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Fish (Osteichthyes) in Biesbosch storage reservoirs (the Netherlands): a method for assessing complex stocks of fish

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Abstract. A new method of habitat volume and CPUE weighting of gillnet catches is proposed and reasonable correspondence was found between the length and weight compositions of acoustic and netting results. The fish stock in three Biesbosch reservoirs (the Netherlands) was studied using an echosounder, Nordic multi mesh gillnets, fry trawling and beach and purse seining. There were up to 11 benthic and open water habitats in the reservoirs based on the depth and slope of the bottom. All these habitats were inhabited by fish but differed in terms of the relative abundance, age and species present, volume and importance. The fish stock can be characterized as a smelt-pikeperch system. In addition to European smelt, important prey fish are common bream and roach. The survival rates of the prey fish were extremely low. The survival rate of percid fish (European perch, pikeperch and ruffe) was much higher. Lack of cyprinid reproduction and a high natural mortality keep the total biomass of fish at less than 100 kg×ha^{-1}.

Key words. Osteichtyes, methods, ichthyology, fish distribution, bank-side reservoirs, acoustics, gillnets, intercalibration, CPUE, *Perca*, *Sander*, *Rutilus, Abramis*, *Osmerus*, *Gymnocephalus.*

INTRODUCTION

Obtaining reliable information on the fish in large inland waters is still extremely difficult and usually requires a combination of methods (Cowx 2002). Acoustic monitoring greatly increases the possibility of surveying these waters quantitatively. The best systems are those with one or very few species living deep enough to be surveyed vertically (Jurvelius et al. 1984, Brenner et al. 1987, Mehner & Schultz 2002, Schmidt et al. 2005, etc.).

There are also water bodies where there are many species and many age classes at all depths and the species composition depends on the depth. Many of the acoustic studies on such multispecies systems simply do not attempt to determine the species of fish present and just use acoustic information to assess the fish stock (Kubečka & Wittingerová 1998, Knudsen & Saegrow 2002, Swierzowski et al. 2002). Attempts to link quantitative information from acoustic surveys with qualitative or semi-quantitative information from captures of fish are done with varying success (Bagenal 1981, Argyle 1992, Dahm et al. 1992, Yule 2000). For complicated situations there are not many examples of successes and the interpretation of acoustic data in terms of quantity for multispecies fish communities still present a challenge (Dahm et al. 1992, Jurvelius et al. 2011).

Table 1. Characteristics of the Biesbosch reservoirs

reservoir	De Gijster (DG)	Honderd en Dertig (HD)	Petrusplaat (PP)
surface area (ha)	305	210	100
volume (10^6 m^3)	40.0	33.5	13.0
maximum depth (m)	27	28	15
average depth (m)	13	15	13
retention time (weeks)	11	9	4

The goal of this study was to combine the results of acoustic monitoring and netting to provide a quantitative estimate of all age groups of all significant species in multispecies fish assemblages in three reservoirs in De Biesbosch (BBR) in the Netherlands. It also sought to use these methods to calculate the overall abundance, biomass, species and age distributions of the fish.

MATERIAL AND METHODS

Study area

The cascade of three artificial bank-side reservoirs (De Gijster – DG, Honderd en Dertig – HD and Petrusplaat – PP; Table 1) in De Biesbosch area near the town of Dordrecht, the Netherlands, was investigated in late August or early September in 2000 and 2002. For site descriptions and map see Ketelaars et al. (1998). Water from the eutrophic River Meuse is pumped into DG (4–10 m^3×s^{-1}) from where it flows into HD, then PP and finally is processed by drinking water treatment plants. The water in the reservoirs is artificially de-stratified by air jetting (0.8 m^3×s^{-1} of air in each jet, 3–6 jets per reservoir; Van Breemen & Ketelaars 1995) and thus temperature, oxygen and plankton concentrations were very homogeneous in the reservoirs. The fisheries in these reservoirs were not managed, stocked or fished except that necessary for the current study (Table 3).

Habitat classification

Reservoirs habitats were classified according to the presence and properties of the bottom, depth and the specific methods used to sample them (Table 2, Fig. 1). In general, habitats were either benthic or pelagic. Using the descriptions in Table 2, near bottom habitats were read from the bathymetric map of the reservoirs and their areas estimated using gravimetric planimetry. Estimates of these areas were used to extrapolate the volumes of the habitats in the reservoir (DV_j, given by Prchalová et al. 2006). The range in depth of the littoral habitat was defined methodologically; 4 m was the depth of the largest seine net used. The height of benthic habitats was set at 1.5 m above the bottom, which is the height of a standard

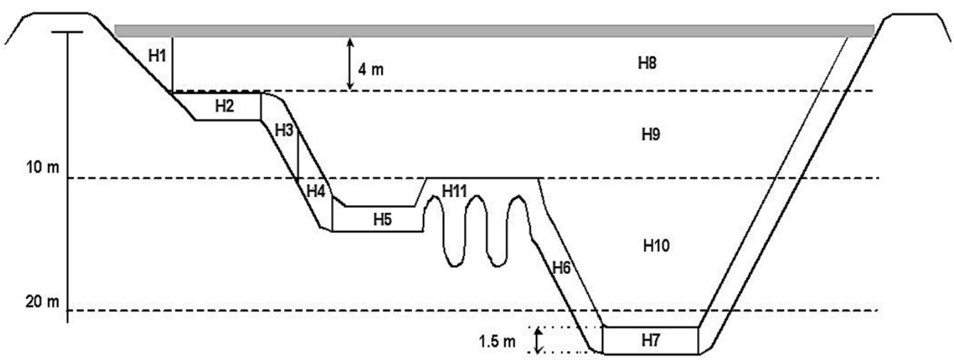

Fig. 1. General scheme of habitat classification presented in the form of a simplified diagram of a Biesbosch reservoir showing the locations of all the habitats. Benthic habitats were always 1.5 m deep.

Table 2. Description of the habitats studied

habitats	no.	code	water layer height	water layer lower depth	other information	reservoirs	sampling tools
benthic:							
littoral	H1	LIT	≤4 m	4 m	near shore region	DG, HD, PP	seine nets, benthic gill nets
shelf	H2	SH	1.5 m	6–7 m	100–200m wide flat area, former polder surface	DG	benthic gill nets, horizontal acoustics
upper slope	H3	US	1.5 m	4–10 m	on the slope	HD, PP	benthic gill nets, vertical acoustics
middle slope	H4	MS	1.5 m	>10 m down to H5 and H6	on the slope	DG, HD, PP	benthic gill nets, vertical acoustics
flat bottom 15 m	H5	FB15	1.5 m	15 m	flat area	DG, HD, PP	benthic gill nets, vertical acoustics
lower slope	H6	LS	1.5 m	>15 m down to H7	on the slope	DG, HD, PP	benthic gill nets, vertical acoustics
flat bottom 20 m	H7	FB20+	1.5 m	>20 m	flat area	DG, HD	benthic gill nets, vertical acoustic
moon landscape	H11	MOON	1.5 m	15 m	area with deep holes and uneven surface	DG, HD	benthic gill nets, vertical acoustics
pelagic:							
upper open water	H8	UOW	≤4 m	4 m		DG, HD, PP	epi-pelagic gill nets, fry trawl, purse seine, horizontal acoustics
middle open water	H9	MOW	≤6 m	10 m		DG, HD, PP	meso-pelagic gill nets, fry trawl, purse seine, vertical acoustics
lower open water	H10	LOW	≤10 m	>10 m down to H7 and H11	>1.5 m from the bottom	DG, HD, PP	bathy-pelagic gill nets, fry trawl, vertical acoustics

Table 3. Sampling effort of the different sampling gear used to survey the Biesbosch reservoirs (years 2000 and 2002)

sampling gear	units of effort	2000	2002
fry beach seine	total length of nets used for night seining (m)	780	810
adult beach seine	total length of nets used for night seining (m)	1400	1350
acoustics	millions of cubic meters sampled	29.7	34.5
benthic gill nets	square meters of net exposed per night	15,114	14,641
pelagic gill nets	square meters of net exposed per night	26,315	25,350
pelagic fry trawl	cubic meters sampled	12,500	61,500
purse seine	cubic meters sampled		108,000

Nordic multi mesh gillnet (Appelberg et al. 1995). Pelagic habitats extend down to either the next open water habitat or the benthic habitat at the bottom of the reservoir.

