g; Vecht: 840-2360 g) and scales were taken for age determination (Elbe: 4-9 years; Vecht: 5-9 years). Radio transmitters (Elbe: LOTEK FRT4, size 47x16 mm, weight in air 17 g, minimal lifespan 12 months, and LOTEK MCFT3A, 51x16 mm, 16.1 g, 18 months) and transponders (Vecht: NEDAP TRAIL, 85x15 mm, 38 g, 24 months or

2000 detections) were implanted in the body cavity, as recommended for long-term tracking studies of fishes (Lucas & Batley 1996), through a 2-3 cm incision about 3 cm behind the base of the left pectoral fin. For the transmitters with external antennae (Elbe), a 15 cm long needle was used to pierce the lateral body wall between the ventral and anal fin for the antenna exit. The incision was closed with three separate stitches, using no resorbable polyester twisted twine (Elbe) or absorbable coated vicryl (Vecht). After a recovery period (0.5 h) in a tank with flowing water, the fish were checked for normal swimming behaviour before release close to the capture site.

In the River Elbe tracking was performed with a LOTEK-SRX-400 receiver and Yagi antennae from a boat once per week during June 1997 to April 2000 in the main monitoring area River km 410-485 (Fig. 6.1). A larger stretch of the main channel River km 287-608 and each tributary up to its second dam was tracked about once per six weeks.

In the River Vecht a newly developed telemetric method based on inductive coupling (NEDAP TRAIL system©; Nedap N.V., Groenlo, the Netherlands) and an existing infrastructure of fixed stations covering the entire river width at each location was used (Breukelaar et al. 1998). Of these, the stations at Genemuiden in River Vecht and Kampen in River IJssel were most relevant to this study (Fig. 6.2). One extra station was added in the River Vecht, 40 m downstream of the weir at Vilsteren (Fig. 6.2) during March 1998 to June 2000. In most cases the direction of movement could be derived from the sequence of recordings at different fixed stations. A downstream direction was generally characterised by one or rarely two detections per passage and upstream direction by at least three (usually much more) detections per passage. This was then used to estimate direction for those passages where sequence of stations was inconclusive. In addition, three hand-held tracking surveys were performed; 11 June 1998 (km 144-156), 16 June 1998 (km 144-156) and 24-25 March 1999 (km 144-176).

During hand-held tracking in both rivers apparently stationary recordings were checked for small movements to determine whether the fish was still alive or the tag was just lying there. In River Elbe, 15 ides could be tracked for more than 12 months, six for less than 12 months and three remained undetected. In River Vecht, 10 were registered for more than 12 months, 14 for less than 12 months and one remained undetected. To determine year-round patterns in individual movement, only ide that were tracked for 12 months or more were considered.

Results

Marked differences in the distance that individuals moved year-round were observed in both rivers (Fig. 6.3). In the River Elbe, four out of 15 individuals were detected on the same river stretch throughout the year with differences of at maximum 10 km (Fig. 3; E1, E2, E6, E11). For the other individuals, movements up to 187 km were found, mostly fast downstream movements after spawning, especially in 1998, and in some fish upstream movements prior to spawning. Similarly, in the River Vecht two individuals released upstream the weir Vilsteren were found never to pass the weir downstream and were tracked in each of the hand-held surveys in a

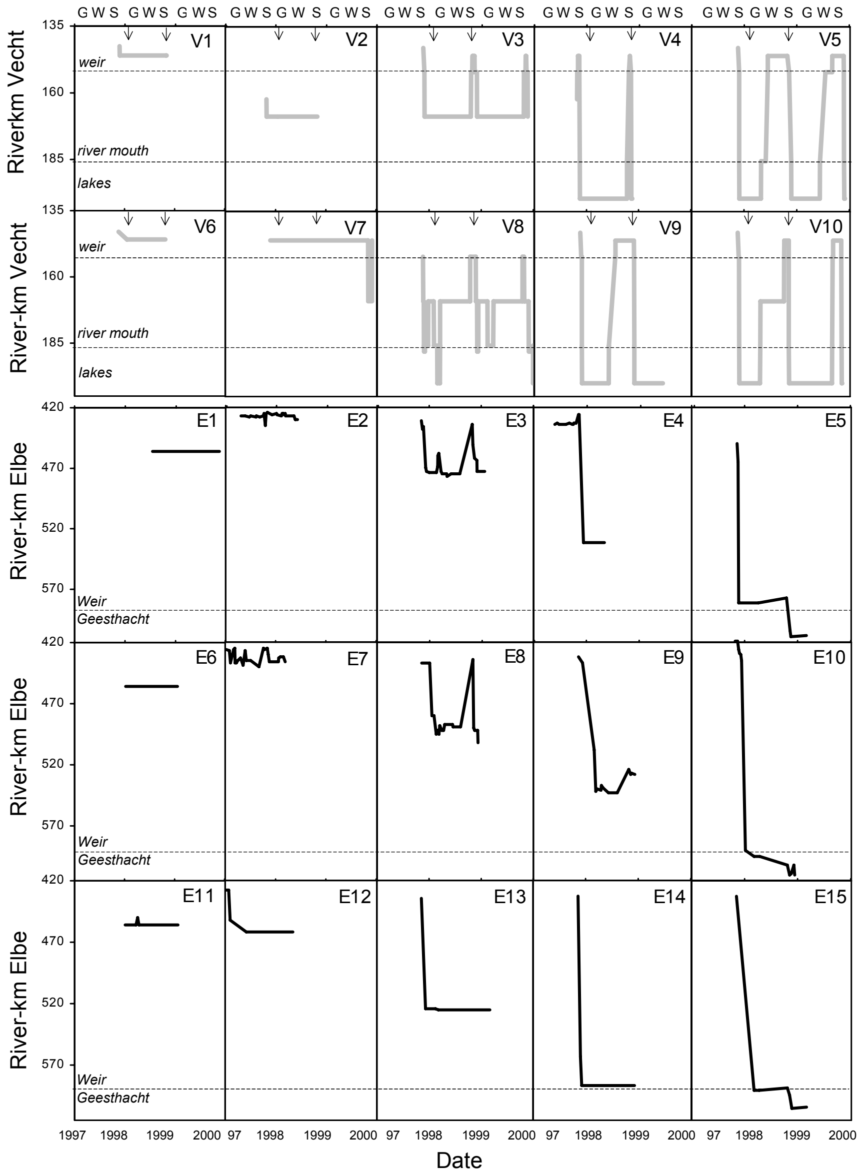


Figure 6.3 *Individual movements patterns of adult ide in the River Vecht (top panels V1-V10) and the River Elbe (bottom panels E1-E15) during 1997-2000. Spawning (S), growing (G) and wintering (W) seasons are indicated in the bar above the top panels. Individuals present upstream, between or downstream the detection stations in the River Vecht were plotted at a fixed position which does not accurately reflect their unknown real position. The arrows indicate hand-held surveys in the River Vecht. In the River Elbe determined positions were connected by lines.*

10 km upstream stretch (V1, V6). One individual was tracked in each of the hand-held surveys upstream from the weir Vilsteren and did not pass this station until it made a short excursion downstream directly after spawning in the third year (V7). Another individual, released in between Vilsteren and Genemuiden, was found

never to pass either station (35 km apart) and was hand-tracked during the second spawning period (V2). Five individuals migrated at least 35 km to the downstream situated lakes (V4, V5, V8, V9, V10). Individuals using a river stretch of more than 100 km were found in both rivers: at least six in the River Elbe with distances up to 187 km (E4, E5, E9, E10, E14, E15), and at least one in the River Vecht that was caught in the second tracking year by a commercial fishermen 116 km downstream from the spawning site where it was tagged and released (V9).

Habitat use appeared most diverse during the feeding and wintering season, when individuals were found in the main channel, groyne fields, connected backwaters and floodplains (during high discharge events) in River Elbe and both riverine habitats and downstream situated lakes in River Vecht. In contrast, during the spawning period, tracked ide in both rivers were only found near river banks with submerged (terrestrial) vegetation and relatively fast flow (0.3-1.0 $m.s^{-1}$), whereas none were found in backwaters or in the middle of the main channel.

For the individuals that could be tracked for two consecutive spawning periods (n = 10 for both rivers), it was examined whether they returned to the previously used spawning site. In River Elbe, the four individuals that moved less than 64 km were found to use the same river km during the next spawning period, whereas none of the six individuals that moved for longer distances (over 90 km) was found to return the next year. In contrast to this, in River Vecht all 10 fish were found to use the same river stretch for spawning in consecutive years.

Furthermore, four individuals in River Vecht exhibited upstream migrations between feeding and wintering habitats (V5, V8, V9, V10), whereas this was not observed in River Elbe.

Discussion

On average, upstream movements occurred mostly prior to spawning and downstream movements mostly directly after spawning (Fig. 6.3), as is mentioned to be a general pattern in ide (Cala 1970) and most other migratory cyprinids (Smith 1991). Variation in individual year-round movement patterns was very high. In both rivers a continuum was found from individuals that were nearly resident using a river stretch of only a few km for spawning, feeding and wintering, to individuals that migrated for long distances up to more than 100 km. There are only few records of cyprinid species moving for longer distances than was found for ide, e.g. *Rutilus frisii* over 1000 km (Nicol'ski 1961, cited in Smith 1991), Colorado squawfish *Ptychocheilus lucius* up to 400 km (Tyus 1985), nase *Chondrostoma nasus* 446 km and barbel *B. barbus* 318 km (Steinmann et al. 1937, cited in Waidbacher & Haidvogl 1998).

Both populations in River Elbe and River Vecht showed a similar continuum of year-round used ranges. Apparently the presence of weirs with fishways in the River Vecht did not severely limit the movements of ide. Four ides succeeded in passing at least two fishways in each of the years they were tracked (V4, V5, V9, V10). One ide passed the most downstream situated fishway in each year to reside directly downstream the weir at Vilsteren during the spawning period (V8). Because the habitat directly downstream appeared to be suitable for spawning it might not have been motivated to pass the fishway at Vilsteren.

There was, however, a marked difference between both rivers in the rate of return to previously used spawning areas ('spawning site fidelity'). Both biological and methodological explanations may account for this. First, we examine if the different experimental set-up of both telemetric studies, i.e. fixed stations versus periodic handheld-tracking, may have resulted in biased estimates for the degree of repeated homing.

When using fixed stations, as in River Vecht, individuals straying out of the study area to spawn elsewhere in the following year cannot be distinguished from individuals that suffered mortality, tag loss or tag failure. Because only individuals that could be tracked for more than 12 months were considered (10 out of 25), this could lead to an overestimation of the rate of repeated homing to spawning areas in River Vecht. A large proportion (15 out of 25) was detected for less than 12 months, even though expected lifetime of the transponders is over two years. Of these 15, one individual was never detected after release, nine were detected downstream the weir Vilsteren only in the first year, but never passed the downstream station in Genemuiden and five individuals migrated downstream to the lakes not to be detected again. Only the latter five might have strayed to different spawning areas the next year, because the other 10 have either lost their tag, experienced tag failure, died or resided in the same stretch for consecutive years. None of the five potential strayers, however, passed the station at the mouth of River IJssel even though this river contains a reproducing ide population (Winter, unpublished data) and is the only other large river flowing into these lakes. Given the lack of straying into the River IJssel, the absence of suitable spawning habitats in the downstream lakes and the strong overfishing in these lakes causing extra mortality, it is most likely that only a few, if any, have used different spawning areas undetected in the second year. Thus, there is indeed strong spawning site fidelity in the River Vecht.

In the River Elbe where weekly hand-tracking in a small area was combined with less frequent tracking of a larger area, fast long distance excursions might remain undetected (Baras 1998). Spawning excursions in River Vecht lasted down to 10 days (Fig. 6.3) and because not all individuals were seen in every tracking, this could lead to an underestimation of the rate of spawning site fidelity in the River Elbe. Of the seven long distance migrants that did not return to the previously used spawning area, only two were not detected for more than two weeks prior to and during spawning, leaving the possibility that spawning site fidelity remained undetected. Even if this were true for these two, the rate of spawning site fidelity was lower than found in River Vecht. Thus, the difference in methods might explain only part, if any, of the observed difference in the rate of repeated homing.

Therefore, the conclusion that ide populations in the rivers Elbe and Vecht exhibit a different degree of return to previously used spawning areas seems justified. It is possible that the rate of spawning site fidelity results from a trade-off between the profitability of previously used spawning sites versus other available spawning sites and the migratory costs that need to be made (Dodson 1997). The first obvious difference between the two rivers is the lack of spawning habitats in the downstream lakes in the River Vecht system, whereas spawning areas in the River

Elbe are present along the entire studied river course. Moreover, water fluctuations during the spawning season in the River Elbe are much larger than in the River Vecht and combined with the shallower sloping banks in the River Elbe versus the steeper banks in the River Vecht, may result in less predictable habitat conditions in the River Elbe than in the River Vecht. The clear-cut division in the River Elbe between individuals using less than 64 km year-round, of which all returned to the same river km during the second spawning season, and individuals using more than 90 km, of which none returned, suggests that for the latter migratory costs outweighed the difference in profitability of the previously used habitats and newly adopted habitats. In contrast, long distance migrating ide using the downstream lakes in the River Vecht system need to make migratory costs to reach suitable spawning areas anyway and may have selected River Vecht over River IJssel because River Vecht has been experienced to be suitable.

Spawning site fidelity as observed for ide, also occurs in the cyprinid Colorado squawfish (Tyus 1985), redside shiner *Richardsonius balteatus* (Lindsey & Northcote 1963) and roach *Rutilus rutilus* (L'Abée-Lund & Vøllestad 1985). For roach spawning in two tributaries of Lake Arungen in Norway and feeding and wintering intermingled in the lake, a high precision in spawning site fidelity was found, with a significant difference between the two studied streams (83.5 % and 92.0 %). The mechanisms behind these repeated spawning migrations, differences between and within cyprinid species, or whether these involve natal homing, are still unknown.

Our results suggest that ide is a flexible species capable of using a wide variety of movement patterns and scales of year-round used area. Moreover, it seems to adjust its movement patterns to different conditions between river systems, as was fund for spawning site fidelity and migrations from feeding to wintering habitats in the Rivers Elbe and Vecht. Thus, it might be less vulnerable to habitat fragmentation by barriers than is usually expected for potamodromous species. Even in these two highly regulated rivers suitable spawning, feeding and wintering habitats are available on small scales. Longitudinal connectivity is likely to increase overall population size, but not necessarily be essential to the existence of viable populations, because at least part of the population seems able to complete its life cycle on a small river stretch. However, a full comprehension of the role of migration and dispersal in ide can only be accomplished when including movements during larval and juvenile stages, which are still very challenging on an individual level.

Acknowledgements

The authors thank Bram bij de Vaate and Andre Breukelaar from RIZA, Lelystad, the Netherlands, for their support and methodological insights and the use of equipment and station infrastructure, Steffen Ohmann for assist in tracking in River Elbe and Niels Daan, Joep de Leeuw and two anonymous referees for valuable comments. The telemetric study in River Vecht was funded by the Ministry of Agriculture, Nature and Food Quality in the Netherlands and in River Elbe by the Federal Ministry of Education and Research in Germany.

References

- Baade, U. and F. Fredrich, 1998. Movement pattern of activity of the roach in the River Spree, Germany. Journal of Fish Biology 52: 1165-1174.
- Balon, E.G., 1975. Reproductive guilds of fish: a proposal and definition. Canadian Journal of Fisheries and Aquatic Sciences 32: 821-864.
- Baras, E 1998. Selection of optimal intervals in fish tracking: an experimental study on *Barbus barbus*. Hydrobiologia 372: 19-28.
- Baras, E. and B. Cherry, 1990. Seasonal activities of female barbel *Barbus barbus* (L.) in the River Ourthe (Southern Belgium), as revealed by radio tracking. Aquatic Living Resources 7: 181-189.
- Breukelaar, A.W., A. bij de Vaate and K.T.W. Fockens, 1998. Inland migration study of sea trout (*Salmo trutta*) into the rivers Rhine and Meuse (Netherlands), based on inductive coupling radio telemetry. Hydrobiologia 371/372: 29-33.
- Cala, P., 1970. On the ecology of ide *Idus idus* (L.) in the River Kavlingean, South Sweden. Reports of the Institute of Freshwater Research Drottningholm 50: 45-99.
- Clough, S. and M. Ladle, 1997. Diel migration and site fidelity in a stream-dwelling cyprinid, *Leuciscus leuciscus*. Journal of Fish Biology 50: 1117-1119.
- Clough, S. and W.R.C. Beaumont, 1998. Use of miniature radio-transmitters to track the movements of dace, *Leuciscus leuciscus* (L.) in the River Frome, Dorset. Hydrobiologia 372: 89-97.
- Clough, S., P. Garner, D. Deans and M. Dadle, 1998. Postspawning movements and habitat selection of dace in the River Frome, Dorset, southern England. Journal of Fish Biology 53 (5): 1060-1070.
- Dodson, J.J., 1997. Fish migration: an evolutionairy perspective. In: Behavioural Ecology of Teleost Fishes.J.G.J. Godin (Editor). Oxford: Oxford University Pres. pp. 10-36
- L'Abée-Lund, J.H. and L.A, Vøllestad, 1985. Homing precision of roach *Rutilus rutilus* in Lake Arungen, Norway. Environmental Biology of Fishes 13: 235-239.
- Lelek, A., 1987. The Freshwater Fishes of Europe 9: Threatened Fishes of Europe. Wiesbaden: AULA-Verlag. 343 pp
- Lindsey, C.C. and T.G. Northcote, 1963. Life history of redshiner, *Richardsonius balteus*, with particular reference to movements in and out of Sixteenmile Lake streams. Journal of the Fisheries Research Board of Canada 20: 1001-1030.
- Lucas, M.C. and E. Baras, 2001. Migration of freshwater Fishes. Oxford: Blackwell Science Ltd. 420 pp.
- Lucas, M.C. and E. Batley, 1996. Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management. Journal of Applied Ecology 33: 1345-1358.
- Lucas, M.C., T. Mercer, G. Peirson and P.A. Frear, 2000. Seasonal movements of course fish in lowland rivers and their relevance to fisheries. In: Management

and Ecology of River Fisheries. Cowx, I.G. (Editor). Oxford: Fishing News Books. pp. 87-100

- Pliszka, F., 1953. The effect of spawning conditions in lakes on young fish populations. Polskie Archiwum Hydrobiologii 1(14): 165-188.
- Schiemer, F. and T. Spindler, 1989. Endangered fish species of the Danube River in Austria. Regulated Rivers: Research & Management 4: 397-407.
- Smith, R.J.F., 1991. Social behaviour, homing and migration. In: Cyprinid Fishes: Systematics, Biology and Exploitation. Winfield, I.J. and J.S. Nelson (Editors). London: Chapman & Hall. pp. 509-529.
- Tyus, H.M., 1985. Homing behaviour noted for Colorado squawfish. Copeia 1985: 213-215.
- Waidbacher, H.G. and G. Haidvogl, 1998. Fish migration and fish passage facilities in the Danube: past and present. In: Fish Migration and Fish Passes. Jungwirth, M., S. Schmutz and S. Weiss (Editors). Oxford: Fishing News Books. pp. 85-98.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing the opportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.

