



Fish recruitment in a canal with intensive navigation: implications for ecosystem management

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The young-of-the-year (YOY) fish community in Oder-Havel-Kanal, a navigable canal in the German lowlands, assessed from May to October 1999, was dominated by tolerant species especially roach *Rutilus rutilus* and perch *Perca fluviatilis*. Roach dominance was high in May and June and low during the rest of the sampling period. The dominance pattern of perch was inversely related to that of roach. Significantly higher densities of significantly smaller YOY fishes were found in bays compared with the straight reaches of the main channel which was the result of an aggregation of 0+ year roach in bays in May and June. Parallel to low structural variability (spawning and nursery habitats), the intensive ship traffic may have been a major force structuring the fish communities in the canals. Measured ship-induced flow velocity in straight reaches was about four times higher than in bays of the canal. Maximum flow velocities caused by barge tows were also four times higher than those induced by pleasure boats. The study demonstrated the relatively low fish reproductive potential of a navigable, artificially embanked lowland canal. To improve fish reproduction, modification of canal banks is highly advisable to preserve existing bays and tributaries and even to create additional ones.

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Key words: young-of-the-year fishes; reproduction; waterway; flow velocity; anthropogenic impact.

INTRODUCTION

World-wide, there are 500 000–600 000 km of navigable inland waterways. The continuously growing network of waterways already has half the length of the rail network (Kubec & Podzimek, 1996), illustrating the global dimension of waterways including canals. In Germany, there are *c.* 6900 km of navigable inland waterways (77% regulated rivers and 23% canals) with a total area of 2320 km² (WSV, 1995) corresponding to *c.* 30% of all German surface waters. Waterways are important freshwater reservoirs and provide refuges for many freshwater organisms (Wolter & Vilcinskas, 2000), allow intensive recreational activities (e.g. angling, pleasure boating, canoeing, swimming and nature study; Caffrey & Donnelly, 1998) and may serve in modern conservation strategies for biotope connection (Jedicke, 1994). These functions are provided independently of the primary objective of waterways to serve as navigation routes.

Fish ecological studies in extreme biotopes such as navigable canals and other artificial ecosystems are scarce but necessary. Firstly, they provide insights into

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the spatial dynamics of fishes including distribution of alien species (Balon *et al.*, 1986), the ecological amplitudes of 'intolerant', threatened fish species (Arlinghaus & Wolter, 2002) and the potential of artificial ecosystems for fish species conservation (Wolter, 2001). Secondly, such research may allow for prognoses about the development of fish communities in heavily modified 'natural' rivers, as many flow-regulated rivers display a habitat similarity to artificial canals. Thirdly, because growing numbers of people are angling in canals, there is an increasing demand for information on fish populations and reproduction rates in canals for inland fisheries management purposes to properly evaluate stocking programmes (Cowx *et al.*, 1990). Finally, the recently passed European Water Framework Directive 2000/60/EEC (22.12.2000) requires the member states to conserve at least a 'good ecological potential' in all heavily modified water bodies. There have been some studies on adult fish communities in canals (Pygott *et al.*, 1990a; Wolter & Vilcinskas, 1997a, 2000). There remains a lack of knowledge, however, of fish fry associations and fish recruitment in canals, although young-of-the-year (YOY) fishes are important indicators of habitat quality (Schiemer *et al.*, 2001). Moreover, estimates of abundance of larval and juvenile fish populations are essential for the practical management of fish stocks.

The aims of this study were to investigate fish recruitment and spatio-temporal distribution patterns of YOY fish associations in an artificial waterway, Oder-Havel-Kanal. This intensively navigated canal is one of the most important waterways in eastern Germany. In navigable canals, one dominant factor structuring the fish community was suggested to be the high larvae mortality as a result of shipping, especially the waves in the straightened, rip rap embanked canal reaches (Wolter & Vilcinskas, 1997b). Thus, it was hypothesized that YOY fish densities should be substantially higher in bays (convex banks) than in the straight reaches of the canal where shipping influence should be substantially higher (Zauner & Schiemer, 1992). Recognizing that shipping produces a harsh environment in the littoral because of wave breakage and propagation of wakes (Mazumder *et al.*, 1996), the study included measurements and analysis of velocity patterns that evolved in the straight reaches and U-turn bays as ships passed along the canal.

MATERIALS AND METHODS

STUDY AREA AND SITE DESCRIPTION

The artificially constructed Oder-Havel-Kanal (OHK) is the central part of the 150 km long Havel-Oder-waterway (HOW) crossing the watersheds between the Rivers Havel and Oder in the north-eastern lowlands of Germany. The OHK was firstly opened in 1620 and has existed in its present form since 1914 (Uhlemann, 1994). For more than two thirds of its length, the OHK is located above the surrounding land and therefore constructed as a special waterproof structure with a clay spalant. As a result, the OHK is 'unusually' straightened, 34 m wide, 3 m deep, with artificial embanked shorelines (95% rip rap and 3.8% sheet pile wall), steep bank slopes (mean 33%) and a negligible flow velocity ($<0.05 \text{ m s}^{-1}$) (Wolter & Vilcinskas, 1998a). Seven per cent of the shoreline is formed by tributaries (four artificial ones) or by bays (convex banks). But, even in the bays the predominant type of embankment is rip rap. The water quality of the OHK is characterized as critically polluted (Landesumweltamt Brandenburg, 1994) and its trophic state is polytrophic to hypertrophic (Wolter & Vilcinskas, 1997b). In contrast to