In the following text, reservoir and habitat names are abbreviated and the codes are given in Tables 1 and 2, respectively.

Direct fishing

All fish were identified and either the length measured (to an accuracy of 5 mm) or split into obvious size groups (large catches of 0+ fish), weighed (to an accuracy of 1 g) and counted. Representative samples of scales and otoliths were collected from several hundred fish in each reservoir for determining age and growth. The sampling effort expended in carrying out the surveys is given in Table 3. All active sampling (acoustics, seining and trawling) was done on the same nights in the last week of August or the first week of September. The gill nets were set in the evening (after 7 p.m.) and hauled back in early in the morning (at 7 a.m.) the following day. The acoustic surveys and seine net fishing were carried out during the same night the gill nets were set. It took 18 people two to three nights to survey each reservoir.

Shore seining

Quantitative shore seining was performed at night. The “fry” seine net was 30 m long, 3 m deep with a mesh size of 6 mm. The net was kept open by the bottom line, which has a weight attached to each end. The area sampled by one seine haul was 270 m^2 (calculated according to Kubečka & Bohm 1991). The areas used for sein netting (up to 10 locations) were located randomly along the shoreline of the reservoirs.

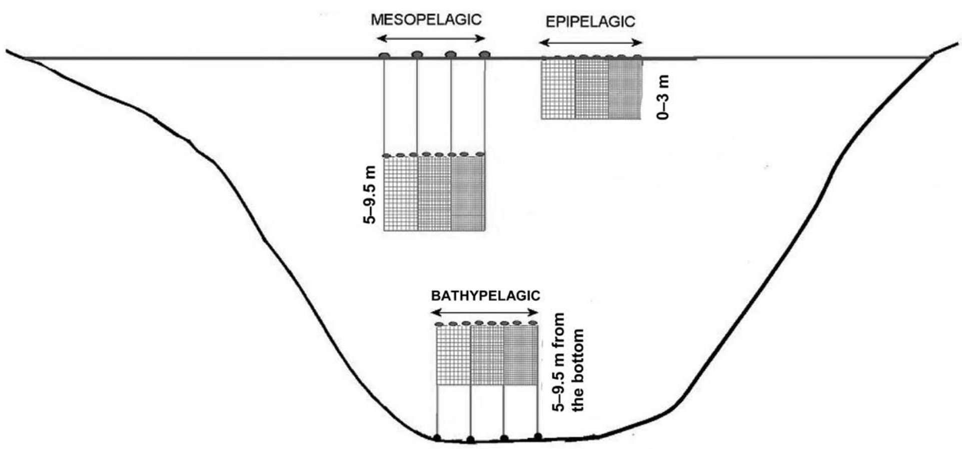

Fig. 2. The scheme of settings of the three types of pelagic gill nets used in BBR. The picture schematically shows three types of mesh but in fact 14 mesh sizes were used.

Gillnetting

Two types of gill nets were used in the current survey:

(1) Benthic gill nets. “Standard Nordic multi mesh gillnets” modified to conform to the specifications of Appelberg et al. (1995) and Kurkilahti & Rask (1996). The mesh sizes were 5, 6.25, 8, 10, 12.5, 16, 19.5, 24, 29, 35, 43, 55, 70 and 90 mm knot-to-knot. They differed from the original design in the extension of the series to 70 and 90 mm meshes and the extension of the size of each panel; the series of nets were 10 times longer than in the original design (the length of each panel was 25 m instead of 2.5 m) with a height of 1.5 m.

(2) Pelagic gill nets (Fig. 2). “Standard Nordic multi mesh gillnets” were modified as described above to the same 5–90 mm range of mesh sizes. Epi-pelagic, surface mounted nets were 3 m high, with each panel 25 m long, which hung from the surface from PET-bottles and a strong float line (sampling UOW). The buoyancy of the float line of the meso-pelagic nets was lower than the weight of a lead line and these slowly sinking nets were kept in the MOW by means of 5 m long ropes attached to the PET-bottles on the surface. The positioning of the bathy-pelagic nets was determined by the increased buoyancy of the float line (the same as that of the epi-pelagic nets) and bricks connected to the lead lines by 5 m long ropes. When installed on FB20+ these nets sampled layers 5–9.5 m above the bottom or the LOW. The meso-pelagic and bathy-pelagic nets were 4.5 m high.

The total catch of all gill nets was standardized to that for a 1000 m^2 net in order to be able to compare the catches in different habitats.

Purse seine

A purse seine made according to Tischler et al. (2000) was used to sample UOW and MOW. The seine was 120 m long, 12 m high with three mesh sizes (10, 8 and 6 mm). The finest mesh was in the very last quarter of the net pulled from the water. The purse seine was set by a special boat, 7.5 m long and 1.3 m wide, powered by a 15 HP outboard engine. The area fished was about 12,000 m^2. This type of sampling was carried out at night.

Table 4. List of the species of fish recorded in different habitats in the BBR during years 2000–2002. LSB – littoral and shallow benthic habitats (<15 m), DBH – deep benthic habitats (≥15 m), PH – pelagic habitats. + – occurred, +(+) – sometimes it occurred, sometimes it was dominant, ++ – always dominant

scientific name	common name	Petrusplaat			Honderd en Dertig			De Gijster		
		LSB	DBH	PH	LSB	DBH	PH	LSB	DBH	PH
Osmerus eperlanus (Linnaeus, 1758)	European smelt	+	+	+	+	+	+(+)	+	+	+(+)
Coregonus sp.	whitefish			+						
Abramis brama (Linnaeus, 1758)	common bream	+(+)		+	+(+)	+(+)	+(+)	+(+)	+(+)	+(+)
Rutilus rutilus (Linnaeus, 1758)	roach	+	+		+(+)	+	+(+)	+(+)	+	+(+)
hybrid roach×bream			+	+	+		+		+	
Alburnus alburnus (Linnaeus, 1758)	bleak				+			+		+
Blicca bjoerkna (Linnaeus, 1758)	white bream				+	+		+	+	
Leuciscus idus (Linnaeus, 1758)	*ide*				+	+	+	+	+	+
Chondrostoma nasus (Linnaeus, 1758)	nase							+		
Cobitis taenia Linnaeus, 1758	spined loach							+		
Cyprinus carpio carpio Linnaeus, 1758	common carp						+			
Scardinius erythrophthalmus (Linnaeus, 1758)	rudd				+		+	+		
Carassius gibelio (Bloch, 1783)	Prussian carp							+		
Anguilla anguilla (Linnaeus, 1758)	European eel	+	+		+	+	+	+	+	+
Gasterosteus aculeatus aculeatus Linnaeus, 1758	three-spined stickleback	+		+	+			+	+	
Perca fluviatilis Linnaeus, 1758	European perch	++	++	+	+(+)	+(+)	+	+(+)	+(+)	+
Sander lucioperca (Linnaeus, 1758)	pike-perch	+	+(+)	+	+	++	++	+	++	++
Gymnocephalus cernuus (Linnaeus, 1758)	ruffe	+	+(+)	+	++	++	+	++	++	+
Cottus gobio Linnaeus, 1758	bullhead	+	+		+	+		+		
Platichthys flesus (Linnaeus, 1758)	flounder		+		+			+		
total number of species		9	8	8	15	11	10	18	10	10

Fry trawl
A conical net with a square opening of 3x3 m and a length of 8 m was used (Jůza & Kubečka 2007). The mesh size was 7 mm in the belly and 4 mm at the cod-end. The trawl was pulled by a 25 HP diesel boat and the desired sampling depth was maintained by a weight attached to the lower rim of the frame and a float on a rope of known length connected to the top of the trawl frame. Towing speed was about 1 m s^{-1} (checked using the Garmin Ettrex Summit GPS). The depth of towing was checked by an echosounder mounted on another boat. The layers sampled were: 0–3 m, 3–6 m, 7–10 m, 12–15 m, and 15–18 m. This sampling was carried out at night.