Over rondtrekkende windes en thuisblijvers

Winde is een riviervissoort waarvan werd aangenomen dat deze in het vroege voorjaar in stroomopwaartse richting de rivieren optrekt om te paaien op stromend water. Na het paaien trekken ze stroomafwaarts om in benedenlopen van de rivieren en aangetakte meren naar voedsel te zoeken. Dit beeld is gebaseerd op patronen die in het verleden verkregen zijn door visserijvangsten en terugvangsten van windes die gemerkt waren. In de huidige studie werden windes in de Vecht uitgerust met kleine zendertjes om ze te kunnen volgen tijdens hun migraties en bij het passeren van vistrappen. Hieruit blijkt dat er geen sprake was van een uniform gedrag voor alle windes, maar dat er veel variatie was tussen de verschillende individuen. Onderzoek met gezenderde windes in de Elbe in Duitsland gaf dezelfde resultaten. Op basis van deze twee zender-experimenten is een inschatting gemaakt van de rol die migratie speelt binnen de populaties winde in de Vecht (25 gezenderde windes) en de Elbe (24 gezenderde windes). In beide studies werden de windes ruim een jaar worden gevolgd, in de Vecht enkelen zelfs tot drie jaar.

In de Vecht is de zender-methodiek toegepast die door Nedap in Groenlo en Rijkswaterstaat RIZA is ontwikkeld voor een omvangrijk zeeforel-onderzoek met detectiestations in het gehele Nederlandse rivierengebied. Elk detectiestation bestaat uit een kabel die in een lus op de bodem de gehele breedte van de rivier afdekt. Wanneer een vis met een zender over het station zwemt wordt de zender geactiveerd en zendt een unieke code terug. Deze informatie wordt vastgelegd in een datalogger die via de telefoon kan worden uitgelezen. Zo is precies bekend wanneer welke vis een station heeft gepasseerd. Voor deze studie werd gebruikt gemaakt van vaste detectiestations in de monding van de Vecht bij Genemuiden en direct benedenstrooms van de stuw bij Vilsteren en in het voorjaar ook in de vistrap. Daarnaast is er enkele malen per boot met een losse antenne verschillende riviertrajecten afgezocht naar gezenderde windes.

In de Elbe werd de radiotelemetrie methodiek van LOTEK toegepast. Het zendertje in de vis zendt continue een radio-signaal uit dat gericht met een antenne kan worden opgezocht. Elke week werd er met een boot een vast traject van 75 km afgezocht naar gezenderde windes. Eens in de zes weken werd een gebied van ruim 300 km afgezocht.

In beide rivieren werden grote verschillen in individuele migratiepatronen gevonden. Sommige windes bleven het hele jaar in een klein gebied van slechts enkele kilometers, anderen migreerden over afstanden tot meer dan 180 km. En alles daar tussenin Sommigen windes trokken in het vroege voorjaar op, anderen in het najaar. Er lijken geen duidelijk gescheiden migratie strategieën onder te liggen, maar eerder een continuüm van verschillende patronen. Opmerkelijk genoeg was de variatie van jaar op jaar voor hetzelfde individu gering. Met name in de Vecht waar een aantal windes meerdere jaren gevolgd zijn, vertoonden ze elk jaar nagenoeg hetzelfde patroon.

Windes die niet meer dan 90 km migreerden in de Elbe, keerden het volgende jaar allen terug naar dezelfde paaiplaats. Diegenen die verder dan 90km trokken paaiden het jaar daarop in een lager gelegen gebied. Dit is wellicht te verklaren doordat er langs de Elbe over de hele rivierlengte geschikte paaiplaatsen waren. In de Vecht daarentegen kwamen de lange-afstands-trekkers uit in meren waar geen geschikte paaiplaatsen aanwezig zijn en keerden daarom wellicht van grote afstand terug naar de hen bekende paaiplaatsen op de Vecht en niet naar bijvoorbeeld de IJssel die ook zeer geschikt is.

Hoe al de verschillende patronen tot stand komen is nog speculatief. Alle gezenderde windes waren volwassen vissen van 5 jaar en ouder. Over de rol die migratie en leergedrag speelt tijdens jongere stadia is vrijwel niets bekend. Uit deze studie is gebleken dat winde dus wel degelijk migreert, maar niet allemaal en ook niet allemaal over even grote afstanden. Goede migratiemogelijkheden zal de omvang van een populatie winde zeer waarschijnlijk ten goede komen, maar gezien de afwezigheid van trekgedrag in tenminste een deel van de onderzochte populaties lijkt het niet absoluut noodzakelijk voor de winde om zich te kunnen handhaven. Dit is toch een iets ander beeld dan hoe winde voorheen te boek stond.

Winde staat hierin zeker niet alleen. Met het sterk toenemende gebruik van zenderstudies in vis blijkt dat grote individuele variatie in de patronen en schaal van de bewegingen eerder regel dan uitzondering is.

Ship lock, weir and fishway at Vechterweerd / Sluis, stuw en fistrap bij Vechterweerd

7

Fishway efficiency, delay and passage behaviour of ide in relation to attraction flow

Erwin Winter

(Submitted for publication)

Abstract

The effectiveness of V-stepped fishways, for adult ide *Leuciscus idus*, a river-dwelling cyprinid, was tested in the River Vecht, the Netherlands. Along all six weirs in this highly regulated river a fishway has been constructed to facilitate upstream migration. Passage success rate and individual delays in relation to hydraulic conditions for ascent and the attraction flow of the fishway were studied in a mark-recapture experiment in April 1996 (340 adult ide with Visible Implant Tags) and in radio-telemetric experiments during 1998-1999 (50 adult ide surgically implanted with Nedap Trail® transponders). For the latter, three fixed detection stations covering the entire width of the river were used, one of which was located directly downstream of the weir at Vilsteren and one in the upper three compartments of the local fishway. In 1996, 11.2 % of the fish released after passing the first downstream weir, successfully passed the next two fishways. In the telemetric experiments, 57 % of the ide that approached the weir at Vilsteren successfully passed ('*overall fishway efficiency*'), predominantly through the fishway and occasionally through the weir-gaps at high-discharge events ('free-flowing conditions'). Individual behaviour patterns indicate that most fish that did not pass the fishway after having approached the weir were not motivated to move further upstream. Thus, the '*true*' fishway efficiency (i.e., the fraction of all '*motivated*' fish that succeed in passing) may be considerable higher then implied by the 57 % as measured. With increasing river discharge and decreasing ratio between fishway discharge and river discharge, pass rate per weir visit ('*attempt*') significantly decreased and delay times significantly increased, giving support for the 'attraction flow hypothesis' stating that the fraction of fish that succeed in finding the entrance ('*attraction efficiency*') is dependant on the ratio of attracting fishway flow to distracting spill flows over weirs or dams.

Introduction

To enhance fish migration along man-made barriers in rivers, such as dams and weirs, many of these have been equipped with fishways, passes, ladders or bypass-channels (Clay 1995). Whether a fish will successfully pass a barrier facilitated with a fishway arguably depends on the ability to locate the entrance guided by environmental stimuli ('*attraction*'); behavioural decisions to use the fishway ('*acceptance*') and the physiological ability to overcome the hydraulic conditions provided in the fishway ('*suitability*'). All these factors are potentially affected by environmental conditions such as discharge, water velocities and water temperature (Smith 1985, Jonsson 1991, Lucas & Baras 2001). To determine the effectiveness of fishways, a distinction is made between the fraction of fish that arrive at the lower side of the barrier that succeeds in finding the entrance, i.e. '*attraction efficiency*'(sometimes referred to as 'entrance efficiency', Moser *et al.* 2002a) and the fraction of fish that entered the fishway that succeeds in successfully passing it as a result of acceptance and suitability, i.e. '*passage efficiency*', together determining '*overall efficiency*' of the fishway (Larinier 1998, Aarestrup et al. 2003). The extra time required to successfully pass the barrier is referred to as '*delay*'.

Most studies on the effectiveness of fishways are restricted to either an evaluation of the suitability of the fish passage facility for upstream ascent or monitoring the species-composition and number of fish that successfully pass the fishway (e.g. Schwalme et al. 1985; chapter 3). Studies of the overall efficiency of these facilities and the factors determining this are still few, especially for non-salmonid fish species (Schmutz et al., 1998; Bunt et al., 1999; Moser et al., 2002b, Oldani & Baigún 2002; Aarestrup et al., 2003). Attraction flow is often mentioned as an important factor in determining passage efficiency, although direct evidence, is still largely lacking (Baras et al 1994, Larinier 1998, Bunt et al. 1999, Gowans et al. 1999, Lucas & Baras 2001, Laine et al. 2002).

To evaluate overall efficiency of V-stepped fishways (Boiten 1990, Cowx & Welcomme 1999), along weirs in the River Vecht for passage by adult ide *Leuciscus idus* (L.), capture-recapture tagging experiments were carried out in 1996 and radio telemetric experiments during 1998-1999. The ide is a river-dwelling (potamodromous) cyprinid that in general migrates upstream prior to spawning, followed by downstream migrations directly thereafter (Cala 1970), although scale of year-round habitat use and migratory patterns vary considerable between individuals (Winter & Fredrich 2003). The techniques used enabled to determine individual delay and passage rate of individuals that approach a weir and, combined with daily hydrological data, to test the attraction flow hypothesis. Because the hydraulic conditions in the type of fishway investigated are suitable for a wide range of fish species and sizes down to 6 cm (chapter 3) and include passage of adult ide (Winter & Fredrich 2003), the suitability of the fishway should pose no constraints for successful passage of adult ide. Therefore, finding the entrance (attraction efficiency) seems the predominant factor determining overall efficiency in this case. The hypothesis is put forward that with an increasing ratio between the 'attracting' flow through the fishway relative to the 'distracting' flow over the weir, delay will decrease and passage success increase due to a higher probability of locating the entrance of the fishway per attempt to pass the obstruction.

Material and methods

Study area

The River Vecht (52°30'N, 6°30'E, 177 km in length, Fig. 7.1) is highly regulated with six weirs to maintain target water levels during periods of low discharge rates. Flow is controlled by overspilling gates that are automatically adjusted in height, keeping upstream water level close to the target (± 0.05 m) while causing abrupt differences in water level (depending on discharge rate up to 3 m; Winter & van Densen 2001). The weirs at Vechterweerd and Vilsteren are equipped with shipping locks (Fig. 7.1). However, these locks can be excluded as possible pathways for upstream passage of ide during most of the year, because they are used only during summer for some recreational shipping.

A series of fishways that bypass each of the six weirs has been constructed during 1987-1994 (Fig. 7.1). They are similar in design (Cowx & Welcomme 1999, chapter 3) and consist of a series of up to 14 basins that are separated by V-shaped overfalls with water level drops of 0.2 m, with water velocities at the overfall not exceeding 1 $m.s^{-1}$ (Boiten 1990, chapter 3). The V-shaped inflow of each fishway is adjusted by hand to match the target upstream water level and ensuring a constant fishway discharge of 1 $m^3.s^{-1}$ according to design. The research has been largely restricted to the two weirs at Vilsteren (river km 156 from source) and Junne (river km 144), while ide for tagging were caught at the most downstream weir at Vechterweerd (river km 166). The outflow of the fishway is situated 45 m downstream of the weir at Vechterweerd, 25 m at Vilsteren and 40 m at Junne.

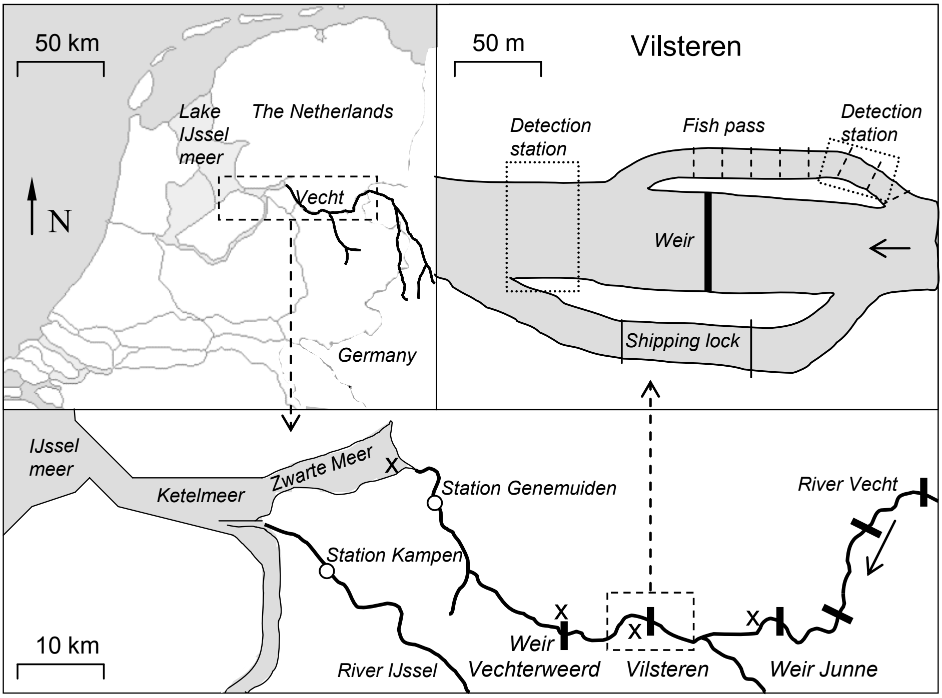


Figure 7.1 *Location of the River Vecht in the Netherlands (top-left panel), weirs (I), catch and release sites (x) and permanent transponder stations (o; bottom panel), and layout of the weir at Vilsteren with detection stations (top-right panel).*

With increasing river discharge, water level directly upstream of a weir remains constant at the target by automatic adjustment of the height of the overspilling gate. This results in a gradual rise of the downstream water level and a consecutive 'drowning' of the lower fishway basins. When the weir is completely lowered, differences between both sides of a weir become smaller than 0.25 m, further indicated as '*free-flowing*' conditions through the weir-gaps and the fishway (Winter & van Densen 2001). If discharge increases further, the fishway becomes completely drowned and water level rises above the target everywhere.

Hydrological data

Based on daily discharge data for Emmerlich in Germany (river km 110) and for the tributary Regge flowing into the Vecht between Vilsteren and Junne (Fig. 7.1), the discharge at weir Vilsteren was estimated according to Winter & van Densen (2001).

Water levels directly upstream and downstream of the weir at Vilsteren were automatically registered on a daily basis.

At Vilsteren, free-flowing conditions commence when river discharge exceeds 90 $m^3.s^{-1}$. Below this value, discharge through the fishway is constant at 1 $m^3.s^{-1}$. For higher values, discharge through the fishway per 'free-flowing' day was calculated from the wet cross-section surface of the upstream entrance and of the weir gaps, using daily upstream water marks and the ratio between current velocities in the weir-gaps and in the fishway as measured during a high-discharge event on 9, 11 and 12 March 1998 (Winter & van Densen 2001).

During the mark-recapture experiment in April 1996, free-flowing conditions did not occur and discharge varied between 9-16 $m^3.s^{-1}$. During the telemetric experiments, free-flowing conditions occurred in 1998 during 8-12 April, 9-13 June, 15-20 September, 9-15 October, 24 October-16 November, 14-30 December, and in 1999 during 4-30 January, 20-25 February, and 1-7 March.

Mark-recapture experiments

In April 1996, adult ide were trapped during their upstream migration with fykenets (length 10 m, stretched-mesh size 20 mm) covering the entire upstream inflow overfall of the fishways at Vechterweerd and Junne (Figure 7.1). Fykenets were emptied daily at 18:00 at Vechterweerd for tagging, and at 8:00 at Junne to check for recaptures (Monday-Saturday; with an additional control at 19:00 on Saturday; Winter & van Densen submitted). The 340 adult ide caught at Vechterweerd were released after tagging in three sessions (Figure 7.2). Fish were anaesthetised with 0,5 $ml.l^{-1}$ 2-phenoxy-ethanol, length and weight were measured and sex was determined from external features. A Visible Implant tag (2.0 x 2.5 mm) with a unique individual code was implanted directly under the skin at the operculum near the adipose eye-lid (Haw *et al.* 1990) with a VI tag injector (Northwest Marine Technology, Inc.). In addition, an alcian blue dye was injected in front of the pelvic fins as a batch mark. All fish were released in the main channel directly upstream of the fishway to allow them to continue their upstream migration and time of release was noted for each individual. The fykenet monitoring of the fishway at Junne continued until 31 may 1996, well beyond the spawning migration period of ide.

Telemetric experiments

A total of 50 adult ide (26 males and 24 females; 40.0-55.5 cm total length, see Appendix) were caught at various sites in 1998-1999 and implanted with Nedap Trail® transponders (Nedap, Groenlo, the Netherlands; Breukelaar et al. 1998) in the body cavity, as recommended for long-term tracking studies of fish (Lucas & Batley, 1996). Surgery procedures have been described by Winter & Fredrich (2003). All fish were released at the site of capture.

Of the existing infrastructure of a network of fixed stations covering entire river widths throughout the Netherlands (Breukelaar et al., 1998), only the detection stations at Genemuiden in River Vecht and Kampen in River IJssel were relevant here (Fig. 7.1). Two extra stations in the River Vecht were added temporarily: one 32 m downstream of the weir at Vilsteren with a detection zone of 50 m length and full river width (March 1998 to June 2000) and one in the upstream part of the fishway covering the three basins at the upstream inflow end of the fishway (this station was available for March-June 1998 and February-June 1999; Fig. 7.1).

Table 7.1. Details of the passage of adult ide at the weir of Vilsteren implanted with Nedap-transponders and released at four locations (cf. fig. 7.1): number that approached the weir, number that passed upstream and the pathway selected for upstream passage (through the fishway, through the weir-gaps during free-flowing events, or unknown when the fishway station was not active during time of passage).

Group (date of release, n fish)	Weir approach	Successful passage	%	Pathway of upstream passage		
				Fishway	Weir-gaps	Unknown
Vechterweerd (n=13)						
1998	9*	5**		5	0	0
1999	1	1		1	0	0
subtotal	10	6	60	6	0	0
Weir Vilsteren (n=2)						
1998	1	0**		0	0	0
1999	1	0		0	0	0
subtotal	2	0	0	0	0	0
Vilsteren-Junne (n=10)						
1998	2	2		0	0	2
1999	2	2		1	0	1
subtotal	4	4	100	1	0	3
Zwarte Meer (n=25)						
1999	7	3**	43	2	1	0
Subtotal by year						
1998	12	7	58	5	0	2
1999	11	6	55	4	1	1
Subtotal by sex						
Male (n=26)	11	6	55	2	1	3
Female (n=24)	12	7	58	7	0	0
Total	**23**	**13**	**57**	**9**	**1**	**3**

* A 10th fish that approached the weir lost its transponder directly downstream the weir at Vilsteren and was not taken into account in to determine the fraction of successful passage.

** In three cases there was one fish that was detected in the fishway, but directly thereafter returned to the downstream weir detection station, and therefore considered to have not been successful in passing the fishway although it can not be ruled out that they successfully passed the fishway and directly thereafter moved downstream over the weir (see Appendix).

The stations send interrogation signals every 4 s. When a transponder is activated by a station, it sends back a unique code and is automatically switched off for the next 2 minutes to save battery life-time. If a fish remains near a station for longer periods, typically detection series with intervals of 2 minutes were registered. The batteries are guaranteed to last for four years when total number of detections does not exceed 1,000.

The detection station downstream of the weir at Vilsteren did not properly function during 15 June-31 July 1998 because of a broken cable. In addition, six ides were present almost continuously during 14-17 March 1999 in the detection area of this station. The unexpectedly high number of detections exceeded the memory of the data logger and caused the loss of previous data from 23 February-13 March 1999. Other fixed stations could be read-out daily by telephone. In addition to the fixed station set-up, three hand-held tracking surveys were performed to check individual positions (Winter & Fredrich 2003).