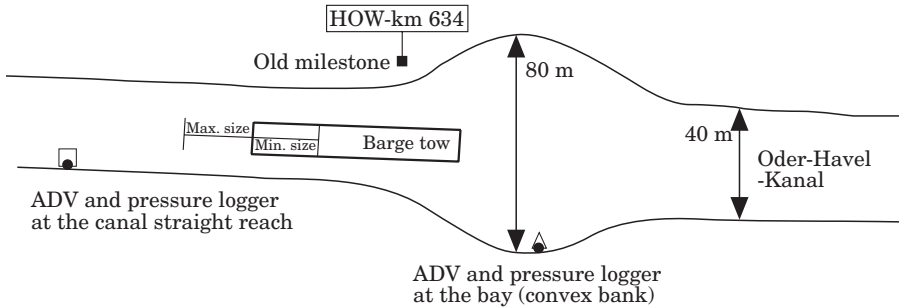


FIG. 1. Accurate scale scheme of transect 2 in the main channel of the Oder-Havel-Kanal and locations of measuring devices in the meso-habitats straight reach and bay. Rectangle indicates characteristic sizes of barge tows.

other lowland canals, submerged macrophytes are common at the shoreline of the OHK (Wolter & Vilcinskas, 1998a). They seldom, however, form dense stands. Overall, the OHK offers only poorly structured habitats for fishes (Wolter & Vilcinskas, 2000). Furthermore, the 53 km OHK-canal stretch sampled is bordered by the Lock Lehnitz in the west (HOW-km 28.2, water level difference 6 m) and by the ship lift Niederfinow in the east (HOW-km 77.9, water level difference 36 m). Neither lock is equipped with fish-ladders which, *inter alia*, limits the migration of fishes from the Rivers Havel or Oder into the OHK (Wolter & Vilcinskas, 1998b).

Two selected sites [HOW-km 70.5 (52°85' N; 13°83' E) and HOW-km 63.5 (52°85' N; 13°73' E)] were surveyed regularly between May and October 1999 within the main channel of the OHK. These sites were considered as representative of the habitat structures in the straightened course of the OHK, covering all available micro- and meso-habitat structures within the main channel. Two main meso-habitats, straight reaches and bays (convex or U-turn banks), were distinguished (Fig. 1).

The first site (transect 1, HOW-km 70.5) consisted of straight reaches and two small bays. In the littoral from the water edge to a water depth of 1 m, submerged macrophytes (*Potamogeton* sp., *Ceratophyllum* sp., *Myriophyllum* sp.) grew in the interstices of the riprap embankment but did not form dense stands. The submerged macrophyte cover was rarely >50% per unit area. Additionally, in the straight reach, a stretch of c. 50 m was covered by emerged macrophytes (*Phragmites communis*). The predominant substratum was rip rap (95% of littoral area). Moreover, there was a small patch where the substratum consisted of gravel and small stones. Bankside bushes and trees were common and increased the shade in the littoral.

The second site (transect 2, HOW-km 63.5) was characterized by straight reaches and a bay covered by submerged macrophytes (*Potamogeton* sp., *Ceratophyllum* sp.) from the bank to a water depth of 2.5 m. A macrophyte cover of >50% per unit area was common in the littoral of the bay. The straight reach was poorly structured and emergent or submergent macrophytes were lacking. Rip rap was the dominant bottom substratum in the littoral (90% of littoral area), with fine silt (mud) covering the canal bed in the bay. Bankside bushes and trees were poorly developed.

FIELD SAMPLING

Between May and October 1999 the littoral YOY fish assemblage of the OHK was studied. Random point abundance sampling (RPAS) by electrofishing was used (Copp & Garner, 1995) using a DEKA 3000 portable electrofishing unit (pulsed DC, 600 V) with a 17 cm diameter ring-anode. Stunned fishes were captured with a separate dip net of 600 µm mesh size. The unit sampling area of the sampling point covered c. 0.5 m² (Bischoff & Wolter, 2001).

At each transect, a distance of 500–600 m was sampled by 100 random points during daytime each month (Garner, 1997). At each point, a set of environmental variables was recorded: water depth (cm), distance from bank (cm), substratum diameter (mud, sand,

gravel and rip rap), macrophytes (none, emergent, floating and submerged), plant cover (0%, 1–75% and >75% per point area), visibility (low, medium and high) and sun exposure (low, medium, high and very high).

In July 1999, the pelagic YOY fish composition of the OHK was sampled between HOW-km 65 and HOW-km 75. Seventy bongo (push) net samples (30 daytime, 40 night-time) were collected with a 0.6 m diameter, 500- μ m-mesh net. This net, equipped with a flowmeter (thus allowing for absolute abundance-estimation), was mounted in front of a boat 4.5 m in length equipped with an engine of 15 PS. Duplicate tows were pushed at 1 m depth with a speed of 1.66 m s⁻¹ for 60 s.

Either the captured fishes were returned immediately to the water after identification, counting and measuring total body length (L_T , to the nearest mm below), or anaesthetized with chlorobutanol (1.1.1-trichloro-2-methyl-2-propanol) and fixed in 5% formaldehyde buffered with sodium tetraborate decahydrate (Na₂B₄O₇ · 10 H₂O). In the laboratory, fish larvae were identified (Koblickaya, 1981) and measured (L_T).