Hydroacoustic split-beam survey
The sonar system was deployed on a specially equipped Dory 13 boat powered with a 15 HP engine. The transducer was attached to a remotely controlled aluminium plate so that the orientation of the beam could be varied, especially horizontally and vertically (Kubečka & Wittingerová 1998). The system used was a SIMRAD EY 500 split beam echosounder operating with a frequency of 120 kHz. An elliptical transducer with nominal beam angles of 4.3 and 9.1 degrees was used for this survey. This transducer had a low side lobe sensitivity (–35 dB two ways) and a good beam shape for horizontal application (an elliptical beam pattern enabled good positioning beneath the water surface, the uppermost at 4 m, UOW). The same transducer was also used for vertical beaming for a depth range from 4 m down to the bottom. The pulse duration was 0.1 ms, the frequency band width 10 kHz and the pulse repetition rate 10 Hz. The Simrad EY 500 software was set to create a new data file after the collection of two MB of data. The reservoir was surveyed by means of a random grid.

The whole sonar system was calibrated using a 23 mm copper standard target centered in the beam using beam centering. The gain of the sounder was calculated according to Foote et al. (1987). The whole sonar system and PC was powered by a 12 V battery. The reverberation level during calm nights was low and the noise threshold was kept at –65 dB for both horizontal and vertical surveys. Echo-integration samples were stored without a threshold.

Post-processing of data was done using Sonar 5 software (Balk & Lindem 2005). The threshold for fish detection by vertical beaming was set to a TS of –56 dB (approximately a length of 2.8 cm according to Love 1971). In horizontal beaming, the TS threshold was kept at –65 dB due to the uncertainty of weak reflections from small targets. The 20 Log R threshold for echo-integration was set according to the TS threshold to see approximately the same target population on the screen. Fish density per m^3 was achieved by dividing the average volume backscattering coefficient S_v by the average backscattering cross-section (σ_{bs}, see Simmonds & Mac Lennan 2005 for definitions). Calculation of real fish lengths from TS was done by applying Love's regression for vertical beaming (Love 1971). The de-convolution sizing procedure of Kubečka et al. (1994) with the sizing regressions from Frouzová et al. (2005) were used for horizontal beaming. The biomass of acoustically detected fish was calculated using the length-weight relationship obtained from netting catches by pooling all species together. Average fish weight W_u was calculated for every 1 dB TS frequency group $_u$. Average weight $\hat{W}$ for whole target population was calculated using the frequency of targets in the group $_u$ (F_u).

$$\hat{W} = \sum_u W_u F_u / \sum_u F_u \qquad (1)$$

Average biomass of fish per hectare was obtained by multiplying the average weight by the density per hectare.

Weighted calculations of fish stock composition and biomass
Assessment of fish stock composition in BBR has several important dimensions:
Species. The most important species of fish in this system of reservoirs were roach, bream, perch, pikeperch, ruffe and smelt (scientific names in Table 4). For these species we provide an estimate of the stock and its age composition. Species were marked by the index $_i$ and the range was 1–n.
Habitat. Eleven types of habitat were recognized in the reservoirs (Fig. 1). All habitats were inhabited by fish, the habitats differed in terms of volume (Prchalová et al. 2006), relative abundance fish (characterized by the Catch-Per-Unit-Effort CPUE, inds 1000 m^2 of gill nets), species and age composition. All results for the whole reservoir were weighted by the volumes and CPUE. The habitats are marked $_j$ ranging between 1 and m.
Length groups. The length groups (by 5 mm) were indexed $_L$, ranging from 1 to r within the whole population and from g to h within one age group. The correction for gill net selectivity in terms of underestimating numbers of small fry was based on fry trawl and purse seine (open water) and shore fry seine (littoral) catches, according to Prchalová et al. (2009).
Age class. The length-frequency distribution of the main species in every habitat was converted to an age frequency distribution using the age-length key obtained from the scale and sagittal otolith readings. Age classes were indexed $_k$, ranging from 0 to p.

Weighted age-species composition
The **Abundance Index** AI_{ijk} was introduced in order to weight both the influence of CPUE and the volume of the habitat $_j$ (DV_j).

$$AI_{ijk} = CPUE_{ijk} * DV_j / V_{tot} \qquad (2)$$

where **CPUE** is Catch Per Unit Effort of gill nets for species $_i$, age class $_k$ in habitat $_j$, and V_{tot} is the total volume of the reservoir. The same procedure was applied for Biomass catch Per Unit Effort (BPUE) of gill nets.

The **Age Class Share** $\boldsymbol{ACSh_{ik}}$ of a species $_i$ is then computed as:

$$ACSh_{ik} = \sum_j AI_{ijk} / \sum_k \sum_j AI_{ijk} \tag{3}$$

The **Species Share** ($\boldsymbol{SSh_i}$) is analogically computed as follows:

$$SSh_i = \sum_k \sum_j AI_{ijk} / \sum_i \sum_j \sum_k AI_{ijk} \tag{4}$$

Parameters ***ACSh*** and ***SSh*** may be transformed to percentage values by multiplying by 100. Table 5 gives an example of the weighted procedure for calculating the *SSh* for HD reservoir in 2002.

For quantitative results it is useful to standardize species and age class shares based on a unit of area (age-class abundance $\boldsymbol{ACA_{ik}}$, inds ha^{-1}).

$$ACA_{ik} = SSh_i * ACSh_{ik} * TFD \tag{5}$$

where *TFD* is the estimate of the total density of fish in a reservoir based on the results of the acoustic survey (inds×ha^{-1}).

Biomass composition

In order to estimate biomass of age class $_k$ and species $_i$, average weight of each age group W_{ik} was calculated in a volume--weighted way. The average volume-weighted catch for a reservoir per average sampling effort in an 'average habitat' $\boldsymbol{AVWC_{iL}}$ was calculated as:

$$AVWC_{iL} = \sum_{j=1}^{m} C_{ijL} * DV_j \Big/ V_{tot} \tag{6}$$

where C_{ijL} was the total catch (in numbers) of species $_i$ in habitat $_j$ and length group $_L$.

The length spectrum of r length groups was than divided into age groups using age length conversion from the scale and otolith readings. If the interval of length groups from g to h corresponded to the age class $_k$, then $\boldsymbol{W_{ik}}$ can be calculated as:

$$W_{ik} = \sum_{L=g}^{h} AVWC_{iL} * W_{iL} \Big/ \sum_{L=g}^{h} AVWC_{iL} \tag{7}$$

where W_{iL} was the average weight of fish species $_i$ in length group $_L$ calculated using the length-weight relationship.

The biomass in age class $_k$ and species $_i$ ($\boldsymbol{B_{ik}}$) can thus be calculated as:

$$B_{ik} = ACA_{ik} * W_{ik} \tag{8}$$

The total biomass of the given species ($\boldsymbol{B_i}$) can be calculated as:

$$B_i = \sum_{k=1}^{p} B_{ik} \tag{9}$$

The total biomass of all fish in the reservoir (B in kg×ha^{-1}) is:

$$B = \sum_{i=1}^{n} B_i \tag{10}$$

Biomass contribution of individual length groups was calculated following the method used by de Leeuw et al. (2003). The length-frequency distribution was divided into length range bins along the x-axis.

