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DIPLOMARBEIT

Comparison of seasonal fish abundance estimates of deep pools in the River Danube by two different sonar systems

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Stefan Singer

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1. Introduction

Horizontal sonar applications are a frequently used method to estimate the abundance of migrating fish in rivers (Enzenhofer et al., 1998; Burwen and Fleischman, 1998; Cronkite and Enzenhofer, 2002; Lilja et al., 2004; Holmes et al., 2006; Rakowitz et al., 2008a, b). In turbid water where visual counting is difficult or impossible the use of sonar may serve as an efficient method to yield an accurate estimation of fish densities (Burwen et al., 2010). Pools in rivers are deep mesohabitats where the visibility through the water column is strongly limited, especial in a large and turbid river like the Danube. Common active and passive fish-catching methods are hardly applicable in these environments, as their efficiency is decreased by the harsh abiotic conditions (i.e. water depth, water current) or the results are strongly biased by a high size and species – specific selectivity (Zalewski and Cowx 1990). Electro-fishing or long-lines give non-representative results of the fish community of deep pools as the effectiveness of electro-fishing is changing with water depth (Zalewski and Cowx, 1990) whereas long-lines capture mainly benthic fish (Bammer, 2010; Goffaux et al., 2005). Abundance estimates resulting from applications of gill nets, drift nets or purse seining are also biased in these habitats (Goffaux et al., 2005). The characteristics of hydroacoustic echo sounding offer several advantages for the estimation of the fish abundance in river pools. The advantages above-mentioned are that with sonar it is possible to accomplish continuous long-term samplings to detect fish movements and fish abundances. It is an inoffensive method for abundance estimations. However, there are some issues which have to be considered when using sonar. So it is not possible to distinguish the different fish species. Boundaries like the water surface or the ground can produce strong reflections so fish in these areas could not be detected. Another limiting factor is the size of the fish and the density (e.g. fish shoal). This negative factor is caused by a low resolution of the sonar. That is why small fish could not be detected and highly packed fish could not be distinguished separately. The main aim of this study was to compare the results of fish abundance and fish size distribution of deep pools in the free-flowing Danube derived from two different sonar systems, a spilt-beam echo sounder (Simrad®, EK 60) and a multi-beam sonar (Soundmetrics®, DIDSON). We further wanted to know to which extend hydraulic features of different pools are reflected in fish abundance and habitat use by fish. Therefore, two pools differing in their location in the river were investigated. One pool behind a groyne (overfall pool) (OP) and one at the outer end of a groyne (groyne-head pool) (GP). As a consequence of their position in the river and their morphology, the prevailing hydraulic conditions at the two sites differed significantly. The study of seasonal and diurnal habitat use, expressed as changes in abundance in these pools should provide further information about their functional role (i.e. as refugial areas) in the river.

To achieve comparable fish density estimates the two systems were run simultaneously for four 24 hour cycles per pool, one in each season. Maxwell and Gove (2007) compared DIDSON and split beam based fish counts with visual fish counts from an observing tower. They showed that both DIDSON and split beam data result in similar abundance estimations. However, their investigation took place in a clear water river where visual counting was possible. At our study site visual counting was not possible because of high turbidity and the water depth of the two pools under investigation. The two sonar systems in the study of Maxwell and Gove (2007) were installed at different sites in the river. As a consequence variations arise of the abundance estimation because the fish abundance could differ between the two spots. In the present study we compared fish abundance estimations from synchronized DIDSON and split beam recordings at the same site in order to enable a comparison of the contemporaneous recorded signals. . The transducer of the EK 60 was arranged in a way that its beam was entirely contained within the sampling volume of the DIDSON. Our goal was to compare the abundance estimates of the two different sonar systems under different hydraulic conditions, i.e. calm and low flow velocity in the overfall pool vs. turbulent and high flow velocity in the groyne-head pool. We further wanted to know to which extent abundance estimates are influenced by different fish densities. Another aspect of interest was the comparison of fish size distribution achieved from the two different sonar systems. It is known that beam angle or orientation of the fish have an effect on the length estimates of split-beam sonars (Burwen et al., 2007) and that the bias of DIDSON length estimates could arise from an increasing range as well as from high turbidity (Burwen et al., 2010). The results of different methods of fish size estimation (mean Target Strength, 95% percentile Target Strength (EK 60), image analyses (DIDSON)) of the signals from the two hydroacoustic systems were compared with fish length with measurements from electro-fishing data of the Danube River in 2006 and 2007. With this data we got an idea of the length size-distribution of the fishes of the Danube. Under the assumption that the length distribution of fishes of the sub-littoral inshore zones of the Danube is similar to the length distribution of the individuals in the two pools we were able to see which sonar system gives the best size estimation of fishes.