Velocity measurements were performed in June 2001 at site two (between HOW-km 63.2 and HOW-km 63.5) to record the flow velocity patterns after ship passages inside the two meso-habitats, straight reach and bay (Fig. 1). These instantaneous three-component velocity measurements were taken simultaneously with two acoustic-Doppler velocimeters (ADV, SonTek., San Diego, U.S.A.) to investigate the effect of navigation. The ADV devices were mounted on a special platform that enables the probe to be fixed without flow-induced vibration. Use of this instrument has the advantage that flow in the sampling volume is undisturbed by the probe tip. Water levels were recorded by pressure loggers (DL/N, STS Co., Sirmach, Switzerland) mounted into perforated steel pipes and placed close to the ADV probes in the two meso-habitats (Fig. 1). The distance of each instrument set from the water edge was c. 1 m and the distance between the two sets was c. 200 m.

DATA ANALYSIS

Data were analysed for YOY fishes because older fishes were not representatively sampled. Relative abundance (% of total catch) and frequency (% frequency of occurrence of a species per sample) were calculated for all species. Categories of relative abundance were classified in intervals on a scale of log₂ (Matthews, 1998) to determine the following six dominance classes according to Mühlenberg (1993): eudominant with relative abundance >16% (2⁴), dominant 8% (2³)—<16%, subdominant 4% (2²)—<8%, recedent 2% (2¹)—<4%, subrecedent 1% (2⁰)—<2%, and sporadic <1% of the total catch.

The Kolmogorov–Smirnov test was used to test the hypotheses of normality and the Levene-test was used to test homoscedasticity of variances. Catch per unit of effort (number of individuals per sample point, CPUE), species number per sample point (SPP), fish total body length per sample point (L_T PP) and abundance (individuals m⁻³) comparisons were performed by one-way ANOVA followed by Dunnett-T3 multiple comparison test, which is recommended in case of heteroscedasticity. ANOVA results were verified by non parametric Kruskal–Wallis- and Mann–Whitney *U*-tests. Fish fauna was compared between transects, meso-habitats, littoral and pelagic using the qualitative Sørensen coefficient and the semi-quantitative Morisita index (Wolda, 1981). Fish faunal breaks were indicated when indices were <0.5 (Matthews, 1986).

Spearman rank correlations were calculated to describe relations between habitat structure and CPUE, SPP and L_T PP because of significant non-normality and variance heterogeneity for the selected and mostly ordinal environmental modalities. An index of linear selection (Strauss, 1979) was used to assess habitat selection by comparing use frequency by fishes with the frequency of available habitat categories. Logistic regressions using a null sample by environmental variables matrix were performed to detect active avoidance patterns of YOY fishes. Habitat structure of transects and meso-habitats was compared using a point-by-environmental variables matrix and discriminant analysis considering only eigen-values >1 and canonical correlations >0.5 relevant (Lozán & Kausch, 1998). Calculations were performed with the SPSS software package (SPSS, 1999). Statistical tests were evaluated at the 95% CL.

The software package TFC Studio (Windows 9x, NT) was used as a data processing tool for ADV measurements. Prior to the data processing, each record was visually inspected to identify possible problems such as spikes or abrupt discontinuities in the velocity time series. Spikes were removed and replaced with values generated by linear interpolation between adjacent data (Sukhodolov *et al.*, 1998).

RESULTS

OVERVIEW OF YOY FISH COMMUNITY

In the transects 1 and 2, 1082 juvenile fishes including 740 YOY fishes of 9 species were collected from 1136 sampling points. The composition of the YOY fish catch (Table I) revealed the dominance of two species: roach *Rutilus rutilus* (L.) and perch *Perca fluviatilis* L. Both species were eudominant (together relative abundance >85%). Chub *Leuciscus cephalus* (L.) and ruffe *Gymnocephalus cernuus* (L.) were subdominant and bleak *Alburnus alburnus* (L.) was subprecedent. More than 40% of all YOY fish species were found sporadically. Overall, perch dominated the fish fry association, because it had not only a high relative abundance but also a high frequency, which was considerably higher than the frequency of roach.

With respect to ecoethological guilds (Table I), the fish fry assemblage of the OHK was dominated by tolerant species (eurytopic and phyto-lithophilic, with relative abundance >93%). Intolerant species such as rheophils, limnophils, phytophils or lithophils were very rare. More than 50% of the YOY species inventory found was listed in German Red Lists for threatened fish species.

SPATIO-TEMPORAL YOY FISH OCCURRENCE AND DISTRIBUTION

Roach and bleak were recorded for the first time in May, ruffe and perch in June, chub and sunbleak *Leucaspisus delineatus* (Heckel) in July, ide *Leuciscus idus* (L.) and tench *Tinca tinca* (L.) in August and dace *Leuciscus leuciscus* (L.) in September (Fig. 2). Roach dominance and CPUE was high in May and June (309 YOY roach) and low in July, August, September and October (34 YOY roach). The pattern of relative abundance of perch was inversely related to that of roach. Ruffe and chub showed a rather homogenous dominance structure from July to September. Except for perch and chub, species abundance declined in October compared to the rest of the sampling period. In July, none of the YOY fish species caught in the pelagic [208 bleak, one gudgeon *Gobio gobio* (L.) and one zander *Sander lucioperca* (L.)] were found in the littoral. Consequently, Sørensen and Morisita indices indicated faunal breaks between the pelagic and littoral YOY fish assemblage in July. Mean absolute abundance (individuals $m^{-3} \pm$ S.E.) of YOY fish was significantly higher (ANOVA, Dunnet-T3, $P < 0.001$) in the littoral during daytime (1.45 ± 0.23) compared with the pelagic during both daytime (0.0017 ± 0.0012) and night-time (0.225 ± 0.003).