RESULTS

Species composition and relative abundance

Representatives of three families dominated the fish assemblages in the reservoirs either in terms of abundance or biomass (Osmeridae – smelt, Cyprinidae – roach and bream, and especially Percidae – perch, pike-perch and ruffe; Table 4). Percids were the dominant fish in all the surveys. Pike--perch and ruffe were always dominant in DG and HD, and perch in PP. The species composition in the littoral habitat in all three reservoirs was usually more diverse than in the benthic and open water habitats (Table 4), indicating that the rarer species usually preferred the littoral habitat. There were more common species and a richer ichthyofauna in DG and HD than in PP (Table 4). The acoustic and gill net surveys revealed that fish occurred in all habitats and at all depths in the BBR reservoirs (Tables 6 and 7). The only relatively empty habitat was the open water of PP.

Netting surveys

The abundance and biomass of fish in catches of the gill nets in HD and DG were very similar (Table 6). In terms of abundance, the richest habitats were littoral, middle slope and UOW. In 2002, there were high numbers of fish in the MOW of both reservoirs. In contrast, the highest biomass was recorded in the deeper benthic habitats (LS, moon landscape) than in those habitats with high numbers of fish, while LOW was always poor in fish. The CPUE in terms of numbers was lower in the deeper habitats, but not in terms of biomass (Table 6). However, a marked difference in the distribution of the different size groups of fish throughout the reservoirs with a few heavy fish in the deeper benthic habitats and many small fish (mostly age 0+) in upper waters of both open water and bottom habitats. In general, this was also the case for the distribution of fish in PP. In PP, however, all open water habitats were rather poor in fish. The weighted averages of CPUE and BPUE were always lowest in PP. The highest weighted average of CPUE was recorded for DG and of BPUE in HD (Table 6).

The weighted length-frequency distribution for all gill net catches corrected for the occurrence of 'late-born bream cohorts' (0+ bream of 30–50 mm, correction according to Prchalová et al. 2009) in the littoral and the open water showed a bimodal pattern in DG in 2002 (Fig. 3a). The first cohort with a modal group of 40 mm and the highest frequency was composed exclusively of 'late-born bream cohort' (bream is a multiple spawner and can produce several cohorts of fry during a season; early spring cohorts are as big as that of other spring spawning species while late cohorts are much smaller). In 2002, this cohort was by far the most numerous of all the species and age groups in DG.

The second peak (modal length 75 mm) corresponded to all other 0+ fish, mostly roach, smelt, ruffe and perch. Older age groups were obviously also present but their numbers were much lower and not apparent in this simplified expression. Cumulative length-frequency distributions (Fig. 4) reveal a small share of larger fish (about 2% of fish larger than 100 mm). Average individual weight of fish caught in the netting surveys varied between 10–30 g (Table 8). The highest average weight was recorded in PP in 2000 (there was a notable lack of small fish) and the lowest in DG in 2002 (due to enormous numbers of 'late spawned bream fry').

Acoustic surveys

The highest acoustic biomass of 66–89 kg×ha^{-1} was recorded in DG (the first reservoir in the cascade, Table 7). There was a slightly lower biomass (45–67 kg×ha^{-1}) in HD but not of abundance. Both abundance and biomass were the lowest in PP. An extremely low biomass was recorded there in 2002 (3.3 kg×ha^{-1}). In DG and HD, the majority of the fish recorded by vertical echo-sounding were below 4 m. However, the share in terms of horizontally recorded fish was significant (30–46% of abundance, 23–38% of biomass). The horizontally recorded biomass in the UOW in PP varied

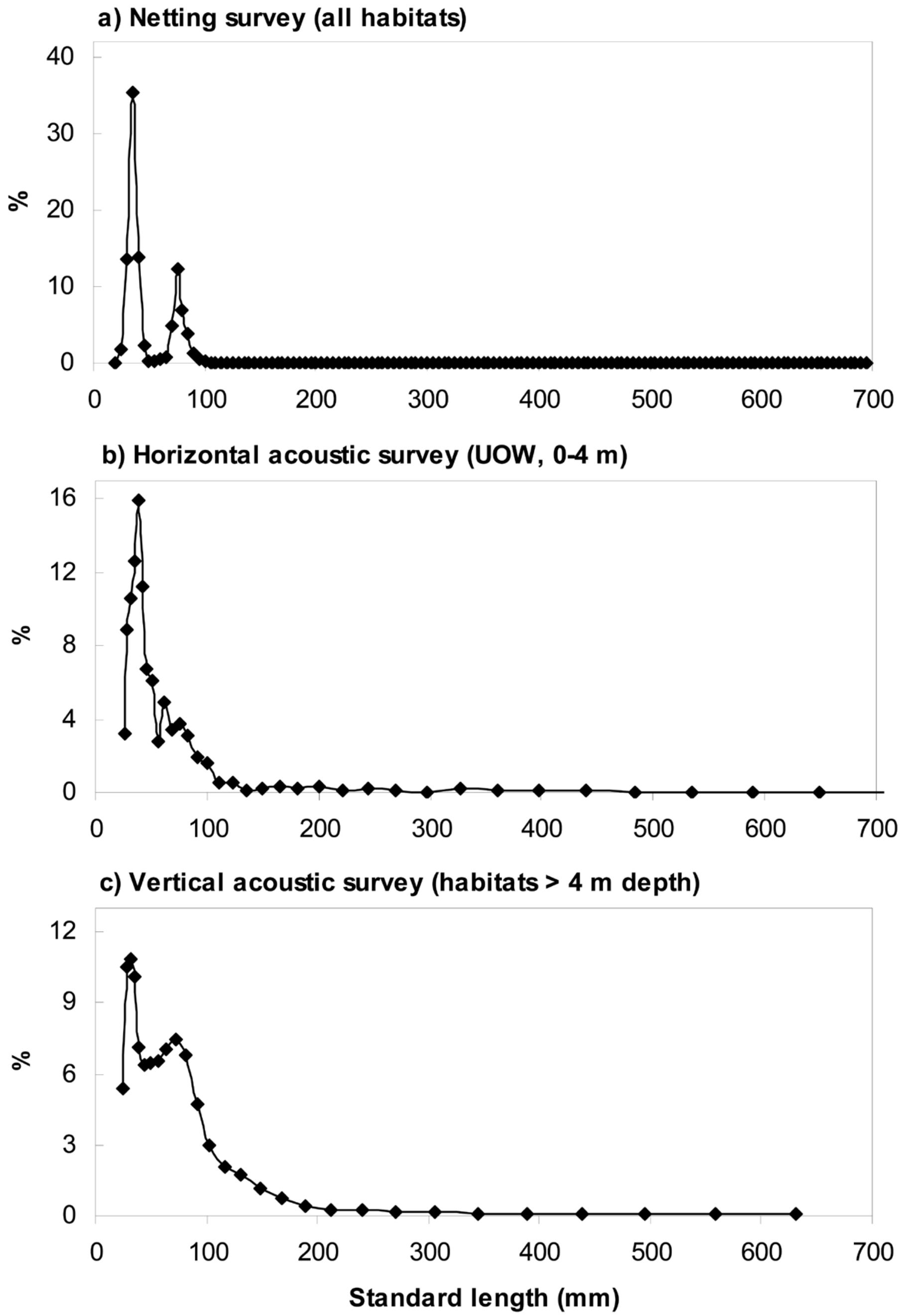

Fig. 3. The length-frequency distribution recorded using weighted volume from the gill net catches compared to the results of the horizontal and vertical acoustic surveys, DG 2002.