Data analysis

In the telemetric experiments, individual delay for ultimately passing fish at Vilsteren was determined by the time between first detection at the downstream weir station and last detection in the fishway station. For individuals passing through the fishway during 23 February-13 March 1999 that had not been detected downstream the weir prior to the logging failure, individual delay could not be determined. Also, for individuals present downstream on 14 March 1999 and passing the fishway afterwards, only a minimum estimate of delay could be made. These were not taken into account in further individual delay analyses, but only used for pooled analyses for all individual observations per day.

For the mark-recapture experiments, the time of recapture at Junne, was known usually with a precision of on average 12 hours, given the 24-hour interval between fykenet checks. Therefore, a minimum and maximum duration between release and recapture was calculated for each recaptured individual. Fish recaptured at Junne had successfully passed the two weirs at Vilsteren and Junne. The 'fastest' recaptured fish (maximum duration between release and recapture of 15 hours) migrated upstream at an average speed of at least 0.4 $m.s^{-1}$ over the 22 km stretch between release and recapture, which is not far below maximum sustained swimming speeds for other species with similar lengths and at similar temperatures (Videler 1993). Therefore, it seems justified to consider that these fish had delay times at the consecutive weirs of close to zero. The value of 15 hours was assumed to apply equally to other individuals for covering the distances between weirs and 'delay time' for passing the two weirs was obtained by subtraction from the measured interval between mark and recapture. Thus, per individual a minimum, maximum and average delay per weir was calculated.

Transpondered fish that approached the weir at Vilsteren, typically showed series of detections with two minutes intervals when present inside the detection area alternated with periods spent outside the detection area. As an indication of the number of attempts to pass the weir, intervals between detections that exceeded 3 minutes were defined as '*visits*', i.e. potential attempts to search for an upstream passage pathway. Number of visits per individual when present downstream of the weir usually ranged between 1-10 per day after first arrival. The 1998 and 1999 data were pooled and all days with at least one visit were ranked by increasing discharge order and classified in three groups with an equal number of visits for discharge rates < 90 $m^3.s^{-1}$ (non free-flowing conditions) and two classes with an equal number of visits at discharge rate > 90 $m^3.s^{-1}$ (free-flowing conditions). The '*passage success rate*' per visit (PSR) per discharge class was then calculated as the ratio between the number of successful passages and the number of visits. Success rate from the telemetry data was not only calculated for the full set including all individuals irrespective of whether they ultimately passed or not, but also for the subset of individuals that successfully passed the weir to avoid potential bias when comparing to the tagging data, which only comprised successfully passing individuals. Moreover, because ide is a river-dwelling species for which it can not be ruled out that they might select habitats directly downstream the weir or even in the fishway for spawning purposes in stead of using them as corridors, not all fish approaching the weir were necessarily motivated to move further upstream.

When assuming a similar number of visits per day of delay per successfully passing individual for the 1996 mark-recapture experiment as measured in the 1998 and 1999 telemetric experiments, *PSR* per discharge class can be calculated for the VI-tagged ides in a similar way as described above.

It is hypothesized that *Delay* and *PSR* are dependant on the hydraulic conditions at weir-fishway locations, i.e. 1) *Delay* increases with increasing river discharge Q_{river}, 2) *Delay* decreases with increasing ratio between fishway discharge and river discharge ($Q_{fishway}/Q_{river}$), 3) *PSR* decreases with increasing river discharge Q_{river} and 4) *PSR* increases with increasing ratio between fishway discharge and river discharge ($Q_{fishway}/Q_{river}$). These hypotheses were tested by linear regression using the following models (with parameter estimates β_0 and β_1 and residual variance e):

$$Delay = \beta_0 + \beta_1\ Q_{river} + e \qquad [1]$$

$$Delay = \beta_0 + \beta_1\ [Q_{fishway}].[Q_{river}]^{-1} + e \qquad [2]$$

$$PSR = \beta_0 + \beta_1\ Q_{river} + e \qquad [3]$$

$$PSR = \beta_0 + \beta_1\ [Q_{fishway}].[Q_{river}]^{-1} + e \qquad [4]$$

All models were tested for different datasets each: (a) for telemetry data of individuals that successfully passed a weir (dataset Tel. succ.) and (b) a combined set of tagging and telemetry data of individuals that successfully passed a weir (dataset Tel. + tag). Models [3] and [4] were also tested for (c) telemetry data including all individuals (dataset Tel. all). Moreover, each of these tests were performed for data including all river discharge rates, and on data for non free-flowing conditions (Q_{river} < 90 $m^3.s^{-1}$).

Results

Mark-recapture experiment 1996

Of the 340 adult ide that were VI-tagged in 1996 at Vechterweerd, 38 (11.2%) successfully passed both fishways at Vilsteren and Junne (Figure 7.2). The fraction of the first group was higher than for the later two groups. One tagged fish was recaptured by a recreational fisherman between the fishways Hardenberg (5th weir when going upstream) and De Haandrik (6th weir, Figure 1) nine days after release just upstream the weir at Vechterweerd and thus passed four fishways during this time span. Total duration for ide that were recaptured at Junne and thus successfully passed two consecutive fishways during 1996 was on average 57 hours (with minimum estimates varying from 0-137 and maximum estimates varying from 15-150 hours).

Individual passage patterns in the telemetric experiment 1998-1999

Of the 13 adult ide released after having passed the fishway at Vechterweerd in spring 1998, 10 approached the weir at Vilsteren, of which one individual had lost its transponder directly under the weir and was excluded from further analyses (Winter & Fredrich 2003, Appendix). Of the remaining nine, six were detected in the fishway. One of these six was detected in the fishway during free-flowing conditions

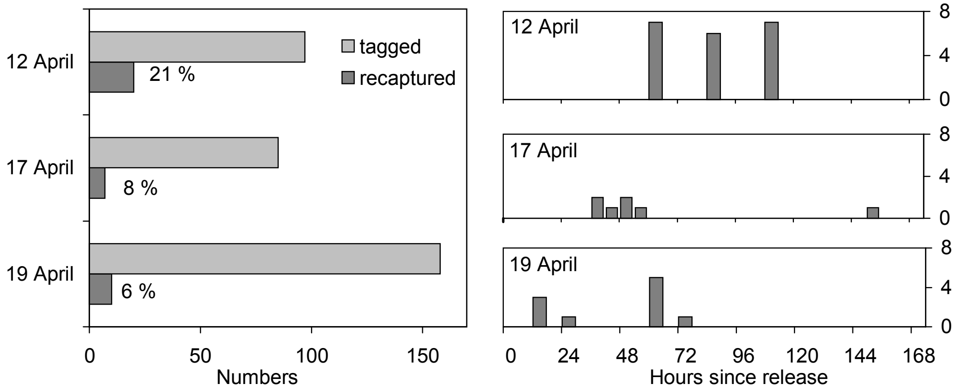


Figure 7.2 *Number of adult ide that have been tagged with VI-tags after passing the fishway at Vechterweerd and released in 1996 (3 batches totalling 340 ide) and the number of tagged ide recaptured after passing the fishway at Junne (left panel). Individual time intervals between release and recapture are given for each of the three batches (right panel).*

for a period of 2 hours. Directly thereafter the same individual was detected downstream of the weir again where it stayed for 11 more days without ever re-ascending the fishway. It was therefore considered not to have successfully passed the fishway although it can not be ruled out that it did pass the fishway and directly thereafter moved downstream again over the weir. Three individuals migrated downstream after the spawning period, one using the fishway and two through the weir gaps (Appendix). One fish re-appeared again in 1999 and successfully passed the fishway, as it did in 1998.

Of the two adult ide released in April 1998 directly downstream of Vilsteren, one left in April directly after release and passed the downstream Genemuiden station. In March 1999, the same individual re-appeared downstream of the weir and resided here until leaving in May to pass Genemuiden again. The other fish was frequently detected throughout April-September directly downstream of the weir (in total 1,629 detections, well over the guaranteed 1,000 detections and thereby potentially having depleted its battery). Although it has been detected in the fishway at six different days (all exclusively in June and well after the spawning season), each time it returned immediately to downstream of the weir. These six days coincided with the only free-flowing event during the entire time this fish was detected. It was therefore considered not to have successfully passed the fishway although it can not be ruled out that it did pass the fishway and directly thereafter moved downstream again over the weir.
Of the 10 adult ide that were released between Vilsteren and Junne directly after spawning, six migrated downstream of Vilsteren, five using the fishway. Of these, three re-appeared downstream of the weir during autumn-winter 1998-1999. They all successfully passed the weir, but because the fishway station was not available for that period, it is unknown whether these fish used the fishway or other pathways (Table 2, Appendix). Another re-appeared the next spring and successfully passed the fishway. These four ides migrated downstream over the weir after the spawning

period. Three fish remained upstream above the weir at Vilsteren during 1998-1999 and were detected during each of the three hand-held trackings. One fish was never detected after release.
Of the 25 adult ide released in lake Zwarte Meer during February 1999, three passed the Kampen station (Fig. 7.1) selecting the River IJssel for spawning, 20 passed Genemuiden selecting the River Vecht and two remained undetected. At least seven approached the weir at Vilsteren, thus having successfully passed through the fishway at Vechterweerd. One fish spent nine days below the weir Vilsteren and was then detected in the fishway under near free-flowing conditions (85 $m^3.s^{-1}$) leaving only overfalls in the two upstream basins, and returned directly thereafter to reside below the weir for another 21 days. It was therefore considered not to have successfully passed the fishway although it can not be ruled out that it did pass the fishway and directly thereafter moved downstream again over the weir. Three fish successfully passed Vilsteren, two using the fishway. The third one was last detected below the weir at free-flowing conditions and must have passed through the weir-gaps because it was detected between Vilsteren and Junne during a hand-held survey in April 1999. All four moved downstream over the weir again after spawning.

Individual delay

The measured individual delay for the nine ide successfully passing at Vilsteren during upstream migrations in 1998 and 1999 was on average 88 hours (range 1 - 328 hours). For four ides passing at Vilsteren the exact delay was unknown. The estimated delay per weir from the mark-recapture data in 1996 was on average 24 hours (range 0-66 hours). Part of the total delay may be caused by the time required to ascend the nine compartments of the fishway. The time spent by individual fish in the three upstream compartments covered by the detection station lasted 2-21 minutes, except for one individual that remained in the detection area for nearly 11 hours.

Table 7.2. *Results of testing 'individual delay' and 'passage success rate' PSR to river discharge (Q_{river}) and the ratio between fishway discharge and river discharge ($Q_{fishway}/Q_{river}$) by linear regression. Different datasets were used for each model: telemetry data of individuals that successfully passed a weir (Tel. succ.); telemetry data of all individuals (Tel. all) and a combined set of tagging and telemetry data of individuals that successfully passed a weir (Tel. + tag). For p<0.05 the percentage of variance explained and parameter estimates for constant β_0 and slope β_1 are given. The models presented are tested for Q_{river}<90 $m^3.s^{-1}$ (i.e. non free-flowing conditions), whereas all models tested for discharge including free-flowing conditions yielded non-significant results (p>0.05).*

Response variate	Explanatory variate	Datasets used	*F*	*p*	Variance explained	Parameter estimates	
						β_0	β_1
Delay	Q_{river}	Tel. succ.	$F_{1,4}$ = 7.94	0.048	58.1 %	- 250	+ 8.2
Delay	Q_{river}	Tel. + tag	$F_{1,38}$ = 61.36	<0.001	60.7 %	- 28	+ 3.7
Delay	$Q_{fishway}/Q_{river}$	Tel. succ.	$F_{1,4}$ = 5.82	0.073			
Delay	$Q_{fishway}/Q_{river}$	Tel. + tag	$F_{1,38}$ = 22.19	<0.001	35.2 %	+ 145	- 1502
PSR	Q_{river}	Tel. all	$F_{1,1}$ = 0.27	0.694			
PSR	Q_{river}	Tel. succ.	$F_{1,1}$ = 5.53	0.256			
PSR	Q_{river}	Tel. + tag	$F_{1,4}$ = 10.32	0.033	65.1 %	+ 0.12	- 0.002
PSR	$Q_{fishway}/Q_{river}$	Tel. all	$F_{1,1}$ = 0.56	0.592			
PSR	$Q_{fishway}/Q_{river}$	Tel. succ.	$F_{1,1}$ = 6.22	0.243			
PSR	$Q_{fishway}/Q_{river}$	Tel. + tag	$F_{1,4}$ = 11.50	0.027	67.8 %	+ 0.0001	+ 1.1

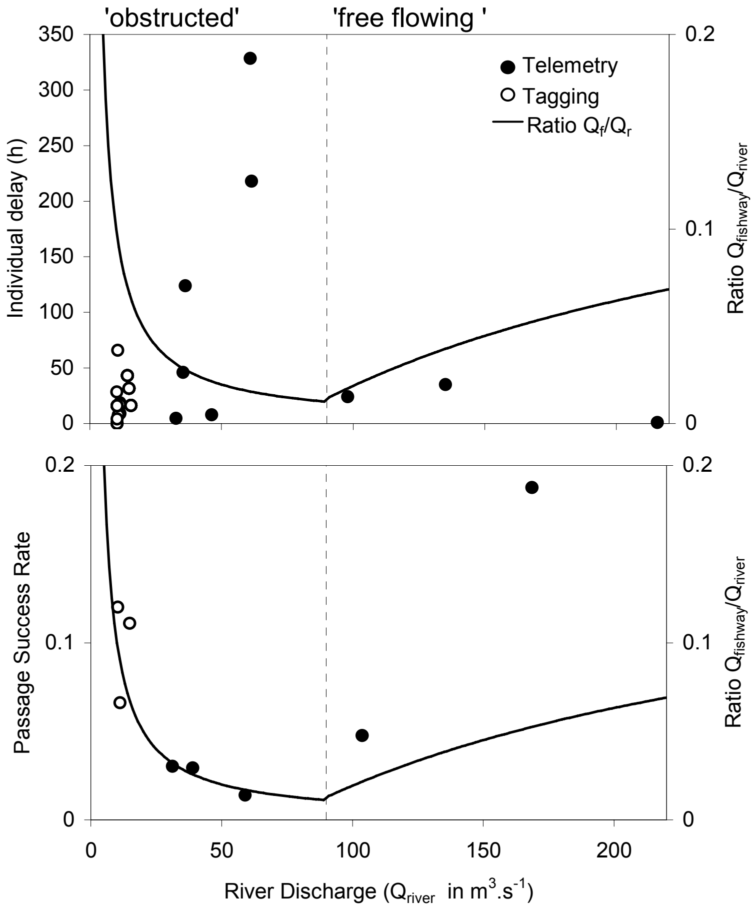


Figure 7.3 *Individual delay of ide directly downstream the weir before successful upstream passage (top panel), and the fraction of visits to a weir leading to successful passage out of total number of visits, i.e. 'passage success rate' PSR, for each of eight discharge classes (bottom panel) in relation to river discharge and the ratio between fishway discharge and river discharge (closed symbols: directly measured with 1998-1999 telemetric experiments at weir Vilsteren; open symbols: estimated from VI-tagging experiment in 1996 for weirs at Vilsteren and Junne. Dotted lines indicate the transition to free-flowing conditions when next to the fishway also the free-flowing weir gap can be used as an upstream passage pathway; the solid line represents the ratio between discharge through the fishway and total river discharge, mainly over the weir).*

Individual delay significantly increased with increasing river discharge for both telemetric data only (Tell.succ.) and including mark-recapture estimates (Tel. + tag) and decreased with increasing ratio fishway/river discharge for the telemetry and tagging dataset (Tel.+ tag) up to the point where free-flowing conditions were reached and passage through the weir-gaps becomes possible (Figure 7.3, Table 7.2). All three individuals passing Vilsteren during free-flowing conditions had relatively small delays, of which one used the weir-gap and two used the fishway.

The eight individuals approaching the weir in either 1998 or 1999 that did not pass (Table 7.1) resided downstream for several days up to six months (Appendix).

Passage of the station at weir Vilsteren during downstream migrations typically lasted only one detection (Appendix). Downstream passage through the fishway was more variable with several individuals passing in less than 4 minutes while others revisited the station up to six times spread over three consecutive days.

Passage success rate
In total, 23 fish were detected to approach the weir at Vilsteren in upstream direction during 1998-1999. Of these, 16 were detected by the fishway station but three of these were again detected downstream of the weir directly thereafter and were considered not to have successfully passed the fishway. This leaves 13 successful upstream passages (57 % of the individuals that approached the weir), of which nine were through the fishway and one passed through the weir-gap under free-flowing conditions. For three the pathway could not be determined. Number of approaches and success rates were similar between years and sexes (Table 7.1).

Success rate per weir visit *PSR* of the successful individuals based on both telemetric and mark-recapture data (Tel. + tag) was significantly decreasing with increasing river discharge and significantly increasing with increasing ratio of flow through the fishway and total river flow for conditions; both with discharge < 90 $m^3.s^{-1}$ only (Figure 7.3, Table 7.2). *PSR* can be predicted directly by $Q_{fishway}/Q_{river}$, since the constant was close to 0 and the slope close to 1, which suggests that number of 'weir visits' as determined in this study is an accurate estimation for number of 'attempts'. Tested models on PSR including only telemetry data yielded non-significant results, where taking all individuals into account resulted in higher p-values than including only successful individuals (Table 7.2). For free-flowing conditions the observed success rate was higher than the ratio predicted. When the number of visits for unsuccessful fish that approached the weir were also taken into account, the telemetric data showed no significant relation with the ratio, neither for all discharge conditions, nor for discharge rates < 90 $m^3.s^{-1}$.

Discussion

There can be little doubt that the construction of fishways in the River Vecht has provided a clear improvement of the opportunities for adult ide to migrate upstream in spring for spawning. During the spring of 1996, high-discharge events resulting in free-flowing conditions did not occur and upstream migration was only possible through the fishways. For the downstream four weirs in the River Vecht this situation occurs in 20% of the years and in the upstream two weirs even in 60% during early spring (Winter & van Densen 2001). In other years, the opportunities for passing through the weir-gaps might be few, as in spring 1998, when only 5 days in April were characterised by free-flowing. Indeed, all ide observed to migrate upstream Vilsteren in that year used the fishway. That adult ide are not only physiologically capable of ascending the strong current through the weir-gaps under free-flowing conditions but also may choose this pathway was proven by one fish in 1999. In the Vecht, the weirs do not present severe bottlenecks for downstream migration. Most ide used the overspilling weirs for downstream passage, although some used the fishways, especially during periods of low discharge in 1998.

Hydraulic conditions within the fishways do not appear to hamper upstream passage based on the observation that some individuals passed the upstream three basins in only a few minutes. This confirms the suitability of this type of fishway for a wide range of species and sizes present (chapter 3). Conditions in the overfalls between basins in the different V-stepped passes along the River Vecht are similar and there is no reason to assume differences in this respect among individual fishways.

Of all ide approaching the weir at Vilsteren in the telemetric experiments at least 57 % moved upstream. However, only 11 % of the ide tagged at Vechterweerd in 1996 passed the two successive weirs and 15 % of the ide tagged in lake Zwarte Meer in 1999 passed the two successive weirs at Vechterweerd and Vilsteren, both indicating a low passage rate per weir. Because the *suitability* of the hydraulic conditions within the fishway can be excluded as a potential bottleneck, the low passage rate must be attributed to one or a combination of the following factors: 1) failing *attraction* leading to the inability of some individuals to locate the entrance; 2) failing *acceptance* leading to avoidance behaviour even though the entrance may have been located; or 3) lack of *motivation* to move further upstream because an suitable target habitat has been reached.