Because of the varying, and patchy fish distribution in May (high S.E.), mean CPUE (\pm S.E.) of YOY fishes was highest in August (1.23 ± 0.14 ; ANOVA, Dunnet-T3, $P < 0.001$ except for comparison with May, $P > 0.05$). As expected, mean L_T PP increased significantly (ANOVA, Dunnet-T3, $P < 0.001$) from May until August and was not significantly different in September and October.

TABLE I. List of recorded YOY fish species and their relative abundance and frequency in the Oder-Havel-Kanal 1999, ecoethological guilds, dominance of adult fish community and vulnerability

Ecoethological guilds							
Species	Common name	Stream velocity ²	Spawning substratum ³	Dominance class (adult community) ⁴	Vulnerability ⁵	Abundance (%)	Frequency (%)
<i>Alburnus alburnus</i> (Cyprinidae, Aa)	Bleak	Eurytop	Phyto-lithophil	Subdominant	ab.	2.57	1.06
<i>Gobio gobio</i> (Cyprinidae, Gg)	Gudgeon	Rheophil B	Psammophil	Sporadic	RL	—	—
<i>Leucaspis delineatus</i> (Cyprinidae, Ld)	Sunbleak	Limmophil	Phytophil	+	RL	0.68	0.26
<i>Leuciscus cephalus</i> (Cyprinidae, Lc)	Chub	Rheophil B	Lithophil	Subprecedent	RL	5.68	2.99
<i>Leuciscus idus</i> (Cyprinidae, Li)	Ide	Rheophil A	Phyto-lithophil	Sporadic	RL	0.14	0.09
<i>Leuciscus leuciscus</i> (Cyprinidae, Ll)	Dace	Rheophil A	Phyto-lithophil	+	RL	0.27	0.18
<i>Rutilus rutilus</i> (Cyprinidae, Rr)	Roach	Eurytop	Phyto-lithophil	Eudominant	ab.	46.22	4.67
<i>Tinca tinca</i> (Cyprinidae, Tt)	Tench	Limmophil	Phytophil	Sporadic	RL	0.14	0.09
<i>Gymnocephalus cernuus</i> (Percidae, Gc)	Ruffe	Eurytop	Phyto-lithophil	Subprecedent	ab.	4.59	2.90
<i>Perca fluviatilis</i> (Percidae, Pf)	Perch	Eurytop	Phyto-lithophil	Eudominant	ab.	39.73	17.87
<i>Sander lucioperca</i> (Percidae, Sl)	Zander	Eurytop	Phytophil	Sporadic	ab.	—	—

+, not caught as adult; —, not caught in the littoral but in the pelagic of the main channel of Oder-Havel-Kanal; RL, Red List; ab., abundant; ¹Kottelat (1997); ²Schiemer & Waidbacher (1992); ³Balon (1975, 1981); ⁴Wolter & Vilcinskas (2000); ⁵According to Red Lists of Brandenburg (Brämick *et al.*, 1999) and Germany (Bless *et al.*, 1994).

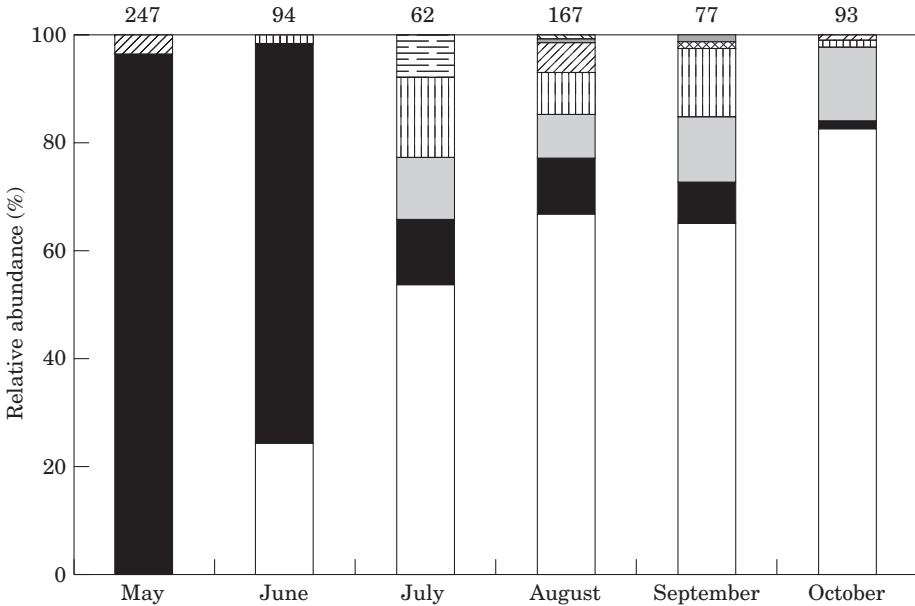


FIG. 2. Relative abundance of YOY fishes caught between May and October 1999 in the main channel of the Oder-Havel-Kanal. See Table I for abbreviation of fish names. Numbers at top of bars are sample sizes. □, Pf; ■, Rr; ◻, Lc; ▨, Gc; ▩, Aa; ▪, Ld; ▫, Li; ▬, Li; ▮, Tt.