Table 5. Explanation of the way the data was weighted in the calculation used to determine the distribution of the species (or age groups) in all the reservoirs (SSh_i)

habitats		species $CPUE_{ij}$ (inds 1000 m^2)									
	$\sum_k \sum_i CPUE_{ijk}$	*Abramis brama*	*Perca fluviatilis*	*Rutilus rutilus*	*Sander lucioperca*	*Leuciscus idus*	*Gymnoc. cernuus*	*Blicca bjoerkna*	*Osmerus eperlanus*	other	DV_j (m^3)
littoral	1219	21	397	223	52	0	521	1	2	2	199,924
upper slope	1574	3	876	64	85	0	536	1	2	7	397,269
middle slope	1644	2	371	320	217	8	714	0	12	0	425,951
FB 15	728	3	103	88	165	0	361	0	8	0	820,585
lower slope	591	2	2	4	232	0	347	0	0	4	238,430
FB 20	235	6	10	0	120	0	88	0	0	11	211,793
moon landscape	714	0	25	74	378	0	229	0	0	8	1.011,910
UOW	2961	82	0	897	3	1	0	0	1977	1	8.019,193
MOW	958	31	0	182	7	0	0	0	738	0	10.874,818
LOW	71	2	3	0	41	0	9	0	15	1	11.300,127
total											33.500,000

	$\sum_k AI_{ijk}$ for individual species								$\sum_k \sum_j AI_{ijk}$ for habitats	
littoral	4.12	79.37	44.58	10.40	0	104.16	0.20	0.40	0.40	243.63
upper slope	1.19	348.01	25.43	33.77	0	212.94	0.40	0.79	2.78	625.30
middle slope	0.85	158.03	136.30	92.43	3.41	304.13	0	5.11	0	700.26
FB 15	2.46	84.52	72.21	135.40	0	296.23	0	6.56	0	597.39
lower slope	0.48	0.48	0.95	55.32	0	82.74	0	0	0.95	140.91
FB 20	1.27	2.12	0	25.42	0	18.64	0	0	2.33	49.77
moon landscape	0	25.30	74.88	382.50	0	231.73	0	0	8.10	722.50
UOW	655.49	0	7193.22	24.06	8.02	0	0	15853.94	8.02	23,742.75
MOW	337.12	0	1979.22	76.12	0	0	0	8025.62	0	10,418.08
LOW	22.60	33.90	0	463.31	0	101.70	0	169.50	11.30	802.31
$\sum_k \sum_j AI_{ijk}$	1025.58	731.72	9526.79	1298.71	11.43	1352.31	0.60	24061.93	33.88	*38,042.89
SSh_i	2.70	1.92	25.04	3.41	0.03	3.55	0	63.25	0.09	100

$* = \sum_i \sum_j \sum_k AI_{ijk}$

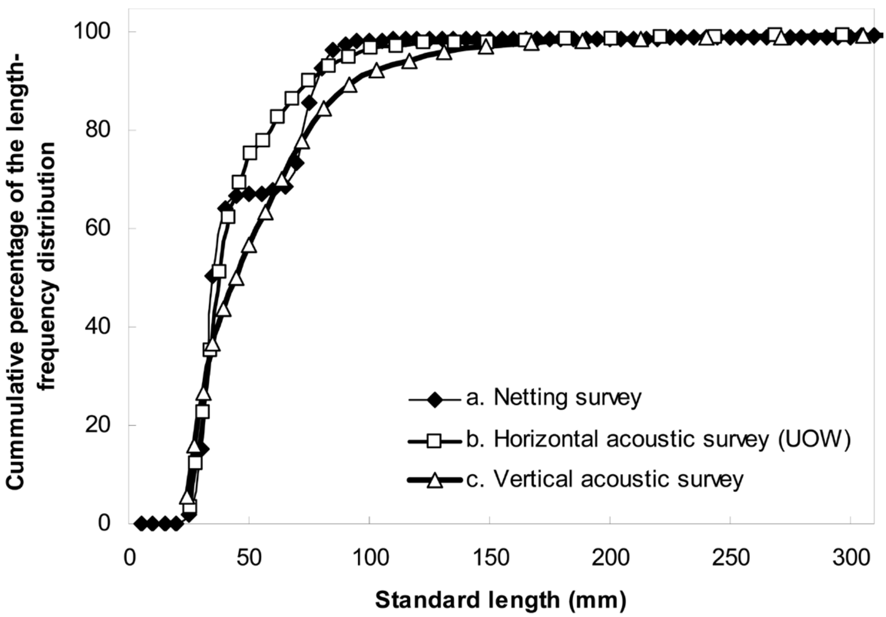

Fig. 4. Cumulative plot of the three data sets of Fig. 3.

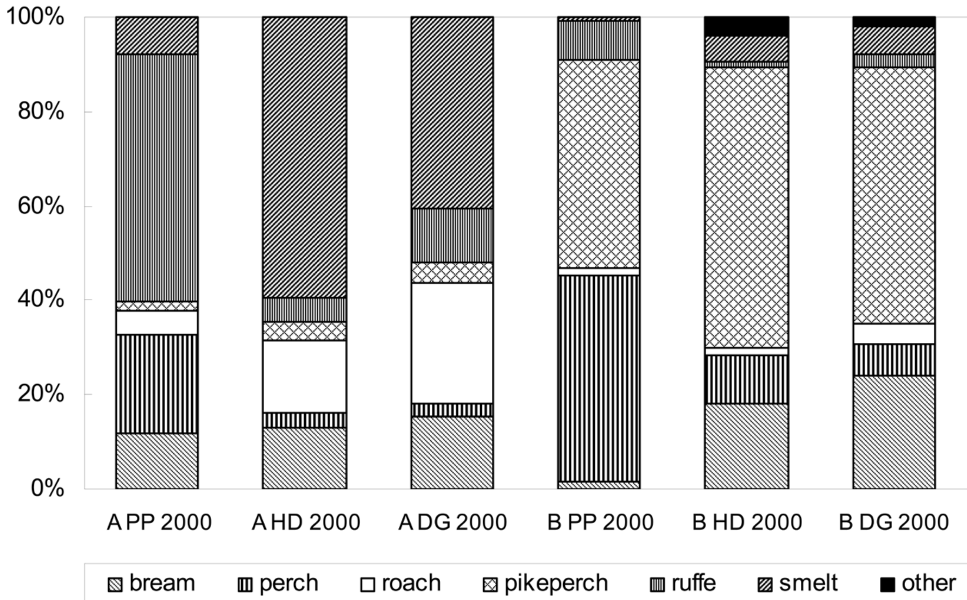

Fig. 5. The weighted species composition ($SSh_{i\%}$, formula 4) in terms of abundance (A) and biomass (B) in BBR in 2000.

Table 6. Gill net CPUE in individual habitats of the Biesbosch Reservoirs during the years 2000 and 2002. Average values are weighted using the DV_j of individual habitats. SD – standard deviation