The observed significant relation between delay and the passage success rate per visit (Figure 7.3) on one hand and the ratio of the flows through the fishway and the weir gates on the other suggests indeed that, as often mentioned, attraction flow of the fishway entrance relative to distracting flow over the weir is an important factor in determining passage success. As in many telemetric studies, number of experimental fish are relatively low and some of the tested models are based on few observations. In addition, combining tagging data with telemetry to calculate delay and *PSR* relied on the assumption that patterns do not differ between the weir at Vilsteren and the weir at Junne, and that the tagged individuals carried out an equal number of visits to the weir (attempts) per day of delay as the transpondered fish. Because river discharge in spring 1996 (tagging) was much lower compared to spring 1998 and 1999 (telemetry) this might not necessarily be true, even though the telemetry data indicated no relation between number of visits per day and discharge rate.

Because all 4 individuals that approached the weir at Vilsteren and did not pass were documented to have passed the similar fishways at Vechterweerd, a failing acceptance of this type of fishway can be rejected as a major factor contributing to the low rate of successive passes of the weirs. There are documented examples where acceptance of a fishway, despite good suitability and a motivation to migrate, was the main factor causing low overall efficiency (Aarestrup et al. 2003). However, it is often difficult to distinguish a lack of acceptance of a fishway from a lack of motivation to move upstream (Schmutz et al. 1998).

In contrast to the low passage rate for all ide combined, all five individuals that were observed to use stretches upstream Vilsteren in 1998 and thereafter migrated downstream Genemuiden to return the next year were successful in passing both weirs at Vechterweerd and Vilsteren in both years (success rate 100% over ten passages). Also, one fish residing downstream the weir in Vilsteren during spring 1998 without ever being detected in the fishway, migrated downstream Genemuiden to return thereafter to the same stretch during spring 1999, again without ever being detected in the fishway. If motivated fish would have only a 57% chance of passing a weir in upstream direction depending on discharge rate, at least some of these individuals would have been expected not to succeed in passing the weirs at either Vechterweerd or Vilsteren in one of the two years. It is also noteworthy that three fish visited the upper basins of a fishway temporarily during high discharge conditions when all basins downstream the detection station in the fishway were 'drowned', only to return immediately to an apparently favoured spot downstream the weir. These are obvious cases, where neither attraction nor acceptance plays a significant role.

The broad picture emerging is thus that motivation plays a critical role in determining fishway efficiency for adult ide along the River Vecht. At least some, if not all, of the fish that approached the weir at Vilsteren but did not pass, were clearly not motivated to migrate upstream but in stead selected the downstream area as their target habitat suitable for spawning (Winter & Fredrich 2003). Thus, the number of 'visits' downstream a weir of ultimately passing individuals after first approach would reflect 'searching' behaviour, whereas the number of 'visits' for resident individuals would reflect other 'habitat use' behaviours such as spawning or feeding. The significance of motivation is also indicated by the marked homing behaviour of several of the tagged fish, performing the same migration in two subsequent years and ending up at the same spots.

This interpretation would lead to the conclusion that, although *overall efficiency*, i.e. the fraction of ide approaching the weir that succeeds in passing the fishway, at the population level may be low, the *true passage efficiency,* i.e. the fraction of *motivated* ide that succeeds in passing the fishways at the River Vecht is much higher than 57 %, and possibly close to 100 %. Often studies assume that all fish approaching a barrier are trying to move upstream and therefore potentially yield an underestimation for *true passage efficiency*, especially for potamodromous fish (e.g. Mader et al. 1998, Bunt et al. 1999; Oldani & Baigún 2002). In studies on anadromous species (e.g. Laine et al. 1998, Moser et al. 2002), the assumption that all specimens are motivated is less problematic because no suitable end goal habitats for spawning are generally present below the obstructions investigated.

Although all motivated upstream migrating ide may ultimately pass all fishways, the passage speed appears to be linked to the ability to find the outflow entrance (Figure 7.3). If the number of 'visits' was a good estimate of the number of actual 'attempts', as is suggested by the close fit with the assumed relationship to relative outflow, this would mean that the range over which the ide search for the entrance is larger than the 32 m between the detection station and the weir, also implying that the entrance of the fishway at Vilsteren for adult ide was sufficiently close to the weir. However, hardly anything is known about searching behaviour downstream barriers, although available results suggest that this may strongly vary among species (Bunt et al. 1999, Bunt 2001, Moser et al. 2002a, Moser et al. 2002b).

Unfavourable ratios, and thus discharge rates in the River Vecht may cause a mismatch between time of appearance at the spawning sites and the time window for optimal spawning conditions (Fleming & Reynolds 1991). In extreme situations delay at barriers can lead to the resorbtion of gametes as was demonstrated for Russian hydropower dams (Shikhshabekov 1971). However, ide apparently find suitable spawning habitat in various stretches of the River Vecht and thus migration delays may not cause a major problem. More likely is that delays may affect the ultimate motivation to move on. Also, attraction and acceptance may be strongly linked to the progress of the spawning season and thus to motivation.

The large variation in individual migration patterns highlights that assuming an average migration behaviour for individuals within a population might lead to serious bias in fishway efficiency estimates. One should be aware that a continuum of different behaviours and motivation within the same species may underly observed patterns and estimates.

The importance of the fishway flow in attracting fish motivated to search for a possible upstream passage pathway may have major consequences in large rivers where fishways are situated in side-channels that get only small fractions of the total river flow. Here considerable delays may be expected, up to a level that true fishway efficiency can be reduced as well, especially when a series of fishways have to be passed before reaching suitable spawning habitat. Studying the feasibility of structures or additional measures to guide fish to the fishway in an upstream direction other than by attraction flow, as is commonly used when avoiding turbine-damage for downstream migrating fish (Larinier & Travade 1999), may be helpful.

Acknowledgments

I thank J. Heinen from RIZA for providing the hydrological data, many recreational fishermen for their help in checking the fykenets during 1996, B. bij de Vaate and A. Breukelaar from RIZA for their support, methodological insights, the use of their telemetric equipment and kind offer to make two detection stations temporarily available for this study. Niels Daan and Bram Huisman for valuable discussion and comments on an earlier version of this paper. This study was funded by the Dutch Ministry of Agriculture, Nature and Food Quality.

References

- Aarestrup, K., M.C Lucas and J.A. Hansen, 2003. Efficiency of a natural-like bypass channel for sea trout (*Salmo trutta*) ascending a small Danish stream studied by PIT telemetry. Ecology of Freshwater Fish 12: 160-168.
- Baras, E., H. Lambert and J.C. Philippart, 1994. A comprehensive assessment of the failure of *Barbus barbus* (L.) migrations through a fish pass in the canalized River Meuse (Belgium). Aquatic Lining Resources 7: 181-189
- Breukelaar, A.W., A. Bij de Vaate and K.T.W. Fockens, 1998. Inland migration study of sea trout (*Salmo trutta*) into the rivers Rhine and Meuse (The Netherlands), based on inductive coupling radio telemetry. Hydrobiologia 371/372: 29-33.
- Boiten, W., 1990. Hydraulic design of the pool-type fishway with V-shaped overfalls. Proceedings International Symposium on Fishways, Gifu, Japan. pp. 483-490.
- Bunt, C.M., C. Katapodis and R.S. McKinley, 1999. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. North American Journal of Fisheries Management 19: 793-803.
- Bunt, C.M., 2001. Fishway entrance modifications enhance fish attraction. Fisheries Management and Ecology 8: 95-105.
- Cala, P., 1970. On the ecology of ide *Idus idus* (L.) in the River Kavlingean, South Sweden. Reports of the Institute of Freshwater Research Drottningholm 50: 45-99.
- Calles, E.O. and L.A. Greenberg, 2007. The use of two nature-like fishways by some fish species in the Swedish River Emån. Ecology of Freshwater Fish: doi: 10.1111/j.1600-0633.2006.00210.x
- Fleming, D.F. and J.B. Reynolds, 1991. Effects of spawning-run delay on spawning migration of Artic grayling. American Fisheries Society Symposium 10, 299-305.
- Haw, F., P.K. Bergman, R. Fralick, R.M. Bucley and H.L. Blankenship, 1990. Visible implanted fish tag. American Fisheries Society Symposium 7: 311-315.
- Laine, A., T. Jokivirta and C. Katopodis, 2002. Atlantic salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L., passage in a regulated northern river – fishway efficiency, fish entrance and environmental factors. Fisheries Management and Ecology 9: 65-77.
- Larinier, M. and F. Travade, 1999. Downstream migration: Problems and facilities. Bulletin Français de la Pêche et de la Pisciculture 353/354: 181-210.
- Larinier M., 1998. Upstream and downstream fish passage experience in France. Fish Migration and Fish Bypasses. Jungwirth M., S. Schmutz and S. Weiss (Editors). Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 127-145
- Lucas, M.C. and E. Baras, 2001. Migration of Freshwater Fishes. Blackwell Science, Oxford, UK.
- Mader, H., C. Unfer and S. Schmutz, 1998. The effectiveness of nature-like bypass channels in a lowland river, the Marchfeldkanal. In Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 384-402.

- Moser, M.L., A.L. Matter, L.C. Stuehrenberg and T.C. Bjornn, 2002a. Use of an extensive radio receiver network to document Pacific lamprey (Lampetra tridentate) entrance efficiency in the lower Columbia River, USA. Hydrobiologia 483: 45-53.
- Moser, M.L., P.A. Ocker, L.C. Stuehrenberg, and T.C. Bjornn, 2002b. Passage efficiency of adult lampreys at hydropower Dams on the lower Columbia River. Transactions of the American Fisheries Society 131: 956-965.
- Oldani, N.O. and C.R.M. Baigún, 2002. Performance of a fishway system in a major South American Dam on the Parana River (Argentina-Paraguay). River Research and Applications 18: 171-183.
- Gowans, A.R.D., J.D. Armstrong, J.D. and I.G. Priedle, 1999. Movements of adult Atlantic Salmon in relation to a hydroelectric dam and fish ladder. Journal of Fish biology 54: 727-740.
- Schmutz, S., C. Giefling and C. Wiesner, 1998. The efficiency of a nature-like bypass channel for pike-perch (*Stizostedion lucioperca*) in the Marchfeldkanalsystem. Hydrobiologia 371/372: 355-360.
- Schwalme K., W.C. McKay and D. Lindner, 1985. Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fish. Canadian Journal of Fisheries and Aquatic Sciences 42: 1815-1822
- Shikhshabekov, M.M., 1971. Resorbtion of gonads in some semi-diadromous fishes of the Arakum Lakes (Dagestan USSR) as a result of regulation of discharge. Journal of Ichthyology 11: 427-431.
- Winter, H.V. and F. Fredrich, 2003. Migratory behaviour of ide, *Leuciscus idus*: a comparison between the lowland rivers Elbe, Germany, and Vecht, The Netherlands. Journal of Fish Biology 63: 1-10.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing the opportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.

Appendix *Overview of telemetric data per individual (#), detection sequence (duration given in minutes - m, hours – h, days – d, or unknown -?) and derived information on up- and downstream passage at Vilsteren and selected passage pathways (fw: fishway, wg: weir gaps; unkn: unknown).*

#	L (cm)	Sex	Yr	Sequence of detections at different stations	Weir approach ***	Upstream passage Vilsteren	Downstream passage Vilsteren
Vechterweerd (March 1998)							
1	40.0	f	1998	G(1m)	no		
2	41.3	m	1998	W(24d)	yes	no	
3	49.1	f	1998	W(6d), F(15m)----W(1m)----G(1m)	yes	fw	wg
3	49.1	f	1999	G(3m)---W(7h),F(16m)----Hjun----W(1m)----G(1m)	yes	fw	wg
4	52.2	f	1998	W(2h)----Hvilst (transponder lost)	(yes)		
5	44.3	f	1998	G(1m)	no		
6	44.9	f	1998	W(3d),F(2m)	yes	fw	no
7	49.7	f	1998	W(3d),F(8h)----W(1m)----G(1m)	yes	fw	wg
8	47.0	m	1998	W(10d),F(1m)----F(5h),W(13m)----G(1m)	yes	fw	fw
9	45.3	f	1998	W(2d)----G(1m)	yes	no	
10	42.2	f	1998	W(4h),F(13m)	yes	fw	no
11	49.7	f	1998	W(3d),F(1m),F(2h),W(40d)	yes	no **	unkn
12	48.3	m	1999	Hvechtw	?		
13	42.2	m	1998	W(5h)	yes	no	
Vilsteren-Junne (April 1998)							
14	45.3	m	1998	F(3d)----W(38d)	no		fw
15	41.8	m	1998	F(1m),W(1m)----G(1m)----G(3d)----W(1h)----	yes	unkn	fw
15	41.8	m	1999	Hjun----W(1m)----G(1m)	no		wg
16	45.1	m	1998	F(2d),W(1m)	no		fw
17	46.5	m	1998	W(1m)----	no		wg
17	46.5	m	1999	----W(>12d),F(15m)----W(16d)	yes	fw	wg
18	45.8	f	1998	Hjun	no		no
18	45.8	f	1999	Hjun	no		no
19	41.2	f	1998	Hjun	no		
19	41.2	f	1999	Hjun	no		
20	46.7	m	1998	F(2d),W(4h)----G(1m)----G(3m)----	no		fw
20	46.7	m	1999	----W(?)----W(1m),G(1m)	yes	unkn	wg
21	45.9	m	1998	F(3d),W(1m)----G(1m)----G(3m)----W(1d)----	yes	unkn	fw
21	45.9	m	1999	----W(1m)----G(1m)	no		wg
22	43.3	f	1998		no		
23	50.3	m	1998	Hjun	no		
23	50.3	m	1999	Hjun	no		
Weir Vilsteren (April 1998)							
24	47.8	m	1998	W(1h)----G(30d)----G(43d)----	no		
24	47.8	m	1999	----W(36d)----G(8d)----G(37d)----	yes	no	
25	46.3	f	1998	W(44d),F(8h),W(3d),F(5d), W(>20d)	yes	**	

#	L (cm)	Sex	Yr	Sequence of detections at different stations	Weir approach ***	Upstream passage Vilsteren	Downstream passage Vilsteren
Zwarte Meer (February 1999)							
26	45.8	m	1999	G(7m)----W(9d),F(13m),W(21d)----G(1m)	yes	no **	
27	44.3	f	1999	G(1m)----W(>4d)----G(1m)	yes		
28	45.4	f	1999	G(3m)----W(?),F(19m)----W(1m)----G(1m)	yes	fw	wg
29	48.8	f	1999	G(12h)----G(6m)----W(>7d)----G(1m)	yes	no	
30	45.2	f	1999	G(1m)----G(1m)	?		
31	44.3	m	1999	G(28d)----W(?)----Hjun----W(1m)----G(1m)	yes	wg	wg
32	46.3	f	1999	G(3m)	?		
33	40.8	f	1999	G(7h)	no		
34	40.9	f	1999	G(30d)----G(1m)	no		
35	42.3	m	1999	G(28d)----G(1m)	no		
36	50.6	m	1999	G(6m)----Hvechtw----G(1m)	?		
37	48.2	m	1999	G(16d)	?		
38	42.1	m	1999		no		
39	39.9	m	1999	G(3d)----G(13m)----Hvechtw----G(1m)	?		
40	41.3	f	1999	G(5m),F(9m)----Hjun----W(7m)----G(1m)	yes	fw	wg
41	55.5	f	1999	G(20h)----G(3m)----G(1m)	no		
42	42.3	m	1999	K(4m)----K(1m)	no		
43	47.3	m	1999	G(8d)----Hvechtw----G(1m)	no		
44	40.4	f	1999	G(1h)----G(1m)	no		
45	41.7	m	1999	G(2d)----Hvechtw----G(1m)	?		
46	48.2	f	1999	K(4h)----K(1m)	no		
47	40.1	m	1999	K(2d)----K(1m)	no		
48	53.1	m	1999		no		
49	49.8	m	1999	G(3m)----W(19d)----G(1m)	yes	no	
50	42.0	m	1999	G(2d)----G(3m)----Hvechtw----G(1m)----G(26m)	no		

* Weir Vilsteren (W), Fishway Vilsteren (F), Handheld tracking (H+stretch), Genemuiden (G), Kampen (K) see Figure 1. a "," indicates detections within 1 day, whereas "----" denotes detections after intervals longer than 1 day

** Detected by the fishway station, but directly thereafter detected downstream the weir at Vilsteren: considered not to have passed to upstream, although successful passage of the fishway immediately followed by downstream passage of the weir can not be ruled out.

*** Due to malfunctioning of the detection station downstream the weir Vilsteren during two periods, a potential weir approach can not be excluded (?).

Gemotiveerde passanten

Het type vistrappen in de Vecht bleek goed passeerbaar voor de meeste soorten en maten vis (hfst 3). Maar of deze vistrappen effectief functioneren hangt daarnaast ook af van de fractie vissen die de ingang van de vistrap weten te vínden. Vis oriënteert zich tijdens de migratie met behulp van vele zintuigen en in stromende wateren speelt de richting en sterkte van de waterstroom een belangrijke rol. Vissen die gemotiveerd zijn om stroomopwaarts te trekken worden bij een stuw of dam geconfronteerd met een scala aan waterstromingen in een onnatuurlijke omgeving. Vaak lopen routes waar stroming vandaan komt dood, zoals bijvoorbeeld bij een stuw of bij de uitstroom van een waterkrachtcentrale. De vis moet uit al deze stromingen de vistrap selecteren om succesvol te kunnen passeren. Dit heeft geleid tot de zogenaamde 'lokstroom'-hypothese die stelt dat de relatieve sterkte van de waterstroom uit de vistrap ten opzichte van de andere stromingen de kans bepaalt op het succesvol vinden van de vistrap. Mits deze opening niet te ver van de barrière wordt aangeboden. Echter, over het zoekgedrag van vis bij barrières in relatie tot patronen in waterstroming is nog maar weinig bekend.

Recent ontwikkelde zendertechnieken maken het mogelijk om dit te kunnen bestuderen. In totaal zijn er 50 volwassen windes in de Vecht van een zender voorzien. Bij de stuw te Vilsteren, de tweede in de rij die vis tegenkomt, zijn twee detectiestations aangelegd (zie hfst 6). Eén direct benedenstrooms de stuw over de volle breedte van de rivier en één in de bovenste bekkens van de vistrap. Hierdoor werd bepaald wanneer een winde aankwam bij de stuw en hoe lang daarna deze eventueel de vistrap succesvol passeerde. Daarnaast zijn er 340 volwassen windes die optrokken via de eerste vistrap in de rij (Vechterweerd) van een merkje voorzien. In de fuikenbemonsteringen bij hoger gelegen vistrappen is gekeken welke en wanneer deze gemerkte windes passeerden.

De zender- en merkgegevens werden gekoppeld aan dagelijkse gegevens over de rivierafvoer en de afvoer via de vistrap om de lokstroom-hypothese te testen. De waterafvoer via de vistrappen is constant rond 1 m^3/s in de gestuwde situatie.. Tijdens hoogwater, wanneer de stuwen volledig gestreken zijn, is er nauwelijks nog verval bij de stuw en vistrap. In deze situatie is de 'verdronken' vistrap meer een vrij stromende nevengeul (zie blz 65). Vis kan dan zowel via de stuwopening als via vistrap stroomopwaarts trekken.