It was hypothesized that (1) the abundance estimates of fish in both pools do not differ between the split-beam and multi-beam sonar system and that (2) there is no difference in the estimates of fish size distribution between split-beam and multi-beam recordings and that (3) the fish length distributions derived from the acoustic sizing do not differ from the length distribution of the catch data.

2. Materials and methods

2.1 Sampling sites:

The hydroacoustic investigations were conducted in the Danube River east of Vienna, Austria in two hydraulically different pools. One pool was located at the Danube River kilometer 1885.6 and the other pool at Danube River kilometer 1887.0 (Fig. 1)

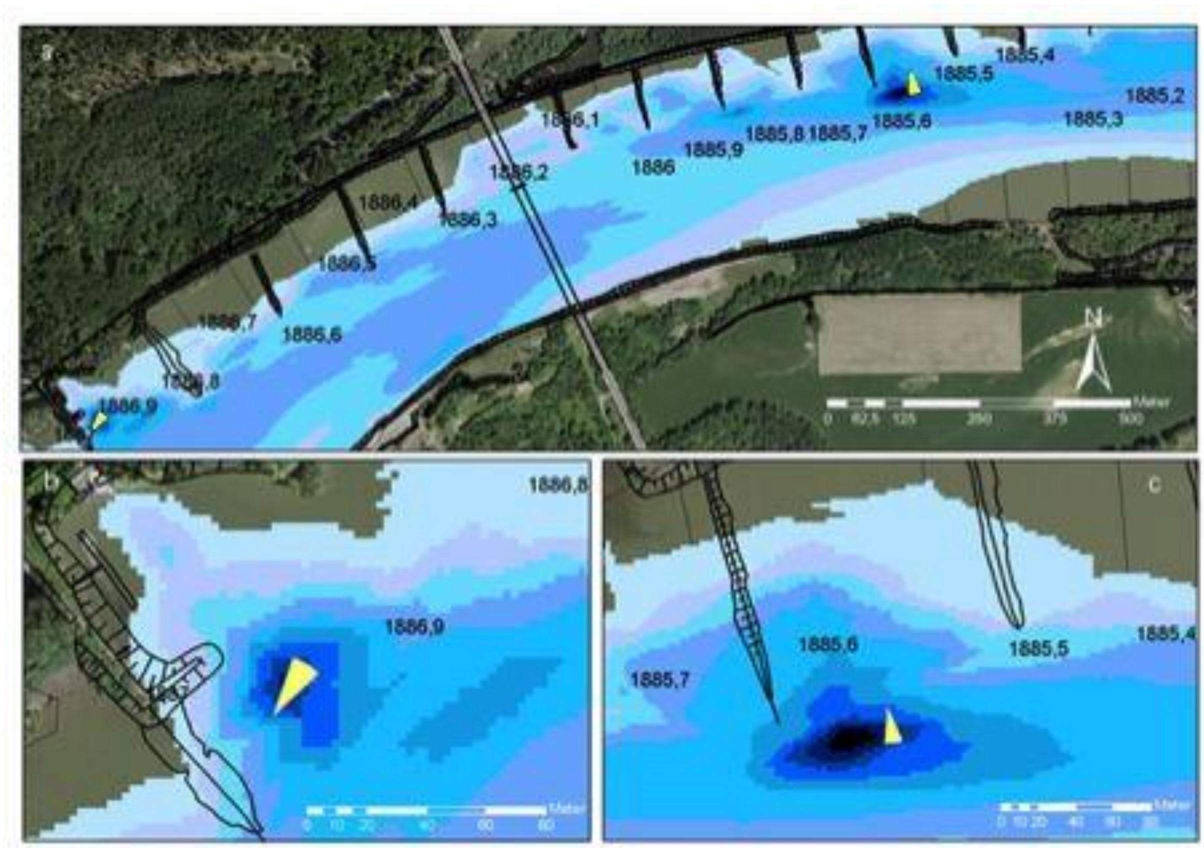

Figure 1 (a) The hydroacoustic sampling sites in the Danube River east of Vienna close to the Austrian – Slovakian border (b) overfall pool at Danube River kilometer 1887.0. (c) groyne-head pool at Danube River kilometer 1885.6. The triangles symbolize the direction and area of the sonar beam. Green: terrestrial areas; Black: groynes, embankments; Blue: Water covered areas. Water depth is indicated from shallow (light blue) to deep (dark blue) areas. Numbers reflect the river kilometers.

Table 1 Outline of the comparative study between split beam and multi beam (DIDSON) sonars in two hydraulically different pools of the Danube River east of Vienna.

pool-type	season	date of recording (24h)	method		coordinates	measuring-point (River-Km)	sea-lever (a.s.l.)	flow velocity [m s^{-1}]	water-temperature [°C]	turbidity [ntu]	conductivity [mµS]
			EK60	DIDSON							
Overfall pool	winter	20.- 21.02.2008	X	X	48°14´33,6627"N 16°89´87.0866"E	1887	154	0.0783	4.2	4.88	447
	spring	30.04. - 01.05.2008	X	X		1887	395	0.3037	11.8	24.34	378
	summer	30. - 31.07.2008	X	X		1887	302	0.1510	17.5	40.79	343
	autumn	08. - 09.10.2008	X	X		1887	202	0.1112	12.5	10.64	410
Groyne-head pool	winter	23. - 24.02.2008	X	X	48°14´81.5374"N 16°91´62.6168"E	1885.6	147	2.0410	5.4	5.4	481
	spring	03. - 04.05.2008	X	X		1885.6	336	1.8633	12.5	19.04	383
	summer	02. - 03.08.2008	X	X		1885.6	287	1.8780	19.8	30.44	346