year	CPUE abundance, 1000 inds×m^{-2} 2000 average	SD	2002 average	SD	CPUE biomass (BPUE), 1000 kg×m^{-2} 2000 average	SD	2002 average	SD
habitat	Petrusplaat (PP)							
littoral	1698	476	2680	792	6.5	2.5	19.0	6.2
upper slope	570	174	2867	709	10.8	8.9	32.8	13.1
middle slope	270	121	2562	1096	5.7	3.2	33.6	5.1
FB 15	771	261	1218	83	29.5	10.3	31.7	0.3
UOW	29	8	64	51	0.1	0.0	1.3	0.5
MOW	6	2	55	63	0	0	0.5	0.6
weighted average	118		293		3.3		4.7	
	Hondred en Dertig (HD)							
littoral	12114	4677	1202	32	26.2	9.3	23.7	1.4
upper slope	1451	410	1573	572	71.4	26.2	44.8	21.6
middle slope	917	170	1645	417	38.1	27.2	65.4	38.2
FB 15	228	70	728	295	14.1	13.1	47.7	13.0
lower slope	201	160	593	311	71.5	66.0	43.2	20.6
FB 20	127	88	234	125	24.1	16.3	40.7	21.5
moon landscape	271	170	714	509	78.5	56.4	50.9	21.2
UOW	1145	228	2880	1093	12.4	2.5	12.9	1.0
MOW	474	130	928	1117	5.6	1.1	7.7	3.8
LOW	57	77	71	24	28.1	18.7	18.7	0.2
weighted average	1012		1106		19.1		16.6	
	De Gijster (DG)							
littoral	1416	522	885	224	15.5	8.5	24.8	5.8
shelf	1350	288	890	116	47.2	21.1	71.9	11.0
middle slope	622	267	234	104	38.8	20.0	35.0	13.9
FB 15	97	25	178	74	26.5	22.1	15.3	7.5
lower slope	45	43	164	49	16.0	26.2	23.4	14.3
FB 20	52	18	115	25	15.1	15.9	23.5	12.5
moon landscape	97	23	191	12	26.5	16.8	27.8	10.0
UOW	931	89	2530	1570	7.9	1.9	12.0	10.9
MOW	190	48	935	471	8.3	3.3	5.8	2.5
LOW	243	294	130	58	12.0	5.2	10.1	1.3
weighted average	539		1329		12.3		13.8	

greatly (4–84% of total biomass). There was some tendency for bimodality in the length-frequency data recorded acoustically in DG (Fig. 3b, c); however, it was less clear in the data for netted fish. Horizontal records seem to indicate more small individuals (‘late spawned bream fry’), whereas both size cohorts were equally abundant in the records of vertical surveys. The length-frequency groups in the acoustic data are not equidistantly spaced along the X axis of Fig. 3 because of the logarithmic relationship between the acoustic target strength and fish length. As for netted fish, large fish are poorly represented and difficult to visualize but are more noticeable in the cumulative expression (Fig. 4). The average weight of the acoustically recorded fish varied between 6–35 g (Table 8). The highest value was recorded in PP in 2000 and the lowest in HD in 2000. There was

Table 7. Acoustic estimates of the abundance and biomass of all the fish in the Biesbosch reservoirs

habitat	year	Petrusplaat		Honderd en Dertig		De Gijster	
		abundance inds×ha^{-1}	biomass kg×ha^{-1}	abundance inds×ha^{-1}	biomass kg×ha^{-1}	abundance inds×ha^{-1}	biomass kg×ha^{-1}
UOW (0–4m)	2002	92	2.79	2997	25.28	2366	25.98
horizontal echosounding	2000	122	0.67	2099	14.98	1076	15.17
rest of water column	2002	345	0.55	3548	41.27	3697	62.69
vertical echosounding	2000	355	16.13	4443	30.17	2412	50.40
whole water column	2002	437	3.34	6545	66.55	6063	88.67
	2000	477	16.80	6542	45.15	3488	65.57
		% estimate of UOW fish in the whole water column					
	2002	21.05	83.53	45.79	37.99	39.02	29.30
	2000	25.58	3.99	32.08	33.18	30.85	23.14

no clear pattern in the average fish weights recorded by horizontal and vertical beaming, which indicates that both small and large fish inhabited both UOW and deeper habitats.

Overall composition of the fish stock

In 2000 and 2002, when all the main habitats were sampled, the weighted estimate of the share of each species showed similar biomass composition in DG and HD (Figs 5–6). Pike-perch typically represented over 50% of the biomass. Bream was often the second most important species followed by smelt, roach and perch. In HD and DG, the dominant species in terms of abundance were either smelt or bream. In both species, the most abundant were the 0+ fish. Smelt were usually dominant

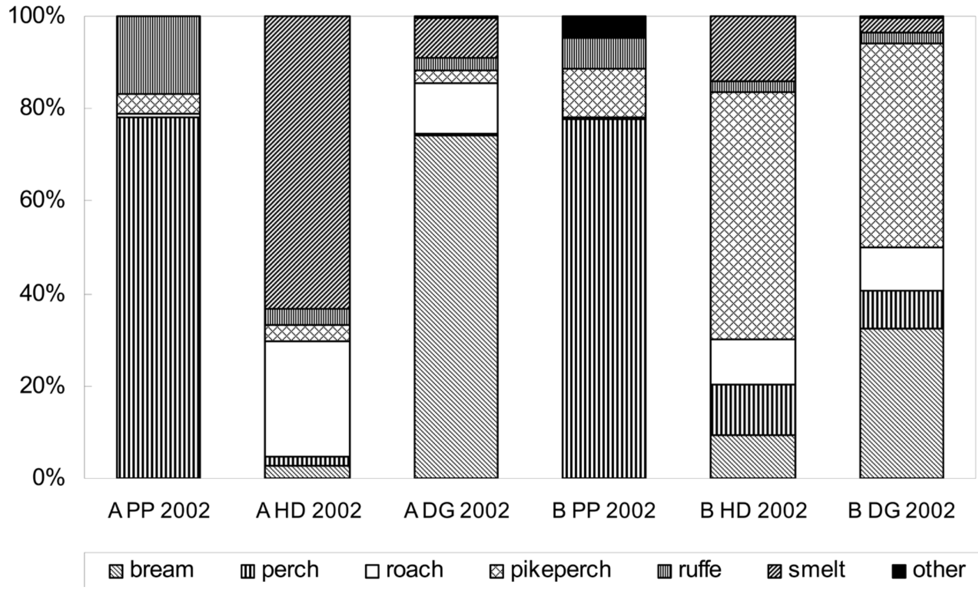

Fig. 6. The weighted species composition ($SSh_i\%$, formula 4) in terms of abundance (A) and biomass (B) in BBR in 2002.