Van alle windes die benedenstrooms van de stuw bij Vilsteren aankwamen heeft 59 % vervolgens ook de vistrap succesvol gepasseerd. Aangekomen bij de stuw werden de meeste windes herhaaldelijk terug gezien op het detectiestation benedenstrooms van de stuw. Door elke keer dat een winde het gebied verliet dat door het detectiestation werd afgedekt als een poging tot passeren te beschouwen, kon het aantal pogingen gerelateerd worden aan het aantal succesvolle vistrap passages (de ‘slagingskans’ per poging). Deze slagingskans bleek een sterk verband te hebben met de verhouding in afvoer via de vistrap versus de afvoer via de stuw, waarmee de lokstroom-hypothese lijkt bevestigd. Hoe meer water er in verhouding tot de vistrap over de stuw ging, hoe lager de slagingskans. De vistrap is blijkbaar steeds moeilijker te vinden. Wanneer er echter zoveel water over de stuw gaat dat deze volledig gestreken is, werd de slagingskans weer snel groter. Logisch, want winde kan dan naast de vistrap ook via de stuwopening zelf passeren.

Dit verband werd alleen waargenomen als de analyse zich beperkte tot de pogingen van de uiteindelijk succesvolle windes. Als alle ‘pogingen’, inclusief niet succesvolle windes, werden meegenomen, was het verband niet waarneembaar. Blijkbaar gedragen de niet-succesvolle windes zich anders. Een ander opmerkelijk resultaat was dat de windes die meerdere jaren achtereen bij de stuw van Vilsteren aankwamen, óf nooit de vistrap passeerden (maar wel altijd via de eerste vistrap waren opgezwommen) óf in beide jaren de vistrap passeerden. Bij een kans van 59% op succes zou je ook een aantal windes verwachten die het ene jaar wel succesvol zijn en het andere jaar niet. Een verklaring hiervoor zou zijn dat niet alle windes die aankomen bij de stuw ook verder stroomopwaarts wíllen trekken. Een deel van de windes zou de relatief snelstromende leefomgeving direct beneden de stuw als einddoel kunnen selecteren om te paaien. Dan zou de werkelijke efficiëntie van de vistrappen veel hoger zijn dan de 59 % die het op het eerste gezicht is. Het bepalen van de motivatie van vis is echter op zijn minst zeer uitdagend zo niet vrijwel onmogelijk.

River Vecht / de Vecht

8

Synthesis

Migratory opportunities over incomplete barriers

Upstream migration of fish in the River Vecht after the construction of the barriers but before the fishways were built was only possible to a limited extent: only 10 of the 32 species recorded were assessed to be able to ascend in 5-30% of the years (chapter 2). The opportunities for upstream migration were highly dependent on both river discharge and water temperature. High discharge events lead to lowering of the weirs and provided windows of opportunity for upstream movements. Whether fish could use these windows depends on their swimming capacity, which is related to their size and to water temperature. Unfortunately for the fish, the chances on meeting high discharge events were largest in early spring when water temperatures, and hence swimming capacity, were lowest (Fig. 8.1). This paradox applies to many temperate rain-fed rivers: at times when windows for upstream migration occur many fish can not use them because of reduced metabolic rates, while overflows are largely absent when the fish have maximum sprinting capacity.

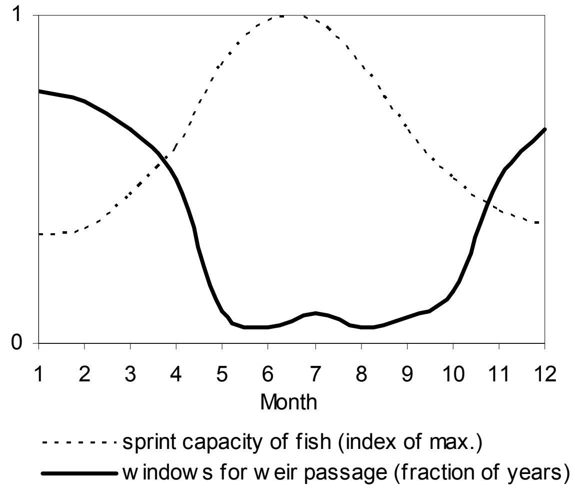


Figure 8.1 *The migration-window/sprint-capacity paradox at incomplete barriers for the weir at Vechterweerd: sprinting capacity doubles for each 10 oC increase in water temperature, but unfortunately most migration windows occurred during the winter months when high discharge events were more frequent and water temperatures low only allowing sprints at ca. 1/3 of the summer capacity, when windows are very few.*

The possibilities for upstream movements can be readily assessed from daily hydrological data series (if these have been collected by the responsible authorities) and from species specific knowledge on sprinting capacity (Box 8.1). Of course, this approach could gain precision if more species–specific data on the swimming capacity were collected. However, whether and to what extent fish actually use these windows to pass the barriers is less known, because there may also be behavioural constraints. The telemetry experiments clearly showed that adult ide do pass the free-flowing weir-gaps (chapter 7). But for how long can fish wait for a window to occur? During which time of year will different species move upstream and which life stages are involved? It is therefore relatively easy to assess if a fish could physically pass a barrier, but whether a fish actually will actually do so requires much more measurements and knowledge. Therefore, the type of barrier assessment followed in Box 8.1 will only yield maximum windows of opportunity for fish migration, but not the degree to which migration actually took place before fishways were provided. Studies aimed at direct measurements of fish passing incomplete barriers are usually performed with telemetry experiments in relative small streams and rivers (Lucas & Batley 1996, Lucas & Frear 1997, Oviedo & Philippart 2002, Geeraerts et al. 2007).

Box 8.1 'SprintFish': a tool for calculating the passage capability of fish

Erwin Winter and Eric Visser

Why did we develop this tool?

Water control in the Netherlands has led to many barriers in waterways that obstruct free movement of fish. The implementation of the EU Water Framework Directive will enforce enhancement of degraded fish communities. Better connectivity in highly fragmented water systems should result in a higher ecological quality, provided that the water quality is adequate. Ongoing efforts involving large investments are taken to mitigate the effects of dams, weirs and sluices by constructing fishways or searching for 'fish-friendly' solutions in water-management. Unfortunately, in most cases the hydraulic aspects of designing technical solutions are calculated or simulated in great detail, whereas the suitability for passage of different fish species and sizes, for which these solutions are meant, are often only based on a few rough assumptions, such as the common practice of setting a maximum water velocity of 1 m.s-1 for fast swimmers and 0.5 m.s-1 for slow swimmers. We can do better than that and developed a simple modeling tool freely available on internet that can calculates the ability for each fish species and size occuring in our freshwaters to ascent a given water velocity over a given distance at a given water temperature. With this tool different scenarios or designs can be compared for various target species, life stages or seasons, but also for already existing barriers the opportunities for ascent can be assessed for the whole range of fish species.

What is it based on?

We used the general relationship between sprint capacity, fish length and water temperature found by Videler & Wardle (1991), combined this with the approach and review on swimming data on freshwater fish occurring in the Netherlands as described in Winter & van Densen (2001). Water temperature plays an important role in the sprint capacity of fish: the burst swimming speed will double with each 10 °C increase in temperature. So there is a big difference if a stickleback wants to pass a strong current in February or in June. We developed a model within a web-application (Java Applet) freely available on internet for everyone to use.

Where to find and how to use it?
This tool can be found on the IMARES website (www.imares.nl) and search for 'SprintFish' or use this link http://orca.wur.nl/sprintfish/ to go to the program directly. The input window requires only three parameters to be filled in: 1) water temperature, 2) distance to be covered by sprinting, 3) water velocity that has to be conquered. The model then calculates for each length per species whether they can pass under the given conditions or not.

For what can this tool be used .... and for what not?
This tool can be helpful when designing fishways, sluices, spillways or other constructions in waterways that lead to higher water velocities over small stretches. Not only structures or barriers that fish are motivated to pass to get upstream, but also the ability to escape from hazardous structures like inleds of hydropower stations or cooling water intakes can be calculated. This might help to search for the best functional and cost-effective way of minimizing the damage or negative effects or maximizing the positive effects for fish tailor-made to the specific location.

Furthermore this tool can be helpful to assess the opportunities for passage of already existing structures. For example, hydraulic conditions at weirs greatly vary in time and throughout the seasons depending on the discharge. At high flows weirs are mostly lowered resulting in free-flowing conditions that fish might be able to pass. Exactly when these 'passage windows in time' have occurred, what the water velocities through the lowered structures were and over what distance they required to sprint is often known by the water authorities or can be derived accurately for each event in retrospect and thus the model can provide a bottom-up approach to estimate the impact for fish.

Besides these water management orientated exercises, it can also be used for biological research purposes like escapement from predators.

Of course a simple tool like this has its restrictions. It can only calculate situations where fish will use sprinting and not for instance when they switch to endurance swimming or use jumping to pass a very small stretch of highest water velocities. In situations where relatively low water velocities have to be conquered over longer distances, sprinting will not be the first option for fish, because they are careful to use this last resort action. If endurance might be a better option than sprinting as derived from the fill in parameters, SprintFish will warn you for this with a message. This tool is only meant to enable assessments based on more precisely determined capabilities of fish to deal with conditions. For a full assessment of the impact of barriers, often additional expertise on fish is needed, such as the role of migration for certain populations, the timing of movements and which life-stages are involved. Nevertheless we hope that this tool will enhance a better incorporation of the specific requirements and abilities of the different fish species when searching for the best 'fish friendly' solution or management.

How efficient are fishways in improving opportunities for migration?

Although the V-stepped fishways as widely used in the Netherlands proved suitable for a broad spectrum of species and sizes (chapter 3), the question remains which part of the fish approaching the weirs with the intention to move further upstream succeeded to do so, because the catch at the exit of the fishways may only have been a fraction of the downstream aggregation. Different approaches and definitions have been used to describe the effectiveness of fishways (Larinier 1998, Lucas & Baras 2001, Aarestrup et al. 2003). Based on this literature supplemented with our findings of the telemetric studies on ide (chapter 7), Figure 8.2 provides a conceptual framework that summarizes and defines the factors and behavioural decisions related to the fraction of fish that is successful in passing barriers. These involve more than just the suitability of the hydraulic conditions in the fishway itself. There are other behavioural decisions involved when fish attempt to cope with these quite unnatural situations. First they have to be able to locate the entrance of the fishway. This may be hampered by other distracting flows over or through the barrier that provide no possibility for passage and the fish may become 'trapped'. The ratio in discharge between the fishway and other competing flows thus appears to be an import factor. However, the exact cues for orientation and searching behaviour in relation to locating the appropriate 'attraction' flow are still largely unknown. Presumably these are related to water velocities (rheotaxis), but the suitable range of velocities that would be suitable to offer is still subject to experimental studies that involve modifying the entrance by trial and error (Bunt 2001, Moser et al. 2002, Katapodis, 2005).

Next, also the acceptance of the fishway as a suitable pathway plays a role. Studies documenting failures in acceptance, even though the fish were considered physically capable of passing, are few (Aarestrup et al. 2003, for sea trout in Denmark; Schmutz et al. 1998, for sander in Austria). However, detecting fish in the entrance that do not pass subsequently is not necessarily a failure of acceptance. It is generally difficult to distinguish between fish that are motivated to move upstream and those that don't. They may simply select the available downstream habitats for other reasons. For instance, fish may feed on the fish aggregating there, or may find suitable spawning areas where water flows faster and or where (artificial) hard substrates prevail (perhaps resembling end-goal habitats present in the more upstream parts of river basins. Or fishways may simply partly limit dispersal of species for which migration is not an essential element of their life history. In the River Vecht, there were a few species that do not seem to accept V-stepped fishways with overflowing overfalls as a means of dispersal, such as sander and flounder (chapter 3). In recent years, three V-stepped fishways have been built in the Dutch part of the Rhine with a new design that included a vertical slot down to the bottom in the middle of the overfall. Here, sander were observed to pass (Winter 2006), whereas not a single sander has been observed to ever pass any traditional V-stepped fishway on the River Vecht (chapter 3). For the River Vecht, it seems also likely that under cold conditions the hydraulic conditions still pose constraints to small-bodied, early migrating species like smelt and three-spined stickleback (chapter 3) .

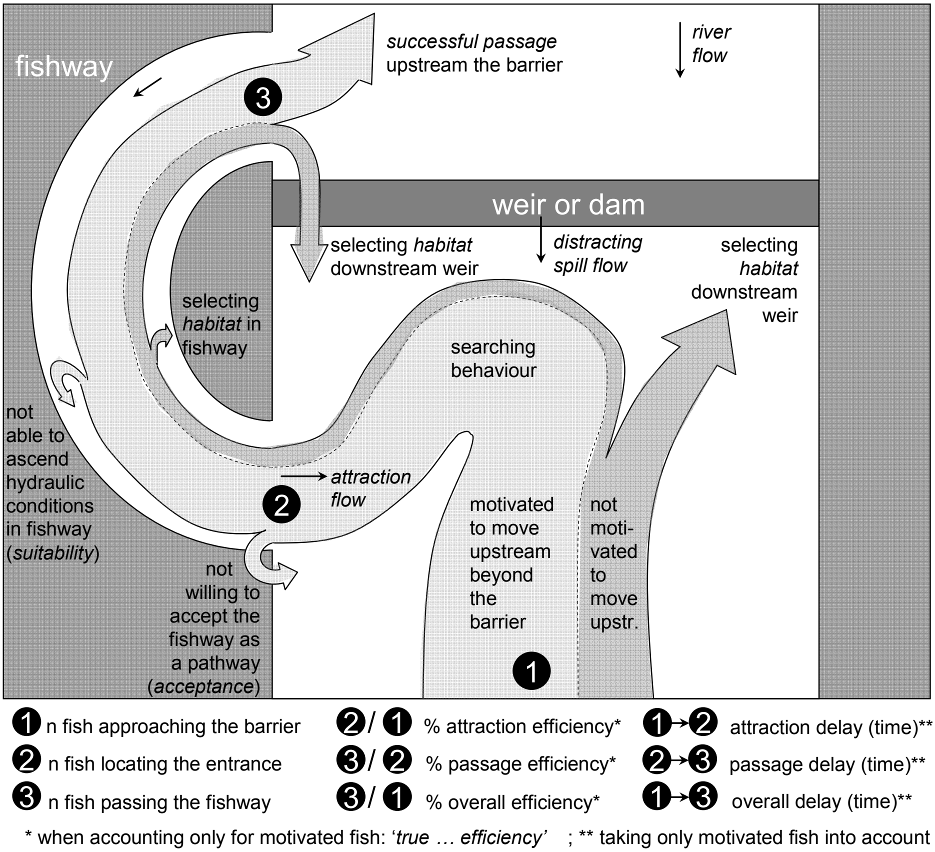


Figure 8.2 *Conceptual framework for determining the efficiency of fishways in bypass-channels. Behavioural decisions and the internal drive to move upstream (motivation) play an important role. For potamodromous species, overall efficiency is easily underestimated if a (large) part) of the fish select habitats downstream in the vicinity of the weirs.*

How fish behave downstream of obstructions is an important feature in determining efficiency, in designing appropriate solutions and in providing clues as to whether fish are motivated to pass. In many studies, all fish approaching weirs are considered to be motivated, but this is definitely not always the case (chapter 7). Especially for potamodromous species it is notoriously difficult to distinguish between the two states (motivated or not motivated), but in practice also shifts in motivation might occur depending on their maturity stage. During the initial stage they may actively search for migratory pathways but if they meet delays along the way, fish might settle for suboptimal habitats situated downstream barriers. With the increasing use of more 'natural' fishways or bypass channels, fish may also select these as their target habitats for whatever the reason was for their movements (Knaepkens et al. 2006). In fact, ide (chapter 7) and sea lamprey (Winter 2006) have been observed to pass the fishway and move to habitats downstream the barrier directly thereafter. All such behaviours obscure the underlying 'true' efficiency of fishways, which is presumably higher than indicated in studies based on the more traditional assumption that all fish approaching fishways are motivated to move upstream. A detailed knowledge of the behaviour of fish may lead to better designs and a close cooperation between hydraulic engineers and fish biologists remains needed.

Ideally, fishways should provide for upstream (and downstream) passage throughout the year. In this study, the focus of the monitoring was on the spring when pre-spawning migrations of most fish were assumed to take place (chapter 3). However, the telemetry data on ide (chapter 6 and 7) and other year-round studies (Prignon 1998; Travade et al., 1998) show that many species migrate upstream in other seasons as well, especially in autumn. Juvenile fish of many fish species have also been observed to use fishways (chapter 3, Mader et al. 1998), but relatively little is known on when and in what numbers they perform upstream movements. Also, eventual bottlenecks for autumn migrating species in the River Vecht, such as river lamprey and houting, are still unrevealed.

An important issue in year-round functioning of fishways is maintenance, especially regarding floating debris. Lack of maintenance may severely hamper their functioning (Larinier 1998). V-stepped overfalls in general are not that susceptible to floating debris, although sometimes debris can linger in their standing waves for extended periods, potentially hampering their functioning

Although we focused on fish, other taxa use the fishways as corridors as well, such as American crayfish (chapter 3). In the V-stepped fishways with vertical slots in the Rhine, hundred-thousands of wool-hand crabs were observed to migrate upstream (Winter 2006).

Effectiveness of fishways in restoring fish communities

As a first step in evaluating the functioning of a series of fishways with regard to the riverine fish community, Fig. 8.2 might help in developing a bottleneck assessment by addressing potential failure factors for the different species and life stages. Determining the different efficiencies, and preferably the 'true efficiencies' that take only the motivated fish into account, is an important aspect. Although the focus of many research programs is usually on a particular site, a series of fishways may still pose a severe problem to long-distant migrants because of the multiplicative effects of the fractions successful and associated temporal delays, even if the true efficiencies are fairly good. The results of monitoring upstream passage at subsequent fishways in the River Vecht show a strong decrease in numbers passing (chapter 3). Whether these fish have found end-goals habitats on stretches in-between weirs or whether this pattern was caused by a low true efficiency is still inconclusive. For adult ide, the true efficiency is presumably much higher than the observed overall efficiency (chapter 7). Although this observation was based, as in most telemetric studies, on relatively few individuals, this may also apply to other fish species in the River Vecht. The absence of large aggregations of fish directly downstream of the weirs as have been observed in the 1970s supports this conclusion. (chapter 4).

The true efficiency can be best studied with telemetry, particularly if a detection station is situated in the entrance of the fishway as well, to distinguish attraction efficiency from passage efficiency. Small-bodied species and life-stages are more difficult to study. Increasingly, the use of PIT-tag telemetry is applied to cover smaller species, but because of the limited detection range (Aarestrup et al. 2003), are restricted to small and shallow streams.

Determining the increase of migratory opportunities by the construction of fishways compared to the former situation is irrelevant in case the barriers (such as large hydropower dams completely obstruct any migration. For the River Vecht, Fig. 8.3 provides a general picture of the annual patterns in various factors contributing to improved conditions.