COMPARISON OF THE MESO-HABITATS 'BAY' AND 'STRAIGHT REACH'

For Sørensen and Morisita indices, CPUE, SPP and L_T PP, there were no significant differences between transects 1 and 2. The data were pooled for further analysis of differences between the meso-habitats, bay and straight reach, within the main channel of the OHK.

Species composition was similar between the two meso-habitats, e.g. Sørensen and Morisita-indices were >0.5 . Relative abundance of roach, however, was considerably higher in bays than the straight reaches. Conversely, perch had a higher dominance in the straight reaches as compared to bays. In general by neglecting seasonal effects, YOY fish density (CPUE) was significantly (U -test) higher in bays than in straight reaches, with the individuals caught in bays being significantly smaller than in the straight reaches (Table II). The length differences were attributable to the dominance of small roach larvae and juveniles in the bays in May and June when hardly any YOY fishes were caught in the straight reaches (Figs 2 and 3). Apparently, in May and June nearly all YOY fishes were aggregated in bays. Their L_T were <20 (May) to 45 mm (Fig. 4). From July until October no statistical differences were detected between bays and straight reaches for mean L_T PP of the total catch (Fig. 4) and of perch and roach.

HABITAT CHOICE

Fish abundance (CPUE) and species diversity (SPP) was correlated positively with plant cover and inversely with substratum diameter (Table III). This pattern was also apparent for CPUE using the Strauss index of linear selection. Smaller YOY fishes were associated with plants, near the shoreline, exposed to

TABLE II. Mean \pm s.e. catch (CPUE), species number (SPP) and total body length per sample point (L_{TPP}) of YOY fishes caught during the sampling period May–October 1999 in the meso-habitats bay and straight reach in the main channel of the Oder-Havel-Kanal

	Bay	Straight reach
CPUE	1.14 \pm 0.24***	0.31 \pm 0.03
SPP	1.22 \pm 0.03	1.23 \pm 0.04
L_{TPP}	55.89 \pm 1.71**	64.41 \pm 0.93

** $P < 0.01$; *** $P < 0.001$.

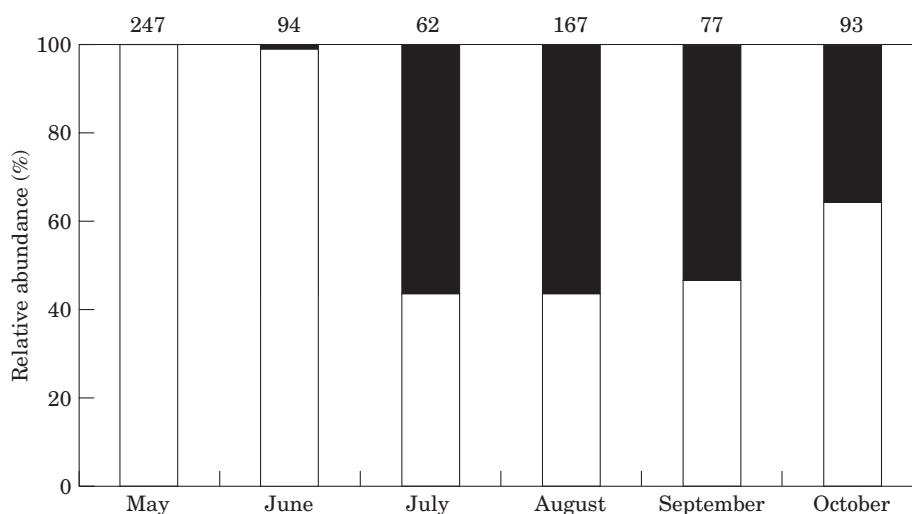


FIG. 3. Relative abundance of YOY fishes caught between May and October 1999 in the meso-habitats bay (□) and straight reach (■) in the main channel of the Oder-Havel-Kanal. Numbers at top of bars are sample sizes.

sun and at reduced substratum coarseness (Table III). Logistic regression of the null samples did not reveal any obvious pattern of habitat avoidance by YOY fishes.

Differences in habitat choice were determined comparing bay and straight reach (Table III). Whereas in the bay, YOY fish distribution was dependent on plant cover, in the straight reach Spearman rank correlations were significant for water depth and distance from bank, which in the bay did not have a detectable effect on habitat choice of fishes.

STRUCTURAL DIFFERENCES BETWEEN TRANSECTS AND MESO-HABITATS

Negligible differences in habitat characteristics were found between transects and meso-habitats. Eigen values of the discriminant functions were < 1 and thus