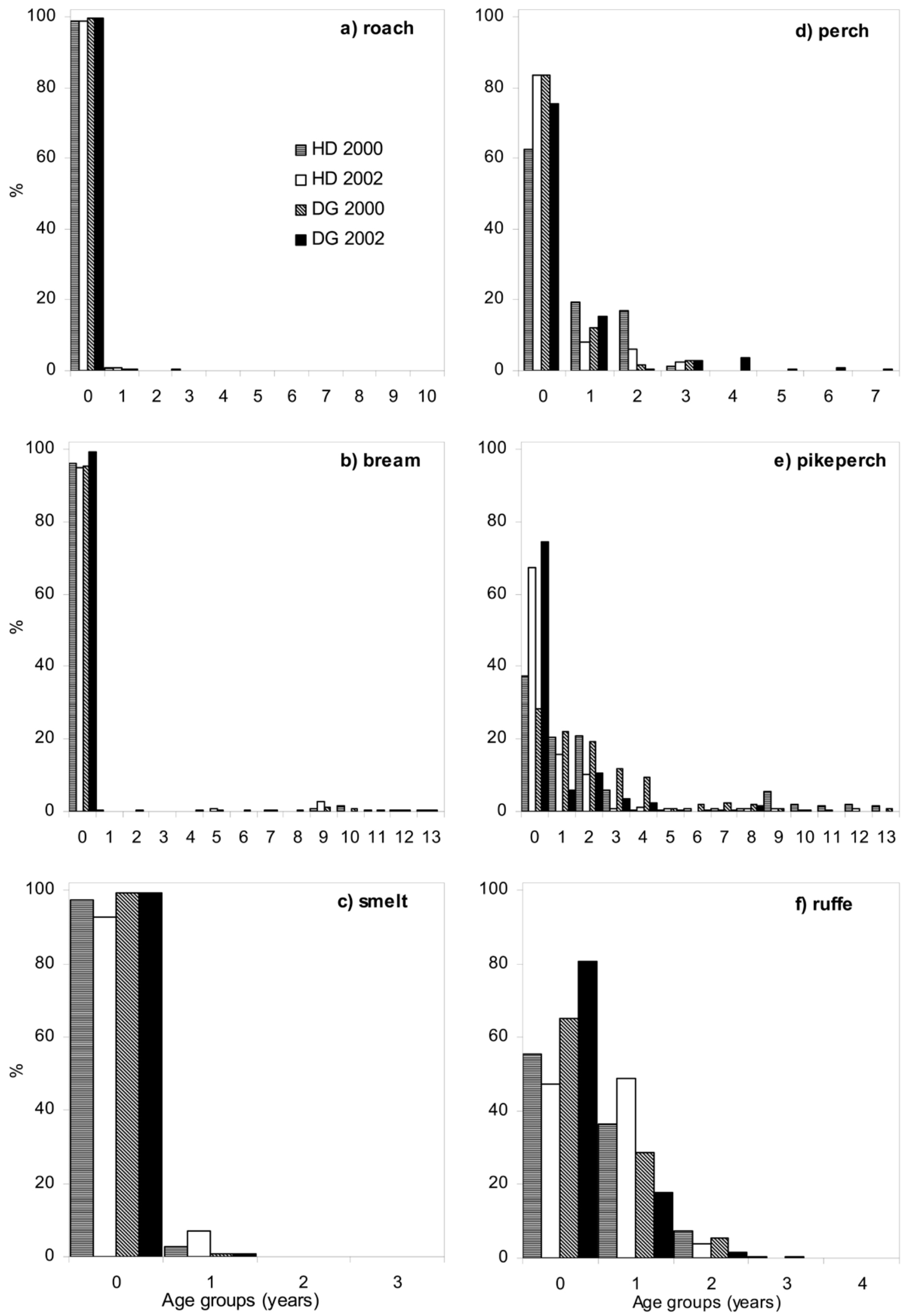

Fig. 7. Age-frequency composition of the main species of fish recorded for HD and DG.

Table 8. Average individual weight (g) of fish surveyed by netting and acoustically

reservoir	year	average weight (g)			
		netting surveys	acoustic surveys		
			horizontal	vertical	combined
Petrusplaat	2000	28.00	5.98	45.44	35.22
Honderd en Dertig	2000	18.89	7.14	6.79	6.90
De Gijster	2000	22.88	14.10	20.90	18.80
Petrusplaat	2002	16.16	30.33	1.59	7.00
Honderd en Dertig	2002	15.05	8.44	11.63	10.17
De Gijster	2002	10.36	14.10	16.96	14.62

(HD 2000, 2002, DG 2000) while the dominance of bream coincided with the appearance of an extremely strong 'late-spawned cohort of bream' in DG in 2002. In PP, both perch and pike-perch made up over 40% of the biomass in 2000 (Fig. 5), while in 2002 the biomass composition was clearly dominated by perch (Fig. 6). The same was true for the abundance composition in 2002. In 2000, the species composition in terms of numbers was more diverse and there were more ruffe followed by perch, bream and smelt (Fig. 5).

Age composition

The weighted age-class composition recorded for BBR had very distinct patterns (Fig. 7). Two groups can be distinguished in the dominant species: cyprinids and smelt (Fig. 7a–c) were clearly the prey species as they had a very short life expectancy. Significantly more than 90% of the individuals were 0+ fish. Older fish were nearly absent. That is nearly all 0+ fish were eliminated before they reached age 1+.

The exception to this pattern was the presence of a few large bream (Fig. 7b) aged 6–13 years, which were uncommon but made up the bulk of bream biomass recorded in Figures 5 and 6 (ind. weight of these fish was 0.7–2.5 kg). Large bream seemed to survive well.

The age-class composition curve was also quite steep for percids (Fig. 7d–f). However, the 0+ fish usually make up just over 50% of all the fish. In all the species of percid there was a noticeable percentage of older individuals including very old individuals of pike-perch. The age-composition of the percids indicated viable self-reproducing populations. The same is possibly the case for smelt, which are capable of spawning at age 1+, while bream and roach are probably more dependent on an allochthonous input of fry.

DISCUSSION

Up to now not many multispecies systems with several species living sympatrically have been successfully studied using a combination of acoustic recording and direct captures of fish (Dahm et al. 1992). It is also uncommon to assess all age classes including 0+ fish. Our original idea was to acoustically survey and net fish in every habitat except the littoral where it is not feasible to do a mobile acoustic survey. We expected to find a reasonable correlation between the acoustic estimate and the CPUE of gill nets (the two most effective methods used so far).

The results of this extensive study were very disappointing (Kubečka et al. 2002). There was no correlation between the results obtained by active sampling with an echosounder during the night and passive sampling using gill nets set in the evening and hauled in the following morning, that is both methods of sampling were used on the same night but the gill nets also caught fish in the evening and morning. Fish apparently undertook extensive diurnal migrations between habitats and times of their maximum activity and consequently maximum catch by passive gear did not correspond to where and when the acoustic survey equipment was placed to record them. If we still want to determine how many fish and of which species and year classes are present in these reservoirs we need to use other methods of sampling.

We assumed that the results of surveys using both acoustic and gill netting methods would provide a good estimate of the fish stocks in the reservoirs (Table 3). An acoustic survey was less habitat-bound, sampling all habitats proportionally, except the littoral and the blind zone near the bottom. The possibility of a bias in surveys of near-bottom fish was investigated by Tušer et al., 2013 and can be important for bottom dwelling fish (percids, mainly ruffe). Underestimates of fish biomass due to the bottom blind zone are less serious (usually <10%, Tušer et al. 2013). Gill net results had to be volume-weighted with respect to habitat volumes and corrected for very small but very numerous 0+ fish (late born bream cohorts, see Fig. 3a), which were recorded by the echosounder and markedly under sampled by the multi mesh gill nets (Prchalová et al. 2009). This weighting procedure for determining species, size and age distribution was more complicated than that used in most surveys.

This study showed the fish community can be segregated into prey and large species (compare also the age-composition presented in Fig. 7). In other systems, the dominance of large fish in the biomass is more apparent (de Leeuw et al. 2003). The high proportion of 0+ fish in the BBRs was partly caused by allochthonous input (pumping from the River Meuse – Ketelaars et al. 1998) and partly by the very high growth rate (modal length 75 mm in August of the first growth season was achieved by roach, smelt, perch and ruffe, Fig. 3a, see also Matěnová et al. 1998 for a report on the high growth rate of bream in the BBRs). During the first growth season, the high growth rate was apparently able to compensate for the high mortality and resulted in the production of a high biomass of 0+ fish, which supported a very high biomass of predatory fish (Figs 5–6).

However, the predation pressure seemed to be strong enough to prevent cyprinids from establishing healthy, self-reproducing populations typical of nearby Dutch lakes (Lammens 1990, Gulati & Van Donk 2002). The reproduction of cyprinids was also not favoured by the uniform artificial shores of the BBRs (Kubečka et al. 1998). The combination of limited opportunities for spawning and predation resulted in a relatively low overall (less than 100 kg×ha^{-1}) and the decline in biomass along the cascade DG-PP.

The estimated level of biomass in the BBRs is very low for Dutch conditions. For the fish pumped from the River Meuse, the BBRs represented a trap with no escape from predation except by growing big enough, like the adult bream and pike-perch.

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REFERENCES

Appelberg M., Berger H.-M., Hesthagen T., Kleiven E., Kurkilahti M., Raitaniemi J. & Rask M. 1995: Development and intercalibration of methods in Nordic freshwater fish monitoring. *Water, Air and Soil Pollution* **85**: 401–406.

Argyle R. L. 1992: Acoustics as a tool for the assessment of Great Lakes forage fishes. *Fisheries Research* **14**: 179–196.

Bagenal T. B. 1981: Fishing gear experiments in Finland. *Report of the Freshwater Biological Association* **49**: 26–31.