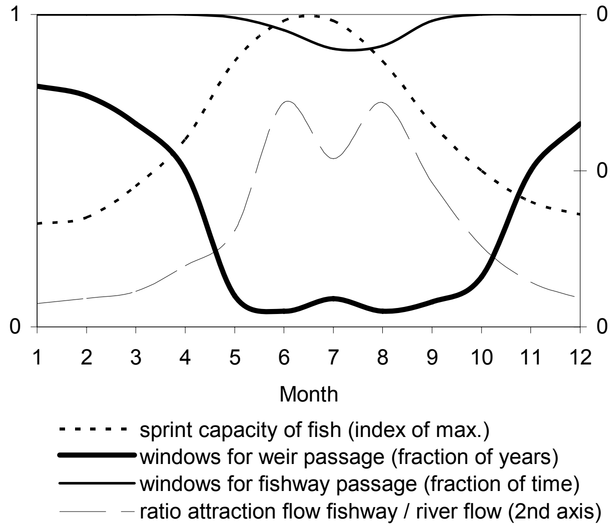


Figure 8.3 *Seasonal patterns in the sprinting capacity of fish, the occurrence of windows for weir passage during high discharge events, extended with the windows for fishway passage (only reduced during dry summer periods resulting in suboptimal functioning fishways), and the ratio between the attraction flow through fishways and the discharge flow over the weir. The windows-sprint paradox is leveled out by fishways: they perform best when sprinting capacity is high and attraction flow ratio's are highest during late spring to early autumn, when previously no migration could take place. During the winter months, fishways are expected to function less because of reduced sprinting capacity and a lower attraction-flow ratio.*

When zooming in on species, specially early migrating small migrants (e.g. three-spined stickleback) are still hampered in their migration because their swimming capacity is too low at this time of year to use either the fishways or the free-flowing conditions (chapter 3, Fig. 8.4) . Species migrating later in spring (e.g. roach) have benefited most because previously few opportunities were available,. Early migrating strong swimmers (e.g. ide) have always had opportunities during at least part of the years, and therefore the improvements are less than for late-spring migrants (Fig. 8.4).

Ultimately, fishways are constructed to restore riverine fish populations and communities rather than just facilitating fish migration (Gherke et al. 2002, chapter 4). To allow for this broader evaluation, the pre-fishway situation should be well documented in terms of the abundance of individual species and the composition of the community. Unfortunately, many evaluation studies are seriously hampered by a lack of reliable time-series data and this applies to the River Vecht as well (chapter 4). Thus, only relative shifts in abundance by species could be determined, but it is not clear whether the overall abundance of fish has increased or has remained the same.

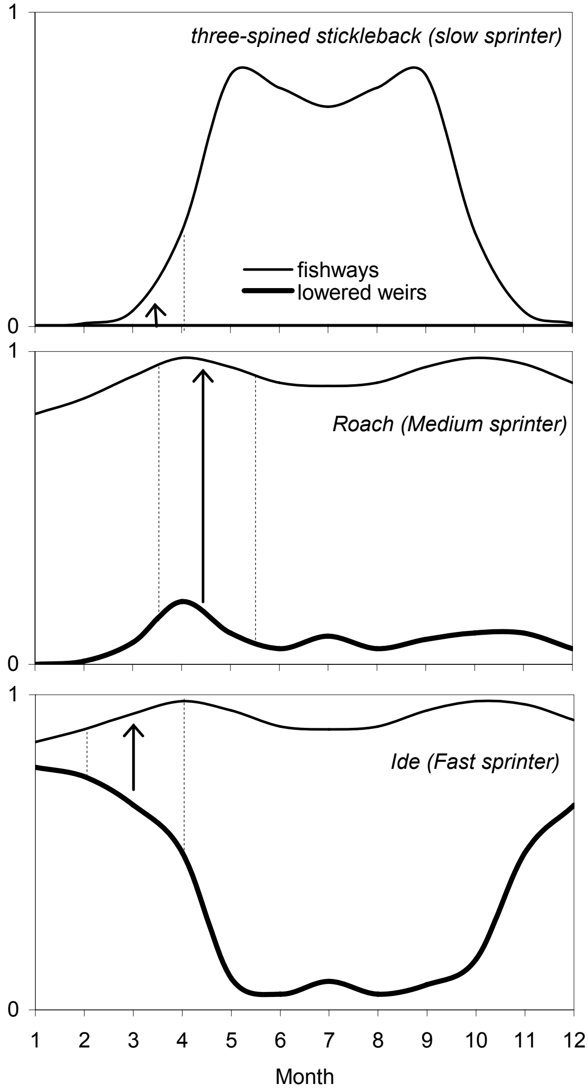


Figure 8.4 *Migratory opportunities during the period before fishways were constructed (only through lowered weirs) compared to the opportunities after the fishways were constructed for three different species: the early migrating and slow-sprinting three-spined stickleback (top), the late-spring migrating and intermediate-sprinting roach, and the early migrating and fast sprinting ide. Areas between the dotted line indicate the respective migration seasons of the species. The improvement of migratory opportunities is indicated by arrows.*

Another problem in evaluating the effects of fishways is to disentangle those of other factors acting simultaneously upon regulated rivers, such as water quality, fisheries, introduction of new species, and hydropower plants. The complex of human impact on aquatic ecosystems makes it notoriously difficult to determine the effect of each factor separately (cf. Dekker 2004) and to assess the effect of measures taken. Most monitoring and evaluation studies of fishways concern a single river or site without paying much attention to other factors affecting the community. Moreover, the results are often only available in local reports and not readily available. If these were published more widely, meta-analyses could be performed based on more general principles regarding type of fishway used and their efficiencies. Such analyses should have more distinctive power in disentangling other factors.

The functioning of a fishway in relation to the importance of migrations in a species may also be described by the 'relative fishway use': the relative abundance of a species/life stage in a fishway passage compared to the relative abundance in upstream river stretches (chapter 4). Ideally, relative fishway use should be based on year-round monitoring, because monitoring during a restricted period may lead to bias. Electrofishing survey data are commonly available for many river systems, and thus relative fishway use based on fishway monitoring and electrofishing is a widely applicable approach that should enable standardized comparisons among different rivers. Comparing species-specific relative fishway use among systems may make it possible to distinguish fishway functioning from the role that fish movements play during different life stages and to identify the environmental factors affecting the functioning. Since a wealth of data has already been collected, appropriate meta-analyses might contribute considerably to our understanding of the effectiveness of fishways in restoring fish communities.

Putting rehabilitation measures in perspective

To indicate how far the current fish community of the River Vecht after various rehabilitation measures still deviates from the natural situation (chapter 5), we used all available (often anecdotal) historical information as well as a suitable geographical reference river as a crosscheck. This combination allows to address the many uncertainties involved in the two approaches separately. The degree of validation for the local situation depends on the quantity and quality of historical data as a reference for the original situation in regulated rivers is usually poor due to the long history of human impact before any rehabilitation measures were taken (Wolter et al. 2005). On the other hand, the data available may help to validate the appropriateness of the reference river.

Of course, restoring connectivity is important in highly fragmented regulated rivers, but given the severe changes that many lowland rivers have undergone and the habitat loss that has taken place, no miracles may be expected from the construction of fishways. Even if these function adequately and are designed for the local conditions and taking into account the biology of species present, improved connectivity can only yield a rehabilitation of riverine fish communities if there are habitats available to be connected. Although connectivity in the River Vecht undoubtedly has greatly improved (chapters 2, 3 and 7), the changes observed in the community were relatively modest (chapter 4). The large deviation of the current community from the 'reconstructed' community is most likely related to the homogeneity of regulated-river systems and the associated loss of suitable riverine habitat. This is for instance illustrated by the strong preference of 0+ ide for shallow sand banks (Box 8.2), which is nowadays a rare habitat, while these were present at a large scale in historic times. Thus, nursery habitat may limit the carrying capacity for juvenile ide, and thus recruitment and population size. Although relative abundance has been improved after the construction of a series of fishways (chapter 4), present abundance appears to be well below historical levels (chapter 5, Box 8.3).

Box 8.2 Young-of-the-year ide prefer shallow sandy shores as nursery habitats

Electric fishing surveys were performed in August 1996 and 1997 along the entire Dutch stretch of the River Vecht (chapters 4 and 6), during which samples of 300 m shore length were taken (40 and 75 samples, respectively). For each sample,, bottom and shore substrate was classified according to five classes, shore length with vegetation (helophytes or terrestrial) in direct contact with water in five classes, and area covered by submerged or floating macrophytes in four classes. Catches of ide were split in 0-group and 1+ group based on the non-overlapping length distribution.

Generalized linear models (GLM) were used to test variance in numbers per sample explained by different class parameters. To meet the assumptions for analysis of variance, catch data were natural-log transformed (Sokal & Rohlf 1995). The model used was:

$$C = \mu + BS_j + SV_k + AV_l + \varepsilon_{jkl} \qquad (1)$$

where C is predicted catch per sample, μ is mean catch per sample, BS_j is bottom and shore substrate (j=riprap, riprap/sand, sand, sand/silt, silt), SV_k=shore vegetation (k=<10%, 10-50%, 51-90%, > 90 %), AV_l=aquatic vegetation (l=0 %, 1-20 %, 21-50 %, > 50 %) and ε_{jkl} is an error term. Any non-significant term (α=0.05) was excluded and the model was refitted with the remaining terms. Residuals were checked by the Wilk-Shapiro test of normality.

For 0-group ide, a strong preference was found for shores with a sandy substrate (Fig. 8.5) (F=76, df=1, p<0.001). The higher abundance in 1996 resulted in a 'spreading out' to the riprap and silt, which suggests a spill-over to suboptimal habitats. Shore vegetation and aquatic vegetation proved insignificant and were therefore omitted from the model. Riprap covered 66% of the shore length in the mainstream, riprap/sand 24%, sand 4%, sand/silt 4% and silt 2%.

Young-of-the-year ide clearly preferred shallow sandy shores as nursery habitats over the more abundant riprap shores reflecting the current condition of the regulated river. The absence or presence of vegetation appears to play no role in its preference.

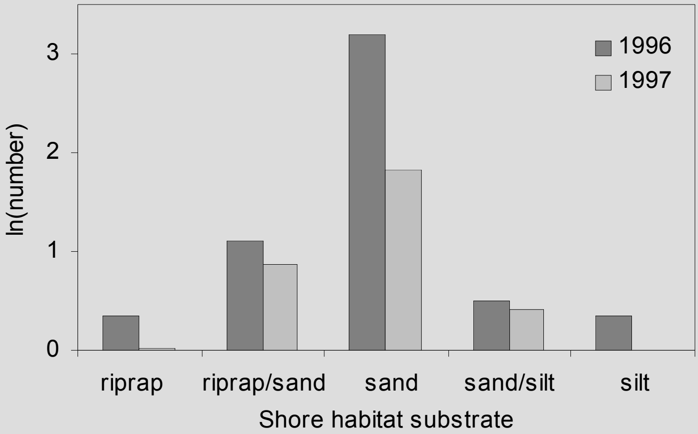


Figure 8.5 *The average natural log-transformed numbers (n/300 m stretch) of 0-group ide per shore substrate class during the 1996 and 1997 August and October electrofishing surveys. The strong preference for sand substrates is highly significant (p<0.001).*

Riprap shore / Steenstortoever

Sand shore / Zandoever

Box 8.3 Historical occurrence of ide in the Vecht region

Before the large rivers in the Netherlands were subjected to numerous regulatory works (construction of dikes, levees, groynes, weirs, sluices, hydropower stations, loss of flood plains) and the estuaries were closed off by dams (Zuiderzee in 1932, Haringvliet in 1970), the Rhine-Meuse delta must have been a suitable habitat for large ide populations. This is supported by the few historical records available (van den Ende 1847, 1849, Redeke 1941). Commercial landings from Lake IJsselmeer gradually decreased from 7 tonnes in 1935 to 2 tonnes in 1940 (unpublished data Havinga 1944).

When examining old written sources, one should be aware that chub and ide have often been confused by the use of the local name 'meun' for both species. In the southern provinces, 'meun' usually refers to chub, whereas in the northern provinces 'meun' refers to ide. An example of this confusion was given by the professional fisher Timmerman from Genemuiden who told me that before 1932 his father caught huge numbers of ordinary 'meun' (ide) in the Zwarte Meer and Vecht-IJssel delta, but only rarely saw a real 'meun' (chub). The large amounts of chub caught according to Redeke (1941) around the 1900s in the former Zuiderzee estuary near Vollenhove were in fact ide.

In the 1850s, ide migrated in large numbers during late winter and early spring from the Zuiderzee upstream into the IJssel, closely followed by massive numbers of smelt Osmerus eperlanus. This phenomenon led to the belief among fishers that the 'ide was trying to escape from the chasing smelt' (van den Ende 1847). Because the species does equally use feeding grounds in brackish water (Cala 1970), abundance has presumably been high when the Dutch delta was still relatively undisturbed, and also in the many smaller rivers, streams and brooks that discharged in brackish waters. The overview by Welcomme (1988) incorrectly mentions the ide as a non-native species in the Netherlands (introduced around 1900s), while it has in fact always been a typical species for the Dutch delta and its river system.

Implications for management

With the implementation of the European Water Framework Directive and the Habitat Directive, the need for restoring connectivity and defining natural references will only increase further. The assessment of migration opportunities in incomplete barriers appears to be relatively easy and the tools and approaches presented here could be applied more widely in evaluation studies. Unfortunately, budgets for restoring connectivity are usually totally consumed by expensive construction works, leaving little room for ex-post monitoring the post-situation, while ex-ante studies are almost non-existent. This leads to a restricted learning-by-experience process and ultimately may be more expensive by constructing suboptimal solutions that have to be adjusted subsequently.

The attraction-flow hypothesis, as confirmed for ide in the River Vecht (chapter 7), implies a severe problem in large rivers, where discharge through the fishway can only be a small percentage of the total flow. In small rivers finding the entrance should not be much of a problem. If the entrance is located nearing the direct vicinity of the barrier, the attraction flow will usually be noticed by fish moving up to the barrier.

Therefore, in large rivers extra measures need to be taken to improve the effectiveness of fishways. Potential solutions include:

- Increasing ratio attraction flow/discharge flow by increasing the size of the fishway;
- Constructing two fishways on either side of the barrier;

- Weir management to attract more fish to the fishway (usually separately adjustable weirs in series next to each other giving opportunities to 'play' with flow.
- Guiding devices in upstream direction (until now absent, although widely used by hydropower plants to avoid fish kills in turbines during downstream migrations). Guiding fish also upstream by structures or adjusting underwater topography is still an unexplored field of expertise.

For fishways to be effective in terms of the total fish community, broad target efficiencies should be stated for the different components:
- Diadromous species: they should aid passage of the entire population with minimal loss of true efficiency;
- Potamodromous species: they should allow migrations and exploratory movements, but not always necessarily at maximum efficiency; only when a large proportion of the population depends on migrations;
- Resident species: they should enable dispersal, recolonization and gene flow between local populations to avoid inbreeding, presumably at relatively low efficiency rates, notwithstanding that the fishways need to be suitable for passage of a broad range of species and life-stages.

Beyond doubt, the best rehabilitation measure is removing the barriers completely and letting rivers take back their natural course. But this option may not be possible within the constraints of for instance shipping or safety against flooding. However, this option should not be neglected before considering fish passage solutions.

Final remarks on the need for connectivity

Movements between habitats plays an important role in many fish species and life stages. Depending on the character of such movements they are usually classified as 'migration' (involving periodically alternating directed movements comprising a large proportion of the population to fulfill specific life history functions) or 'dispersion'(involving individuals performing undirected movements), although definitions vary among scientists (Lucas & Baras 2001). Movements may involve different life stages depending on life history strategies, and be in upstream, downstream or lateral directions:
- Eggs drifting downstream with currents;
- Fish larvae moving downstream, where drift may not be as passive as commonly thought (Reichard et al. 2002);
- Juveniles were formerly assumed to predominantly perform downstream movements, but also upstream migrations take place, but there is increasing evidence (Mader et al. 1998, Lucas & Baras 2001, chapter 3) that juveniles perform much more upstream movements than previously considered. As yet, the role of juvenile migration and the fraction of the population involved remains largely unknown for many species;
- The typical pattern for anadromous and catadromous fish is for adults to migrate upstream and downstream, respectively, for spawning, and for juveniles to migrate in the opposite direction. However, adults of pomatodromous may show very different individual patterns, more often along a continuum than following a few alternative strategies depending on where their target areas are located.

With the increasing use of telemetry, the picture emerges that individual behaviour patterns of migrating fish species are much more variable than thought of before, although the patterns are sometimes remarkably robust from year to year for individuals (e.g. chapters 6 and 7). On the role of learning and experience in fish behaviour much remains to be learned by us as well. Behavioural studies often yield surprising results (Box 8.4, Box 8.5), which only underlines how little we know on individual behaviour and which decisions fish make. In fact, fish are still often treated as uniformly programmed 'robots' acting on instinct. As a consequence, conclusions drawn at the population level by assuming some underlying average behaviour of individuals might be completely different from the outcome of a continuum of very different behaviours in reality. In fact, sampling might easily give a biased picture of population behaviour, because catch probabilities for the sampling method chosen (e.g. fykenets, active gear or selection of sampling locations) may strongly differ between individuals showing different behaviour. For example, if discharge rates would have been lower during spring 1998, enabling continuous fishing with fykenets at the exit of fishways (catching the then assumed 'all migratory' adult ides), probably a sufficient number of ide would have been caught to implant all available transponders. However, additional electrofishing was needed to catch more ide. Among these, some showed resident behaviour that would not have been detected if sampling was restricted to the fykenets. The differences between these two samples would not have been detected if the original research plan could have been followed.

Box 8.4 Local knowledge on a large scale?

Ide appears to be a flexible species in terms of migration patterns, ranging from individuals that are virtually resident to individuals migrating over distances > 200 km. However, for those individuals that could be followed for several consecutive years, patterns were fairly rigid. Each individual appears to adopt its personal migration pattern that is repeated in subsequent years. One may speculate about the origin of the large variation among individuals, but given its character of a continuum rather a bimodal distribution, a genetic origin appears less likely (other than perhaps regarding more risk-taking individuals versus more conservative ones). Rather these patterns may gradually evolve during the life history of an individual by a combined process of learning by trial and error where suitable habitats may be found in different seasons and homing to those areas that have proven suitable during the previous season. Thus, the learning would be largely restricted to the juvenile stages, whereas the behaviour of mature individuals might be become more habitual. The basis for establishing fixed individual migration patterns must lie in good navigational skills to relocate favourable habitats located previously. Which cues they use for navigation is unknown, but navigational skills are not uncommon among fish (particularly the long distant migrants such as salmonids).

A fine example of the navigation skills is given by a female ide that was transpondered in February 2004 in the Amer (Fig. 8.6). After release, it moved upstream into the River Meuse during the spawning season. Then it swam back to the Amer, turned right into the Waal, left into the Pannerdens Canal and right again into the IJssel. After passing Kampen it headed for lake IJsselmeer. After this detour, it swam back the entire (onlogical upstream-downstream) route with at least 10 different 'decision'-confluences within a few days (De Leeuw & Winter 2006).

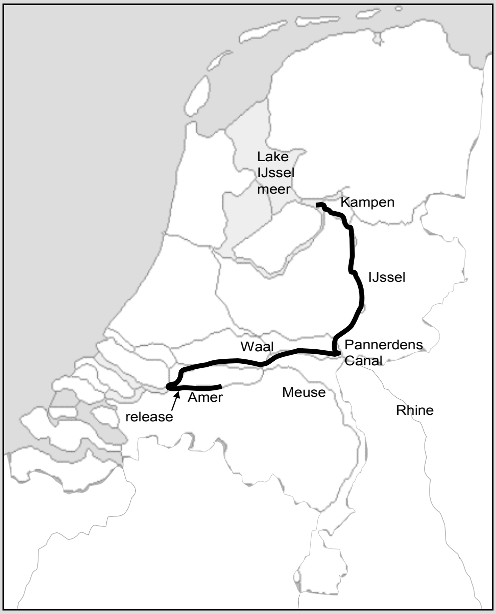


Figure 8.6 *Migratory round trip of a female adult ide.*

Box 8.5 Patient males and hit-and-run females

The spawning behaviour of ide is still poorly known. During electrofishing surveys in March 1997 (in the middle of the spawning season) along the shore of the outer bend directly downstream of the weir at Junne, we caught exclusively running males at regularly spaced intervals. This observation suggests that males hold small territories in which they try to lure females as has been described for bream (Poncin et al. 1996).