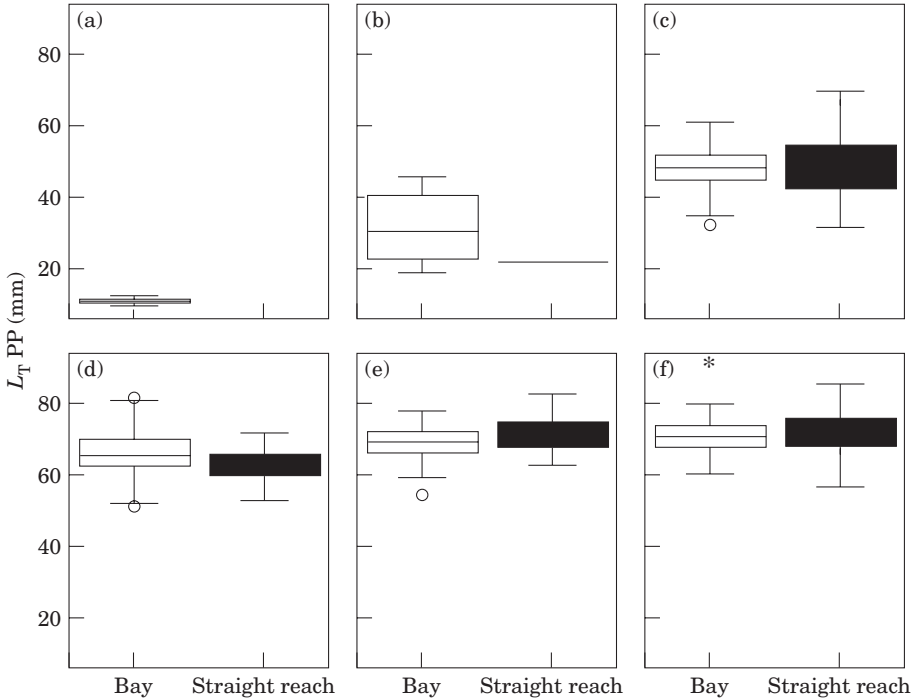


FIG. 4. Box plots of mean YOY fish total body length per point caught in (a) May, (b) June, (c) July, (d) August, (e) September and (f) October 1999 in the meso-habitats bay and straight reach in the main channel of the Oder-Havel-Kanal. ○, *, outliers.

were not of relevance. There was a high degree of structural homogeneity within the transects 1 and 2 and meso-habitats bay and straight reach of the main channel of the OHK.

FLOW VELOCITY FOOTPRINTS WITHIN MESO-HABITATS DUE TO NAVIGATION

In the absence of navigation, the flow velocity in the OHK is $<0.05 \text{ m s}^{-1}$. The passage of a typical barge tow in the OHK (length, 80–110 m; width, 7–9 m; tonnage, 680–1000 GRT; speed, $1.9\text{--}2.3 \text{ m s}^{-1}$) resulted in an increase of the flow velocity in the straight reach up to 80 cm s^{-1} . Inside the bay, the same barge tow induced a flow velocity four times smaller [Fig. 5(a)]. The maximum water level depression during barge passages was *c.* 20 cm and differed only slightly between locations [Fig. 5(b)]. Barge tows affected the flow velocity patterns in a similar way, whereas the passage of smaller pleasure boats (length, $<13 \text{ m}$; width, $<4 \text{ m}$; speed, $<3 \text{ m s}^{-1}$) induced a maximum flow velocity of 20 cm s^{-1} (Fig. 6).

DISCUSSION

GENERAL FISH RECRUITMENT PATTERN

Fish recruitment in 1999 was representative of the adult fish assemblage in the OHK (Wolter & Vilcinskis, 1997a, 2000) and showed within the structural constraints of an extreme biotope a typical pattern of chronology of appearance,

TABLE III. Spearman rank correlation coefficients between catch (CPUE), species number (SPP) and total body length per sample point (L_{TPP}) and various environmental modalities in the main channel and in the meso-habitats bay and straight reach of the Oder-Havel-Kanal in 1999

	Water depth	Distance from bank	Plant cover	Substratum diameter	Sun exposure	Visibility
Main channel						
CPUE	NS	NS	0.21**	-0.16**	NS	NS
SPP	NS	NS	0.12*	-0.17**	NS	NS
L_{TPP}	NS	0.22**	-0.13*	0.17**	-0.29*	NS
Bay						
CPUE	NS	NS	0.31**	-0.17*	NS	NS
SPP	NS	NS	0.18*	-0.17*	NS	NS
L_{TPP}	NS	NS	-0.17*	NS	-0.45**	NS
Straight reach						
CPUE	-0.17*	-0.22*	NS	NS	-0.22**	NS
SPP	-0.24**	-0.26**	NS	-0.18*	-0.24**	NS
L_{TPP}	0.28**	0.50**	NS	0.17*	NS	NS

NS, not significant ($P>0.05$); * $P<0.05$; ** $P<0.01$.

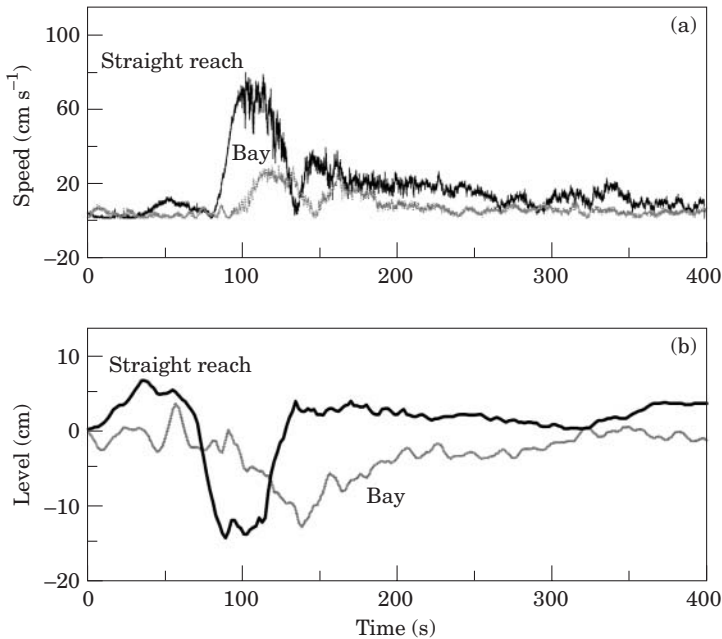


FIG. 5. Flow velocity (a) and water surface elevation (b) produced by a barge tow in the meso-habitats bay and straight reach in the main channel of the Oder-Havel-Kanal (see Fig. 1) in June 2001.