BALK H. & LINDEM T. 2005: *Sonar4 and Sonar5-Pro Post Processing Systems* (*Operating Manual*). Oslo: Lindem Data Acquisition, 341 pp.
BRENNER T., CLASEN J., LANGE K. & LINDEM T. 1987: The whitefish (Coregonus lavaretus (L.) of the Wahnbach Reservoir and their assessment by hydroacoustic methods. *Schweizerische Zeitschrift für Hydrobiologie – Swiss Journal of Hydrobiology* **49**: 363–372.
COWX I. G. 2002: Principles and approaches to the management of lake and reservoir fisheries. Pp.: 378–393. In: COWX I. G. (ed.): *Management and Ecology of Lake and Reservoir Fisheries*. Oxford: Blackwell Science, 401 pp.
DAHM E., HARTMANN J., JURVELIUS J., LÖFLER H. & VÖLTZKE V. 1992: Review of the European Inland Fisheries Advisory Commission (EIFAC) experiments on stock assessment in lakes. *Journal of Applied Ichthyology* **8**: 1–9.
DE LEEUW J. J., NAGELKERKE L. A. J., VAN DENSEN W. L. T., HOLMGREN K., JANSEN P.A. & VIJVERBERG J. 2003: Biomass size distributions as a tool for characterizing lake fish communities. *Journal of Fish Biology* **63**: 1454–1475.
FOOTE K. G., KNUDSEN H. P. VESTNES G., MACLENNAN D. N. & SIMMONDS E. J. 1987: Calibration of acoustic instruments for fish density estimation. *ICES Cooperative Research Report* **144**: 1–70.
FROUZOVÁ J., KUBEČKA J., BALK H. & FROUZ J. 2005: Target strength of European freshwater fish and its dependence on fish body parameters. *Fisheries Research* **75**: 86–96.
GULATI R. D. & VAN DONK E. 2002: Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-art review. *Hydrobiologia* **478**: 73–106.
JURVELIUS J., LINDEM T. & LOUHIMO J. 1984: The number of pelagic fish in lake Paasivesi, Finland, monitored by Hydroacoustic methods. *Fisheries Research* **2**: 273–283.
JURVELIUS J., KOLARI I. & LESKELA A. 2011: Quality and status of fish stocks in lakes: gillnetting, seining, trawling and hydroacoustics as sampling methods. *Hydrobiologia* **660**: 29–36.
JŮZA T. **&** KUBEČKA J. 2007: Efficiency of three fry trawls to sample freshwater pelagic fry community. *Fisheries Research* **85**: 299–304.
KETELAARS H. A. M., KLINGE M., WAGENVOORT A. J., KAMPEN J. & VERNOOIJ S. M. A. 1998: Estimate of the amount of 0+ fish pumped into a storage reservoir and indications of the ecological consequences. *International Review of Hydrobiology* **83**: 540–558.
KNUDSEN F. R. & SÆGROV H. 2002: Benefits from horizontal beaming during acoustic survey: application to three Norvegian lakes. *Fisheries Research* **56**: 205–211.
KUBEČKA J. & BOHM M. 1991: Ichthyofauna of Lake Jordan, one of the oldest man-made lake in Central Europe. *Journal of Fish Biology* **38**: 935–950.
KUBEČKA J., ČECH M., VERNOOIJ S. M. A., WAGENVOORT A. J., PETERKA J., HLADÍK M., VAŠEK M., PRCHALOVÁ M., FROUZOVÁ J., DRAŠTÍK V., ŘÍČAN O., POKORNÝ O. & KETELAARS H. A. M. 2002: Composition, biomass and habitat preferences of the fish stock in three artificially destratified Dutch reservoirs. Pp.: 131–134. In: VRBA J. & STRAŠKRABOVÁ V. (eds.): *Extended Abstracts of 4th International Conference on Reservoir Limnology and Water Quality*. *České Budějovice, August 2002*. České Budějovice, 390 pp.
KUBEČKA J., DUNCAN A., DUNCAN W., SINCLAIR D. & BUTTERWORTH A. J. 1994: Brown trout populations of three Scottish lochs estimated by horizontal sonar and multi-mesh gillnets. *Fisheries Research* **20**: 29–48.
KUBEČKA J., SEĎA J., DUNCAN A., MATĚNA J. & KETELAARS H. 1998: Fish stock biomass and composition in various European reservoirs and their ecological consequences. *International Review of Hydrobiology* **83**: 559–568.
KUBEČKA J. & WITTINGEROVÁ M. 1998: Horizontal beaming as a crucial component of acoustic stock assessment in freshwater reservoirs. *Fisheries Research* **35**: 99–106.
KURKILAHTI M. & RASK M. 1996: A comparative study of the usefulness and catchability of multimesh gill nets and gill net series in sampling of perch and roach. *Fisheries Research* **27**: 243–260.
LAMMENS E. H. R. R. 1990: The relation of biotic and abiotic interactions to eutrophication in Tjeukemeer, The Netherlands. *Hydrobiologia* **191**: 29–37.
LOVE R. H. 1971: Dorsal aspect of an individual fish. *Journal of Acoustical Society of America* **49**: 816–823.
MATĚNOVÁ V., KUBEČKA J., MATĚNA J. & SEĎA J. 1998: Growth rate and capacity of cyprinid fish in lowland European reservoirs with different fish density. *International Review of Hydrobiology* **83**: 585–590.
MEHNER T. & SCHULZ M. 2002: Monthly variability of hydroacoustic fish stock estimates in a deep lake and its correlation to gillnet catches. *Journal of Fish Biology* **61**: 1109–1121.
PRCHALOVÁ M., KUBEČKA J., HLADÍK M., HOHAUSOVÁ E., ČECH M. & FROUZOVÁ J. 2006: Fish habitat preferences in an artificial reservoir system. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* **29**: 1890–1894.
PRCHALOVÁ M., KUBEČKA J., ŘÍHA M., MRKVIČKA T., VAŠEK M., JŮZA T., KRATOCHVÍL M., PETERKA J., DRAŠTÍK V. & KŘÍŽEK J. 2009: Size selectivity of standardized multimesh gillnets in sampling coarse European species. *Fisheries Research* **96**:51–57.
SCHMIDT M. B., GASSNER H. & MEYER E. I. 2005: Distribution of an underfished vendace, Coregonus albula, population in a mesotrophic German reservoir. *Fisheries Management and Ecology* **12**: 169–175.

SIMMONDS E. J. & MACLENNAN D. N. 2005: *Fisheries Acoustics: Theory and Practice* (*2nd Edition*). Oxford: Blackwell Science Ltd., 437 pp.
SWIEZOWSKI A., GODLEWSKA M. & POLTORAK T. 2000: The relationship between the spatial distribution of fish, zooplankton and other environmental parameters in the Solina reservoir, Poland. *Aquatic Living Resources* **13:** 373–377.
TISCHLER G., GASSNER H. & WANZENBÖCK J. 2000: Sampling characteristics of two methods for capturing age-0 fish in pelagic lake habitats. *Journal of Fish Biology* **57**: 1474–1487.
TUŠER M., PRCHALOVÁ M., MRKVIČKA T., FROUZOVÁ J., ČECH M., PETERKA J., JŮZA T., VAŠEK M., KRATOCHVÍL M., DRAŠTÍK V. & KUBEČKA J. 2013: Simple method to correct the results of acoustic surveys for fish hidden in the deadzone of an echosounder. *Journal of Applied Ichthyology* **29**: 358–363.
VAN BREEMEN L. W. C. A. & KETELAARS H. A. M. 1995: The influence of artificial mixing and other factors on algal biomass in the Biesbosch reservoirs. *Journal of Water Supply Research and Technology – Aqua* **44**: 65–71.
YULE D. L. 2000: Comparison of horizontal acoustic and purse seine estimates of salmonid densities and sizes in eleven Wyoming waters. *North American Journal of Fisheries Management* **20**: 759–775.