The results from the telemetry experiments in 1998-1999 indicate that for the 14 females and 15 males that migrated into the River Vecht prior to the spawning period and left the river subsequently, time spent on the river during spawning was considerable longer for males than for females (Fig. 8.7). Some females stayed for only a few days, presumably to drop their eggs and leave, whereas 80% of the males stayed at least one month.

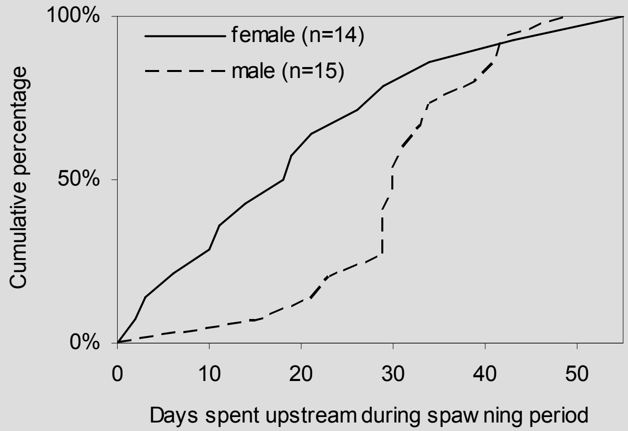


Figure 8.7 *The cumulative fraction that female and male ide 'stay' upstream during the spawning period.*

My conclusion is that, if we want to understand the dynamics of riverine fish populations and rehabilitate those species that suffered from human impacts, science has to invest in studying individual behaviour and its variance within species. In taxa where direct observations are more easily collected, this insight has gained support already for a long period. Fish behaviour is much more complex and sophisticated than many fishers, managers and scientists are willing to give them credit for. I fully agree to a speaker who at the end of his symposium presentation on a study on behavioural aspects of North American brook trout stated: 'Fish do as they damn well please'.

References

- Aarestrup, K., M.C. Lucas, and J.A. Hansen, 2003. Efficiency of a natural-like bypass channel for sea trout (Salmo trutta) ascending a small Danish stream studied by PIT telemetry. Ecology of Freshwater Fish 12: 160-168.
- Bunt, C.M., 2001. Fishway entrance modifications enhance fish attraction. Fisheries Management and Ecology 8: 95-105.
- Cala, P., 1970. On the ecology of ide *Idus idus* (L.) in the River Kavlingean, South Sweden. Reports of the Institute of Freshwater Research Drottningholm 50: 45-99.
- De Leeuw, J.J. and H.V. Winter, 2006. Telemetriestudie naar migratiebariëres voor riviervis (winde, barbeel, kopvoorn, sneep). IMARES-rapport C074/06.
- Dekker, W., 2004. Slipping through our hands: Population dynamics of the European eel. PhD-thesis, University of Amsterdam, the Netherlands.
- Geeraerts, C., M. Oviedo, H. Verbiest, D. Buysse, J. Coeck, C. Belpaire and J.C. Philippart, 2007. Mobility of individual roach *Rutlius rutilus* (L.) in three weir-fragmented Belgian rivers. Hydrobiologia 582: 143-153.
- Gehrke, P.C. D.M. Gilligan and M. Barwick, 2002. Changes in fish communities of the Shoalhaven River 20 years after construction of Tallowa Dam, Australia. River Research and Applications 18: 265-286.
- Katopodis, C., 2005. Developing a toolkit for fish passage, ecological flow management and fish habitat works. Journal of Hydraulic Research 43: 451-467.
- Knaepkens, G., K. Baekelandt and M. Eens, 2006. Fish pass effectiveness for bullhead (*Cottus gobio*), perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) in a regulated lowland River. Ecology of Freshwater Fish 15: 20-29.
- Larinier, M., 1998. Upstream and downstream fish passage experience in France. In Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 127-145.
- Lucas, M.C. and E. Baras, 2001. Migration of freshwater Fishes. Oxford: Blackwell Science Ltd. 420 pp.
- Lucas, M.C. and E. Batley, 1996. Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management. Journal of Applied Ecology 33: 1345-1358.
- Lucas, M.C. and P.A. Frear, 1997. Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid. Journal of Fish Biology 50, 382-396
- Mader, H., C. Unfer and S. Schmutz, 1998. The effectiveness of nature-like bypass channels in a lowland river, the Marchfeldkanal. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 384-402.
- Moser, M.L., P.A. Ocker, L.C. Stuehrenberg, and T.C. Bjornn, 2002. Passage efficiency of adult lampreys at hydropower Dams on the lower Columbia River. Transactions of the American Fisheries Society 131: 956-965.

- Prignon, C., J.C. Micha and A. Gillet, 1998. Biological and environmental characteristics of fish passage at the Tailfer Dam on the Meuse River, Belgium. In: Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors), Fishing News Books, Blackwell Science Ltd.: Oxford, UK. pp. 69-84.
- Oviedo, M. and J.C. Philippart, 2002. The impact of small physical obstacles on upstream movement of six species of fish (Synthesis of a year telemetry study in the River Meuse basin). Hydrobiologia 483: 55-69.
- Poncin, P., J.C. Philippart and J.C. Ruwet, 1996. Territorial and non-territorial spawning behaviour in the bream. Journal of Fish Biology 49 (4): 622-626.
- Redeke, H.C., 1941. Fauna van Nederland X (Pisces). Sijthoff's, Leiden, the Netherlands.
- Reichard, M., P. Jurajda P and M. Ondrackova, 2002. The effect of light intensity on the drift of young-of-the-year cyprinid fishes Journal of Fish Biology 61 (4): 1063-1066.
- Schmutz, S., C. Giefling, and C. Wiesner, 1998. The efficiency of a nature-like bypass channel for pike-perch (Stizostedion lucioperca) in the Marchfeldkanalsystem. Hydrobiologia 371/372: 355-360.
- Sokal, R.R. and F.J. Rohlf, 1995. Biometry: the principles and Practice of Statistics in biological Research. Third Edition. WH Freeman and Company: New York, USA.
- Travade, F., M. Larinier, S. Boyer-Bernard and J. Dartiguelongue, 1998. Performance of four fish pass installations recently built on two rivers in south-west France. In Fish Migration and Fish Bypasses. M. Jungwirth, S. Schmutz and S. Weiss (Editors). Fishing News Books, Blackwell Science Ltd., Oxford, UK. pp. 146-170.
- Van den Ende, W.P., 1847. Lijst van eenige vischsoorten, die in den IJssel bij Zutphen worden gevangen. Verslag der werkzaamheden Vereeniging tot Bevordering der Inlandsche Ichtyologie: eerste deel. An. Nijhoff, Arnhem, the Netherlands. pp 11-15.
- Van den Ende, W.P., 1849. Verslag der werkzaamheden: tweede deel. Vereeniging tot Bevordering der Inlandsche Ichtyologie. An. Nijhoff, Arnhem, the Netherlands.
- Videler, J.J. and C.S. Wardle, 1991. Fish swimming stride by stride: speed limits and endurance. Reviews in Fish Biology and Fisheries, 1: 23-40.
- Welcomme, R.L., 1988. International introductions of inland aquatic species. FAO Fisheries Technical Papers N° 294, Rome, FAO, 318 p.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing the orportunities for upstream migration of non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.
- Winter, H.V., 2006. Vismigratie via de vistrappen bij Hagestein en Maurik tijdens het voorjaar van 2006. IMARES-rapport C092/06.
- Wolter, C., A. Bischoff and K. Wysujack, 2005. The use of historical data to assess fish faunistic reference conditions for large lowland rivers in northern Germany. Large Rivers Vol. 15 No. 1-4, Archiv für Hydrobiologie Suppl. Vol. 155/1-4: 37-47.

Vistrappen door een vissenoog bekeken

Om de effecten van de aanleg van vistrappen langs barrières zoals dammen en stuwen te kunnen bepalen is het noodzakelijk om ook de mate van migratie belemmering in de periode voordien te bepalen. Meestal is dit niet vooraf gemeten. Soms is dit ook niet nodig: een hoge stuwdam maakt alle migratie onmogelijk. Maar in gevallen zoals met de stuwen op de Vecht, waarbij de barrières een deel van de tijd passeerbaar zijn voor sprinters (hfst 2), is dit wel nodig. Het sprintcapaciteit model (box 8.5) waarbij op basis van waterstanden en afvoergegevens bepaald kan worden wat de migratiemogelijkheden zijn is breed toepasbaar. Omdat vaak wel gedetailleerde afvoerreeksen beschikbaar zijn, kan deze aanpak ook worden ingezet in veel andere rivieren.

Het functioneren van vistrappen kan op verschillende niveau's worden geëvalueerd:

1. De *geschiktheid* van de vistrap: bepaald door de fractie van de vistrap intrekkende vissen die de omstandigheden in de vistrap weet te overwinnen (hfst 3);
2. De *vindbaarheid* van de vistrap: bepaald door de fractie van de optrekkende vissen die de ingang van de vistrap weet te vinden (hfst 7);
3. De *efficiëntie* van de vistrap: bepaald door de fractie van alle optrekkende vissen die de vistrap succesvol weet te passeren (hfst 7);
4. De *effectiviteit* van de vistrap: bepaald door de mate waarin populaties of visgemeenschappen hersteld zijn (hfst 4).

Inzicht in het gedrag van vis is een belangrijke en helaas vaak zwaar onderschatte factor bij het bepalen van het functioneren van vistrappen op al deze niveau's.

Als een optrekkende vis een vistrap kán passeren wil dat niet zeggen dat deze ook gáát passeren. Een mooi voorbeeld is snoekbaars. Tijdens de gehele Vecht-studie is er nooit één snoekbaars waargenomen die via de vistrappen met V-vormige overlaten omhoogtrok, terwijl ze wel beneden de stuwen zijn waargenomen. In de Nederrijn zijn recentelijk vistrappen gebouwd met niet alleen een V-vormige overlaat, maar ook een sleuf in het midden tot op de bodem. Via deze vistrappen trokken vele snoekbaarzen omhoog. Beide typen zijn fysiek prima te overwinnen voor snoekbaars, maar kennelijk wil deze niet te dicht aan de oppervlakte passeren.

Het vinden van de ingang van de vistrap door winde bleek afhankelijk van de verhouding tussen de lokstroom uit de vistrap en de ‘afleidende’ stroming over de stuw. Hoe kleiner de afvoer via de vistrap ten opzichte van de totale rivierafvoer, hoe geringer de kans op het vinden van de vistrap (hfst 7). In grote rivieren is deze verhouding vaak erg ongunstig, terwijl de vistrappen juist daar een enorm achterland moeten ontsluiten voor optrekkende vis. Over het zoekgedrag van vis bij barrières is nog heel weinig bekend. Hierdoor is het moeilijk om bijvoorbeeld de beste locatie voor de ingang van een vistrap te bepalen. Of om vis te ‘leiden’ naar de ingang door de waterstromingen te optimaliseren via gericht stuwbeheer.

Om de effectiviteit van vistrappen op het herstel van populaties en visgemeenschappen te bepalen is het nodig om kennis op te bouwen over de rol van migratie binnen populaties van verschillende soorten. Voor welk deel van de populatie is migratie van belang? En over welke afstanden? Hoeveel verschil is er tussen individuen? Met moderne zendertechnieken is hierover recentelijk voor een aantal soorten veel kennis verkregen. Maar dit betreft vaak alleen de volwassen stadia (hfst 6). Wat de rol van migratie en verspreiding is tijdens de jonge levensstadia, of voor kleine vissoorten, is vrijwel onbekend. Slechts met een goed inzicht in het gedrag van vis kunnen we ook optimale oplossingen ontwerpen om migratieproblemen op te lossen. Dit vergt een flinke investering in fundamentele kennis over visgedrag. Maar trial-and-error oplossingen voor migratieproblemen zonder goede kennis van gedrag levert vaak dure en slecht werkende constructies. Hiervan zijn wereldwijd tal van voorbeelden te noemen.

Het herstellen van migratiemogelijkheden met vistrappen is uiteraard geen tovermiddel. Rivieren zijn op tal van factoren door de mens beïnvloed. Als andere zaken zoals de kwaliteit van het water of aanwezige habitats, introductie van exotische vissoorten of ziekten, klimaatveranderingen of een te hoge benutting van visstanden nog een sterke rol spelen in een rivier, zal het positieve effect van toegenomen migratiemogelijkheden wellicht pas zichtbaar worden als deze andere bottlenecks ook zijn opgeheven (hfst 5).

River Vecht at Hardenberg / De Vecht bij Hardenberg

Finally…

Authors addresses

- Wobbe G. Cazemier
  Formerly RIVO the Netherlands Institute for Fisheries Research
  Current address: Siriusstraat 22, 1974AB IJmuiden, the Netherlands
  (w.g.cazemier@quicknet.nl)

- Wim L.T. van Densen
  Institute for Marine Resources and Ecosystem Studies IMARES
  P.O. Box 68, 1970 AB IJmuiden, the Netherlands
  (wim.vandensen@wur.nl)

- Frank Fredrich
  Leibniz Institute of Freshwater Ecology and Inland Fisheries
  Müggelseedamm 310, 12587 Berlin, Germany
  (frank.fredrich@exmail.de)

- Malgorzata Lapinska
  Department of Applied Ecology, University of Lodz
  12/16 Banacha Street, 90-237 Lodz, Poland
  (malapi@biol.uni.lodz.pl)

- Joep J. de Leeuw
  Institute for Marine Resources and Ecosystem Studies IMARES
  P.O. Box 68, 1970 AB IJmuiden, the Netherlands
  (joep.deleeuw@wur.nl)

- Eric G. Visser
  Institute for Marine Resources and Ecosystem Studies IMARES
  P.O. Box 68, 1970 AB IJmuiden, the Netherlands
  (eric.visser@wur.nl)

Curriculum vitae

Hendrik Volken Winter, roepnaam Erwin, werd geboren op 3 juni 1966 te Hoogeveen. Na het doorlopen van het VWO aan het Menso Alting College te Hoogeveen, begon hij in 1984 met de opleiding Milieukunde aan het Van Hall Instituut te Groningen. Een stage met als onderwerp de determinatie en verspreiding van vislarven in het Tjeukemeer binnen het promotie-onderzoek van Wolf Mooij bij het Limnologisch Instituut te Oosterzee was de eerste kennismaking met wetenschappelijk onderzoek aan vis. Na afronding hiervan ging hij in 1988 werken als medewerker oppervlaktewaterkwaliteit bij het Waterschap Noord- en Zuid-Beveland te Goes. In 1990 besloot hij Milieuhygiëne te gaan studeren aan Wageningen Universiteit. Binnen deze studie koos hij voor de specialisaties Aquatische Ecologie en Visserijbiologie. Een tweetal afstudeeronderwerpen wakkerden zijn interesse voor ecologisch onderzoek verder aan. Binnen een marien mesocosm experiment van Katja Philippart aan het DLO-Instituut voor Bos- en Natuuronderzoek te Texel heeft hij de effecten van eutrofiëring op benthische macrofauna bestudeerd. Daarna heeft hij een onderwerp aan trends in visetende vogels en vis op het IJsselmeer bij Rijkswaterstaat RIZA te Lelystad uitgevoerd onder begeleiding van Peter Mous, Mennobart van Eerden en Tom Buijse. Aansluitend aan zijn studie begon hij als AIO van de vakgroep Aquacultuur en Visserij van Wageningen Universiteit in 1995 aan een promotie-onderzoek aan de effecten van vistrappen op het herstel van riviervispopulaties. Hierbij werd hij gedetacheerd bij het Nederlands Instituut voor Visserijonderzoek RIVO te IJmuiden. In 2000 trad hij in dienst van het RIVO, tegenwoordig onderdeel vormend van IMARES, waar hij onderzoek uitvoert op het gebied van vismigratie en riviervis-ecologie, voornamelijk in Nederland en omstreken maar ook aan de Wolga in Rusland in samenwerking met Wageningen Universiteit, Universiteit Utrecht, RIZA en Russische universiteiten en instituten.

List of publications

Peer reviewed papers:

- Winter, H.V., M. Lapinska and J.J. de Leeuw, in press. The River Vecht fish community after rehabilitation measures: a comparison to the historical situation by using the River Biebrza as a geographical reference. River Research & Applications.
- Borcherding, J., C. Pickhardt, H.V. Winter and J.S. Becker, in press. Migratory history of North Sea Houting *Coregonus oxyrinchus* (L.) caught in Lake IJsselmeer (The Netherlands) inferred from scale transects of ^{88}Sr:^{44}Ca ratios. Aquatic Sciences 69.
- Jansen, H.M., H.V. Winter, M.C.M. Bruijs and H. Polman, 2007. Just go with the flow? Route selection and mortality during downstream migration of silver eels in relation to discharge. ICES Journal of Marine Science 64: 1437-1443..
- Winter, H.V., H.M. Jansen and A.W. Breukelaar, 2007. Silver eel mortality during downstream migration in the River Meuse, a population perspective. ICES Journal of Marine Science 64: 1444-1449 .
- De Leeuw, J.J., R. ter Hofstede and Winter, H.V., 2007. Sea growth of anadromous brown trout (*Salmo trutta*). Journal of Sea Research 58 (2): 163-165.
- Winter, H.V., H.M. Jansen and M.C.M. Bruijs, 2006. Assessing the impact of hydropower and fisheries on downstream migrating silver eel, *Anguilla anguilla*, by telemetry in the River Meuse. Ecology of Freshwater Fish 15: 221-228.
- Winter, H.V., H.M. Jansen, B. Adam and U. Schwevers, 2005. Behavioural effects of surgically implanting transponders in European eel, *Anguilla anguilla*. In: Spedicato, M.T., Marmulla G., & Lembo, G. (Editors). Aquatic Telemetry: Advances and Applications: FAO-COISPA, Rome: 287-295.
- De Leeuw, J.J, A.D. Buijse, R.E. Grift and H.V. Winter, 2005. Management and monitoring of the return of riverine fish species in the Netherlands. Large Rivers 15, no.1-4. Archiv für Hydrobiologie_Suppl. 155/1-4: 391-411
- Winter H.V. and F. Fredrich, 2003. Migratory behaviour of ide, *Leuciscus idus*: a comparison between the lowland rivers Elbe, Germany, and Vecht, The Netherlands. Journal of Fish Biology 63:871-880.
- Kranenbarg, J., H.V. Winter and J.J.G.M. Backx, 2002. Recent increase of North Sea houting *Coregonus oxyrhynchus* and prospects for recolonisation in the Netherlands. Journal of Fish Biology 61 Suppl. A: 251-253.
- Winter, H.V. and W.L.T. van Densen, 2001. Assessing the opportunities for upstream migration by non-salmonid fishes in the weir-regulated River Vecht. Fisheries Management and Ecology 8: 513-532.