density and growth (Fig. 2; Floyd *et al.*, 1984; Schlosser & Angermeier, 1990; Scheidegger & Bain, 1995; Garner, 1996). The relative abundances of the most dominant adult fishes were well matched by the dominance structure of the YOY

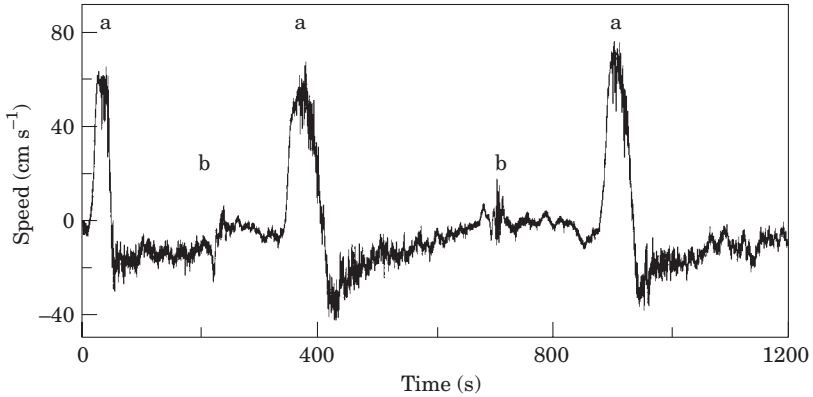


FIG. 6. Velocity patterns of three barge tows (a) and two pleasure boats (b) measured in the straight reach (see Fig. 1) in the main channel of the Oder-Havel-Kanal in June 2001.

fish community (Table I). Two species, sunbleak and dace, were recorded for the first time whereas six sporadic adult fishes, asp *Aspius aspius* (L.), burbot *Lota lota* (L.), rudd *Scardinius erythrophthalmus* (L.), three-spined stickleback *Gasterosteus aculeatus* L., spined loach *Cobitis* sp., white bream *Abramis bjoerkna* (L.), were not detected as YOY fish, which confirms low recruitment of these species. The aim of the study was to sample habitats representative of the straightened canal course. In contrast, Wolter & Vilcinskas (1998b) sampled several specific micro-habitats (e.g. mouth of tributaries) with higher habitat variability, which were not considered in this investigation. Therefore, it was not expected that the whole species assemblage would be sampled as YOY fishes. In the present study, the recruitment of several species of the adult fish assemblage in the OHK was underestimated. This stems from the fact that some species such as bream *Abramis brama* (L.) are known to spawn in tributaries of the OHK and colonize the main channel as older fish (Arlinghaus, 2000) and other species such as bleak prefer the pelagic early in ontogenesis (Copp, 1992). Both habitats were not sampled regularly and pelagic fish are generally under-represented in electrofishing surveys (Reynolds, 1996).

IS THERE AN INFLUENCE OF SHIPPING ON YOY FISH DISTRIBUTION?

Complex interactions of biotic, abiotic and spatial factors determine the structure of fish communities (Jackson *et al.*, 2001). Recently, there is a growing body of evidence for rivers (Gaudin, 2001) and waterways (Wolter & Vilcinskas, 1997b), that abiotic factors such as physical disturbances are of higher significance in controlling fish diversity, population dynamics and production than biological interactions such as predation and competition (Schiemer *et al.*, 2001). River regulation, channelization, rip rap embankment and reduction of shoreline structures (Copp, 1990a; Jurajda, 1995; Scheidegger & Bain, 1995; Wolter & Vilcinskas, 1997a; Schmetterling *et al.*, 2001) enhance the negative effects of physical disturbances such as flood pulses in regulated rivers (Pearsons *et al.*, 1992; Schiemer *et al.*, 2001) or ship-induced waves in waterways (Wolter & Vilcinskas, 1997b). This is most pronounced in straightened and monotonously embanked canal courses and urban watersystems (Wolter & Vilcinskas, 2000; Wolter, 2001). Exposed to flow, YOY fishes are known to prefer conditions of

low flow at the shoreline (Floyd *et al.*, 1984). This particularly applies in the first days after hatching, because swimming ability and resistance to current velocities are not only species specific (Garner, 1999) but also length specific (Mann & Bass, 1997). Therefore, with increasing fish length, YOY fishes are able to resist higher water velocities which enables habitat shifts and habitat partitioning between species (Gaudin, 2001). In the OHK, the main physical disturbances are increasing water currents during ship passages (Figs 5 and 6). In May and June, nearly all YOY fish sampled from the littoral were found in bays (Fig. 3), where flow velocity during ship passages was substantially lower than in the straight reaches (Figs 1 and 5). Although adult fishes including roach were observed to spawn in straight reaches, roach larvae were not caught there in May (Fig. 3). Generally, significantly higher YOY fish densities (CPUE) and significantly smaller fishes were found in bays (Table II), which confirmed the main hypothesis of this study. With increasing L_T , YOY fishes were apparently able to colonize the straight reaches with less risk of being washed out by ship waves (Fig. 4). Therefore, median L_T of YOY fishes were not significantly different in samples taken in bays and straight reaches from July to October. It remains uncertain, however, whether the distributional patterns of the YOY fish assemblage, especially in May and June, is attributable to a preference of YOY fishes for bays, passive drift of fish larvae or high mortality in the straight reaches precluding YOY fishes being sampled.

Although the observed YOY fish distribution in the OHK cannot be directly linked to the shipping-induced flow velocity by structuring the YOY fish community, there are at least four indications that support this hypothesis: (1) roach larvae are strictly bound to low flow patches near the shoreline (Copp, 1990b; Garner, 1996; Mann, 1996) and displacement velocity for larvae of 7.5 mm was reported to be 6.9 cm s^{-1} (Lightfoot & Jones, 1996). In the OHK even among (loose) vegetation, however, current velocities reached up to 20 cm s^{-1} in bays and 80 cm s^{-1} in straight reaches (Figs 5 and 6). Therefore, in the OHK apart from high predation pressure because of a lack of refuges in vegetated micro-habitats and shallow water areas (Bischoff & Wolter, 2001), a high mortality as a result of shipping was conceivable, most likely in the straight reaches (Wolter & Vilcinskas, 1997b). This may explain the substantial decline of roach abundance after the high densities observed in May and June (Fig. 2) and the lack of YOY fishes in straight reaches in these months (Fig. 3). These findings agree well with those of Duncan *et al.* (2001), that YOY fishes avoided sites with a flow velocity $>20 \text{ cm s}^{-1}$ in the River Thames. Generally, depending on the substratum roughness, older (and larger) YOY fishes are able to resist higher water velocities up to 60 cm s^{-1} (Mann, 1996). This may have allowed YOY fishes to colonize the straight reaches from June onwards (Fig. 4). Overall significantly smaller fishes were found in bays (Table II), which further substantiates the hypothesis that the higher shipping induced flow velocities in straight reaches inhibit colonization by smaller YOY fishes with a restricted swimming ability; (2) although the known biotic interactions would favour roach over perch in hypertrophic ecosystems (Persson *et al.*, 1991), perch dominate in canals (Wolter & Vilcinskas, 1997b). In the aquatic ecosystems of German lowlands, perch typically spawn in March or early in April (Wolter *et al.*, 1999). Many authors report, apparently genetically fixed, ontogenetic habitat shifts with perch

larvae moving out into the pelagic area and after some time returning to the shallow-water areas of the littoral (Urho, 1996). Migration back to the littoral seems to take place gradually when the fish have reached a length of 8 to 40 mm (Urho, 1996). Although perch were certainly present in the OHK in May, YOY perch were recorded for the first time in June (Fig. 2). At that time, the whole population of YOY perch was offshore and could not be caught in the littoral. In July, the movement back into the littoral was probably completed because no perch were sampled in the pelagic. Offshore perch larvae may be less influenced by ship waves than roach larvae in the littoral which are strictly bound to the shoreline. This pattern might favour perch over roach under anthropogenic influences in canals, which has led to the proposition of 'perch as an indicator species for structural degradation in regulated rivers and canals' (Wolter & Vilcinskis, 1997b); (3) nearly all ecospecies (e.g. YOY roach, bream, chub and gudgeon), except juvenile bleak and perch and zander larvae, prefer shallow water <1 m deep, within 6 m of the bank with some plant cover (Garner, 1996). Thus, it was expected that the sparse macrophyte stands in the OHK would be densely populated by YOY fishes to increase growth and reduce predation risk (Garner, 1996). Although within the main channel a positive aggregation of smaller YOY fishes and plant cover was detected, no correlations were observed for the straight reach alone (Table III). It is suggested that strong water currents combined with a slightly lower abundance of macrophytes in the straight reaches inhibit YOY fishes from colonizing vegetation in these areas. In bays, water currents after ship passages seemed to be not too high to inhibit colonization of plants by YOY fishes (Table III). Contrasting correlations in bays and straight reaches may be interpreted as a result of the differences in water currents (Fig. 5), because habitat structure was similar between the meso-habitats within the main channel of the OHK; (4) Linfield (1985) suggested an avoidance behaviour of fishes in relation to navigation. In the OHK, in tributaries which are rarely subject to ship traffic, significantly higher YOY fish densities were detected (Arlinghaus, 2000). This indicated that even tolerant (e.g. eurytopic) fish species found better reproduction zones and nursery areas in tributaries where (a) the effect of navigation was practically absent, and (b) habitat variability was greater (Arlinghaus, 2000).

The present study did not verify a mechanical impact of ship-induced waves and associated shear stress on larval fishes directly (Morgan *et al.*, 1976; Holland, 1986). In addition to the potential impact of navigation on YOY fishes discussed, however, several negative effects of intensive navigation on YOY fishes may occur in the OHK including disturbance of habitat, resuspension of canal bed substratum and hence increase of turbidity, dislodgement and damage of eggs and larvae, flow velocity-induced higher energy cost for feeding as well as reduction of aquatic vegetation and food resources such as invertebrates (Hofbauer, 1965; Morgan *et al.*, 1976; Holland, 1986; Murphy *et al.*, 1995; Jude *et al.*, 1998). This may result in a shift in the fish community composition with increasing boat traffic and a reduction in total fish biomass (Linfield, 1985; Pygott *et al.*, 1990b). Further studies are necessary to allow for an objective evaluation of a negative impact of ship waves on YOY fishes.

This study demonstrated the relatively low fish reproductive potential of navigable, artificially embanked lowland canals. To improve fish reproduction,

modification of canal banks is highly advisable to preserve existing bays and tributaries and even to create additional ones.

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