Other publications:

- Górski, K., A.E. Minin, J.J. de Leeuw, H.V. Winter and L.A.J. Nagelkerke, in press. Influence of flood pulse and water temperature on fish spawning migration in the Volga-Akhtuba floodplains. Proceedings of the GosNIORCH Symposium, September 2007, Russia.
- Bruijs, M. C. M., R. H. Hadderingh, U. Schwevers, B. Adam, U. Dumont and H.V. Winter, in press. Managing human impact on downstream migrating European eel (*Anguilla anguilla*) in the River Meuse. In: J. M. Casselman and D. Cairns (Editors). Eels at the edge. American Fisheries Society, Symposium 58, Bethesda, Maryland.
- Adam. B., M.C.M. Bruijs, U. Dumont & H.V. Winter, 2004. Anthropogene Einflüsse auf die Aalabwanderung in der Maas – Ergebnisse eines EG-Forschungsprojekts. Österreichs Fischerei 57 (11/12):269-277.
- Winter, H.V. 2004. Heeft schieraal een annuleringsverzekering? Onze Zoetwatervisserij 2004.
- Winter, H.V. & A.D. Buijse, 2003. Het belang van migratie voor de visstand in de Maas. Natuurhistorisch Maandblad, Oktober 2003 jaargang 92: 243-248.
- Leeuw, J.J. de, H.V. Winter and A.D. Buijse, 2002. Riviervis terug in de rivieren? De Levende Natuur 103: 10-15.
- Winter, H.V., 2002. Nieuwe vissoort in Nederland: de Marmergrondel. Trendsinwater, editie 7: augustus 2002.
- Winter, H.V. 1997. Winde; een prachtvis voor vliegvissers èn biologen. Onderzoek naar de winde-populatie op de Overijsselse Vecht in relatie tot de aanleg van vistrappen. De Nederlandse Vliegvisser 1997: 7-10.
- Winter, H.V. and M.F. Leopold, 1993. Aalscholvers en snoekbaarzen: lekker maar gevaarlijk? Vogeljaar 41: 115.

Dankwoord

Eindelijk is er dan toch een wintercollectie uitgekomen. Niet iedereen zal dit nog verwacht hebben. Ik heb er lang over gedaan om het af te ronden, maar er gelukkig ook veel van geleerd, veel prachtigs mee mogen maken, met mooie gedreven mensen mogen samenwerken en veel aan over gehouden. Hiervoor ben ik heel dankbaar en dit alles is me heel wat waard.

Het veldwerk aan de Vecht was prachtig, intensief en vaak veel improviseren. Hendrik-Jan Westerink heeft altijd met veel loyaliteit en vindingrijkheid een berg veldwerk verzet binnen mijn uiteraard altijd ruim van te voren precies geplande veldacties. Ik kijk daar met veel plezier op terug, al heb ik nog niet alle verloren weddenschappen ingelost geloof ik. Ook met Dirk den Uijl was het uitermate plezierig veldwerken en na afloop biljarten in het Wapen van Dalfsen. Bovendien hebben beiden mij in de loop van de jaren een supermarkt vol aan etenswaren toegestopt, zodat ik als arme AIO onderweg niets hoefde te kopen bij tankstations. Dolf Schelvis heeft goed werkende en zeer praktische constructies bedacht en zelf gemaakt in de RIVO-werkplaats die hun nut in de harde praktijk bewezen. Dat we zulk maatwerk en technisch meedenken niet meer in eigen huis hebben is een groot gemis.

Medewerkers van Rijkswaterstaat hebben gedurende het vele veldwerk altijd enorm geholpen en veel mogelijk gemaakt. Met name At de Groot, Gerrit van de Belt, Jan Nijboer en Wim Laarman waren altijd bereid mee te denken aan oplossingen, gaven me de beschikking over al hun faciliteiten aan de Vecht en zo kon ik bijna onbeperkt mijn gang gaan bij de verschillende stuwen en vistrappen. Daarnaast waren ze altijd bereid om bij te springen waar dat nodig was en dat gebeurde nog wel eens. Ik zal ook nooit vergeten hoe ik van Gerrit van Hezel nota bene op kerstavond een email binnen kreeg met een schat aan informatie over historische data en visgegevens uit oude archieven. Wat een mooi kerstkado.

Wobbe Cazemier en Wiel Muyres hebben veel pionierswerk verricht om vismigratie problematiek en vistrappen op de kaart te zetten. Veel van de aangelegde vistrappen in Nederland zijn hier een rechtstreeks gevolg van. Daarnaast heeft Wobbe veel werk op de Vecht verricht in de periode voordat de vistrappen aangelegd zijn. Van dit alles en van hun ruime kennis en ervaring heb ik de vruchten mogen plukken.

Bram bij de Vaate en André Breukelaar van het RIZA hebben mij de kans geboden om aan het eind van mijn AIO-periode met telemetrie aan de gang te kunnen gaan door kosteloos materiaal en inzet beschikbaar te stellen. Samen met Koos Fockens en Gerben Slob van Nedap hebben ze een uniek transpondersysteem en netwerk ontwikkeld. Hierdoor heb ik mijn onderzoek flink kunnen verdiepen en kon ik metingen aan het gedrag van vis uitvoeren die daarvoor niet mogelijk waren. Hier heb ik na het uitvoeren van mijn promotie-veldwerk verder op voort kunnen bouwen binnen latere vismigratie-onderzoeken aan bijvoorbeeld schieraal. Dank hiervoor!

Ook al zat ik op afstand van Wageningen, Wim van Densen heeft mij tijdens mijn AIO-jaren altijd zeer inspirerend begeleid. Zijn helicopter-view, frisse insteken, prikkelende vragen en relativeringsvermogen ("vistrappen zijn niet veel minder

wetenschappelijk dan ijsberen, kwantummechanica of Rembrandt"), hebben mij altijd heel erg goed gedaan. Ik zal de vistrapbemonsteringen en merkacties die Wim, Annemiek en Inse hebben helpen uitvoeren tijdens een lang paasweekend onder grote publieke belangstelling nooit vergeten. Annemiek Verhallen was bovendien zeer goed thuis in het waterbeheer van de Vecht en heeft onder andere kunnen organiseren dat we met de meetdienst van Rosannepolder hoogwatermetingen aan de stuwen hebben kunnen uitvoeren.

Binnen afstudeeronderwerpen en stages hebben Marco Traa, Sina Ly, Mark van de Weerd, Date de Vries en Marc van Buuren meegeholpen aan mijn onderzoek. Kee en Nanne Kingma van Boerhoes, hebben de bonte stoet aan veldwerkers altijd gastvrij onderdak geboden in hun perfect aan de Vecht gelegen boerderij.

Het meten van de optrek van vis via de vistrappen heeft alleen maar plaats kunnen vinden omdat veel vrijwilligers van hengelsportverenigingen uit Zwolle, Ommen en Hardenberg en enkele beroepsvissers hieraan mee hebben willen werken. Met Ab Dekker als inspirerende kennisbron die al een leven lang viste op winde met een witte hengel ("net als de meeuwen steekt die niet af tegen de hemel").

Goed, het veldwerk was dus aangenaam en zeer inzichtgevend, maar het moest ook nog opgeschreven worden. Dit dacht ik wel even naast mijn nieuwe werk bij het RIVO te gaan doen. En ik heb het inderdaad ook naast mijn werk gedaan, ... alleen niet even.

Niels Daan heeft gedurende het gehele traject een belangrijke rol gespeeld binnen mijn promotiewerk. Hij heeft mij altijd gesteund in de begeleidingscommissie en is vooral tijdens de schrijffase van onschatbare betekenis geweest. Aan de vele koffievlekken op becommentariëerde uitgeprinte velletjes was te zien dat het moeilijk wakker blijven was bij mijn eerste schrijfselen. Met zijn grote onderzoekservaring, scherpzinnig gevoel voor logica en redactionele skills heeft hij mijn en onze kladversies van artikelen enorm verbeterd. Ik heb veel geleerd van het vele rood.

Daarnaast wil ik Tom Buijse en Rob Grift danken voor hun rol in de begeleidingscommissie en daarna. Toms grote internationale expertise op het gebied van riviervisecologie en raad en steun op allerlei gebied, hebben me vaak geholpen. Rob was de andere AIO van de vakgroep die aan riviervis werkte. Hij was duidelijk sneller en efficiënter dan ik. Ik heb veel opgestoken van Rob op gebieden die bij mij braak liggen.

During my visits to the University of Vienna, I really enjoyed the stimulating discussions with Fritz Schiemer, Hubert Keckeis and their group. Thanks for sharing your knowledge on river fish and for showing me your very interesting and the often still natural river systems of the Danube and tributaries. And the evenings with an Austrian beer were very pleasant as well.

Thanks also to my foreign colleague researchers Frank Fredrich and Malgosia Lapinska for sharing your data and research results. Our comparative studies between the Vecht and the Elbe and Biebrza yielded two in my opinion nice papers.

Bram Huisman wil ik graag danken dat hij als promotor wilde optreden en mijn draft versies heeft becommentarieerd. Helaas is het mij niet gelukt om het tijdig na zijn emeritaat af te ronden. Gelukkig toonde zijn opvolger Johan Verreth zich eveneens bereid om als promotor op te treden. Dank voor het snelle toeslaan toen vrijdagmiddag 7 december de Aula beschikbaar kwam. Het hebben van een mooie datum heeft me in de eindfase zeker geholpen om de laatste hand eraan te leggen. Daarnaast wil ik Adriaan Rijnsdorp bedanken dat hij ook als promotor wil optreden. Zijn nimmer aflatende gedrevenheid en enthousiasme voor visonderzoek werkt stimulerend en aanstekelijk.

Mijn paranimfen Jan Jaap Poos en Gijs Spijkers zijn elk op hun eigen manier heel belangrijk voor me geweest. Jan Jaap was mijn 'partner in crime' waarmee ik vele avonden en weekenden zowel op de Dokweg als op het RIVO heb doorgebracht. Tussen het werk door met een Chinees maandmenu en de beamer naar 'Scratch: the history of hiphop' kijken was onvergetelijk. Met Gijs heb ik veel afleiding gehad. Tennissen, snookeren, zeilen, windsurfen op oliestranden ... van alles. Maar ook genietend van een whiskey en ouwehoeren over hoeveel ecologie van economie kan leren en vooral andersom natuurlijk. Ik ga mij straks in de Aula erg prettig voelen tussen deze twee kerels.

Ik heb altijd met heel veel plezier gewerkt bij het RIVO, nu opgegaan in IMARES, en heb het hier nog steeds heel erg naar mijn zin. Er werken hier veel bevlogen mensen er is voldoende bewegingsvrijheid voor eigen initiatieven. Met Joep de Leeuw heb ik veel interessant werk aan vismigratie en riviervis-ecologie kunnen opzetten. We hebben samen al veel mooie 'visoperaties' in binnen- en buitenland uitgevoerd. Goeie discussies en vaak eten op het strand waren (en blijven) hierbij erg prettige bijkomstigheden. Henrice Jansen, Sieto Verver en Ingrid Tulp waren altijd bereid mee te denken over figuren, formuleringen en feiten op onmogelijke tijden. Ingrids idee om korte Nederlandse samenvattingen achter elk hoofdstuk van haar proefschrift te zetten mocht ik overnemen. Het zou mooi zijn als ik daarmee mijn proefschrift net zo toegankelijk heb gemaakt als het hare.

De bibliogirls Suze Koudenburg en Cécile Huber hebben mij op onnavolgbare manier altijd snel van zelfs de meest obscure literatuur voorzien. Zij zijn volkomen onvervangbaar! Arnold Herf en Jan van der Heul hebben veel voor me geregeld en veel van me gepikt (niet in crimineel opzicht maar qua uitspoken van mij). Floor Quirijns was altijd beschikbaar als klankbord en meedenker als ik weer eens teveel hooi op mijn vork had genomen en heeft me veel meer geholpen dan ze zelf waarschijnlijk denkt. Eric Visser heeft in no-time de prachtige java-applet sprintfish gemaakt. Het klimclubje met naast Jan Jaap en Floor ook Gerjan Piet, Nicola Tien en Olvin van Keeken, was altijd een mooie en gezellige afleiding. Met Willem Dekker kun je altijd inhoudelijk sparren. Het voelt erg luxe om deze lijst van prettige collega's die het werken aan mijn proefschrift naast mijn werk erg aangenaam hebben gemaakt met gemak nog veel verder uit te kunnen breiden. Top!

Ook buiten mijn werk heb ik veel steun en hulp gehad. Joyce Woudenberg heeft hierbij een heel belangrijke rol gespeeld. Bij haar en haar familie voelde ik mij altijd erg thuis. Ik heb veel van haar geleerd op vlakken die niet erg ontwikkeld waren bij mijzelf, maar waar zij een kei in was. Ik kijk hier met een bijzonder dankbaar gevoel en grote waardering op terug. Mijn ouders, Goos en Ferda, hebben altijd meegeleefd en meegelezen, me op alle vlakken gesteund en in een mooi warm

nest opgevoed. Thomas Zwiers en Antje Kingma hebben een altijd welkom plekje en oor aan de Vecht. Baukje de Jong dank ik voor alle al dan niet opgedrongen spontane eet- en drinkgezelligheid. Ellen Potma heeft heel veel voor me betekend tijdens de laatste eindsprint, in mijn geval alweer zo'n twee jaar. Ik kijk uit naar een leven met weer meer vrije tijd en heb zin om me vol het zwarte gat in te storten dat iedereen me beloofd heeft.

Rachel van Esschoten heeft er een heel mooi boekje van gemaakt vind ik, ook al zal het niet altijd even gemakkelijk zijn geweest om te moeten wachten op mijn aangeleverde teksten.

Ik realiseer me dat een schrijfstijl waarbij ik iedereen die ik dank direct aanspreek misschien wel zo persoonlijk was geweest. Maar daarvoor is het nu te laat. Geheel voorspelbaar had ik dit dankwoord allang in moeten leveren. Ik hoop echt dat het me gaat lukken om mezelf en anderen met minder last-minute werk op te zadelen. Dat zou pas echt een bedankje voor jullie allen zijn.

Tot slot dank ook aan iedereen die ik hier vergeten ben te noemen maar toch een bijdrage heeft geleverd en aan iedereen die inmiddels zelf vergeten is een bijdrage te hebben geleverd.


84-63-YA

Training and Supervision Plan Graduate School WIAS		
Name PdD student: Erwin Winter		
Project title: A fisheye view on fishways: Effects of fishways on fish communities		
Group: Aquaculture and Fisheries		
EDUCATION AND TRAINING		
The Basic Package	year	ECTS*
Course on philosophy of science and/or ethics	1996	1.5
WIAS Introduction Course (partly)	1997	0.6
Subtotal Basic Package		**2**
Scientific Exposure		
International conferences		
Int. Conference on 'Fish Migration and Fish Bypasses', Vienna, 24-27 Sep	1996	1.2
Int. Symp. & Workshop on 'Manag. and Ecol. of River Fisheries', Hull, 29 Mar-3 Apr	1998	1.5
Fourth Conference on Fish Telemetry,Trondheim, Norway 26-30 June	2001	1.2
Int. Symp. 'Linking indiv. behaviour to pop. ecology of fish'. Silkeborg, Denmark Aug	2004	1.2
Int. Conference on Ecohydraulics, Christchurch, New Zealand, 19-23 February	2007	1.2
Seminars and workshops		
Int. Workshop on 'Ecology of 0+ fish in large rivers'. Grieterbusch, Germany	1995	0.6
Seminar 'Fish in rivers', RIZA, Heerewaarden, 26 May	1998	0.3
Workshop 'Wanderfischgruppe' IKSR, Koblenz, Germany 26 January	2000	0.3
Presentations		
Oral: International Workshop on 'Ecology of 0+ fish in large rivers'	1995	1.0
Poster: Int. Conf.e & Workshop on 'Fish Migration and Fish Bypasses'	1996	1.0
Oral: Int. Symp. & Workshop on 'Manag. and Ecol. of River Fisheries'	1998	1.0
Oral: Seminar 'Fish in rivers', RIZA, Heerewaarden, 26 May	1998	1.0
Oral: 'Fish migration and fishway efficiency', IKSR Workshop	2000	0.3
Oral: 'Ide, rigid behaviour in a flexible species', Colloqium at Groningen University	2001	0.5
Oral: 'Fishway efficiency and ide', Colloqium at Vienna University	2001	0.5
Oral: 'Migratory behaviour of ide in the Elbe and Vecht' Fourth Conf. telemetry	2001	1.0
Oral: 'Ideal distribution in ide?' Int. Symp. 'Linking indiv. behaviour to pop. ecology	2004	1.0
Oral: 'A fisheye view on fishways', Int. Conference on Ecohydraulics	2007	1.0
Subtotal Scientific Exposure		**16**
In-Depth Studies		
Disciplinary and interdisciplinary courses		
PhD Winter School on Population Dynamics, N.W.O.	1996	1.5
Training 'Identification of fish larvae' (dr S. Staas, University of Cologne)	1996	1.2
Advanced statistics courses		
Advanced statistics for ecology & multivariate analysis, Biometris	2005	1.7
PhD students' discussion groups		
Fisheries work meetings		1.0
Subtotal In-Depth Studies		**5**
Professional Skills Support Courses		
Vaarbewijs I & II, ANWB	1996	1.5
Practical course and training Electrofishing, OVB	1996	0.3
VI-tagging procedures (NMT technology)	1996	0.3
Field training transponder procedures (OVB)	1998	0.3
WIAS Course Techniques for Scientific Writing (Dr. Grossman)	1997	1.2
Personal Effectivity: Team Time trainingen	2006	1.5
Subtotal Professional Skills Support Courses		**5**
Didactic Skills Training		
Lecturing		
Rehabilitation of river fish populations	2002	0.6
Fish migration & life history strategies: concept & definitions + excursion (3 years)	2005-7	1.9
Migration in fish: concepts and research methods (Radboud University Nijmegen)	2006	0.6
Supervising practicals and excursions		
Practical Fisheries Biology	1996/7	3.0
Supervising theses		
MSc Thesis Marco Traa: 'Distribution of fish in a the regulated river Vecht'	1996	2.0
MSc Thesis Sina Ly: 'Fish larvae in the River Vecht in relation to migration'	1996	2.0
MSc Thesis mark van de Weerd: 'population structure of ide in the River Vecht'	1997	2.0
MSc Thesis Date de Vries:'Optimizing river Vecht management for fish populations'	1998	2.0
BSc Thesis Marc van Buuren: 'Distribution of fish larvae in the Rvier Vecht'	1998	1.0
Subtotal Didactic Skills Training		**15**
Education and Training Total (minimum 30)		**44**

** One ECTS credit point represents a study load of 28 hours.*

Colofon

Foto omslag:
Willem Kolvoort

Bijschrift omslagfoto:
Ik was zeer getroffen door de prachtige sfeer en het perspectief van deze foto en ben de beste onderwaterfotograaf van Nederland zeer dankbaar dat ik deze kon gebruiken voor mijn omslag. Net als de persoon aan de rand van het water heb ik mij als buitenstaander een beeld proberen te vormen wat er onderwater allemaal toe doet. Ik heb geprobeerd het ook vanuit een vissenoog te bekijken door in te zoomen op individueel gedrag, maar echt in de huid kruipen van een vis zal een utopie blijven. Dat elke vis een eigen wil en beslisruimte heeft is voor mij echter zonneklaar. En bovendien, als je geen migratiemogelijkheden geeft aan voorns .... worden het uiteindelijk bittervoorns.

Omslag-ontwerp:
Rachel van Esschoten (Diving Duck, www.divingduck.nl)

Fotoverantwoording:
Sieto Verver (blz 8)
Joep de Leeuw (blz 70, 92, 116)
At de Groot (blz 132)
Annemiek Verhallen (blz 48, 65 boven)
Erwin Winter (de meeste overige foto's)

Lay-out:
Rachel van Esschoten (Diving Duck, www.divingduck.nl)

Druk:
Drukkerij van Denderen BV, Groningen

Wageningen Universiteit en IMARES hebben bijgedragen aan de druk- en productiekosten