	autumn	11. - 12.10.2008	X	X		1885.6	167	2.0410	12.5	9.86	406

The pool at the Danube River kilometer 1887.0 was hydraulically classified as 'overfall pool' (OP) due to its position directly downstream of a transversal groyne. Its special hydraulic characteristics at increased water levels of the water flow 'falling over the transversal groyne' and digging into the ground behind it (Fig. 1b). It was located close to the river bank and far off the shipping channel. Discharge Regimes are defined after the "Kennzeichnende Wasserstände der Donau" (Tritthart et. al, 2011). At low water discharge ($LQ_{\text{ Hainburg}}$= 1543 m^3s^{-1}) its maximal water depth was 10.1m. At a standard low water discharge (SLQ = 975m^3s^{-1}) as well as beyond a topographical water depth of -5 m the volume of the overfall pool is 14201.58 m^3 (The topographic depth is the water depth based on the actual ground profile). To calculate the Volume of both the overfall-pool and the groyne-head pool we used the pool area determined by Tritthart et al. (2009). The water depth was measured along linear transects. At standard low water discharge a transversal current velocity profile of the overfall pool shows a slight horizontal flow velocity (U = 0.010 – 0.100 ms^{-1}) as well as a circular and not turbulent flow direction (Fig.2 c). At mean discharge (MQ = 1930 m^3s^{-1}) the transversal profile shows a slight horizontal flow velocity (U = 0.010 – 0.100 ms^{-1}) and a flow that is directed to the ground slightly digging and slightly turbulent (Fig.2 e). At a high discharge based on 10-year flood event (HQ_{10} = 7300 m^3s^{-1}) the transversal profile shows a low horizontal flow velocity (U = 0.010 – 0.100 ms^{-1}), however a strong digging and strong turbulent flow direction which is vertically directed to the ground (Fig.2 g). At a longitudinal current velocity profile the flow velocity is continuously increasing from *SLQ* (*U* = 0.075 – 0.750 ms^{-1}) to *MQ* (*U* = 0.125 – 1.250 ms^{-1}) to *HQ* (*U* = 0.250 – 2.500 ms^{-1}) and shows a uniform flow direction (Fig.2 d, f, h).

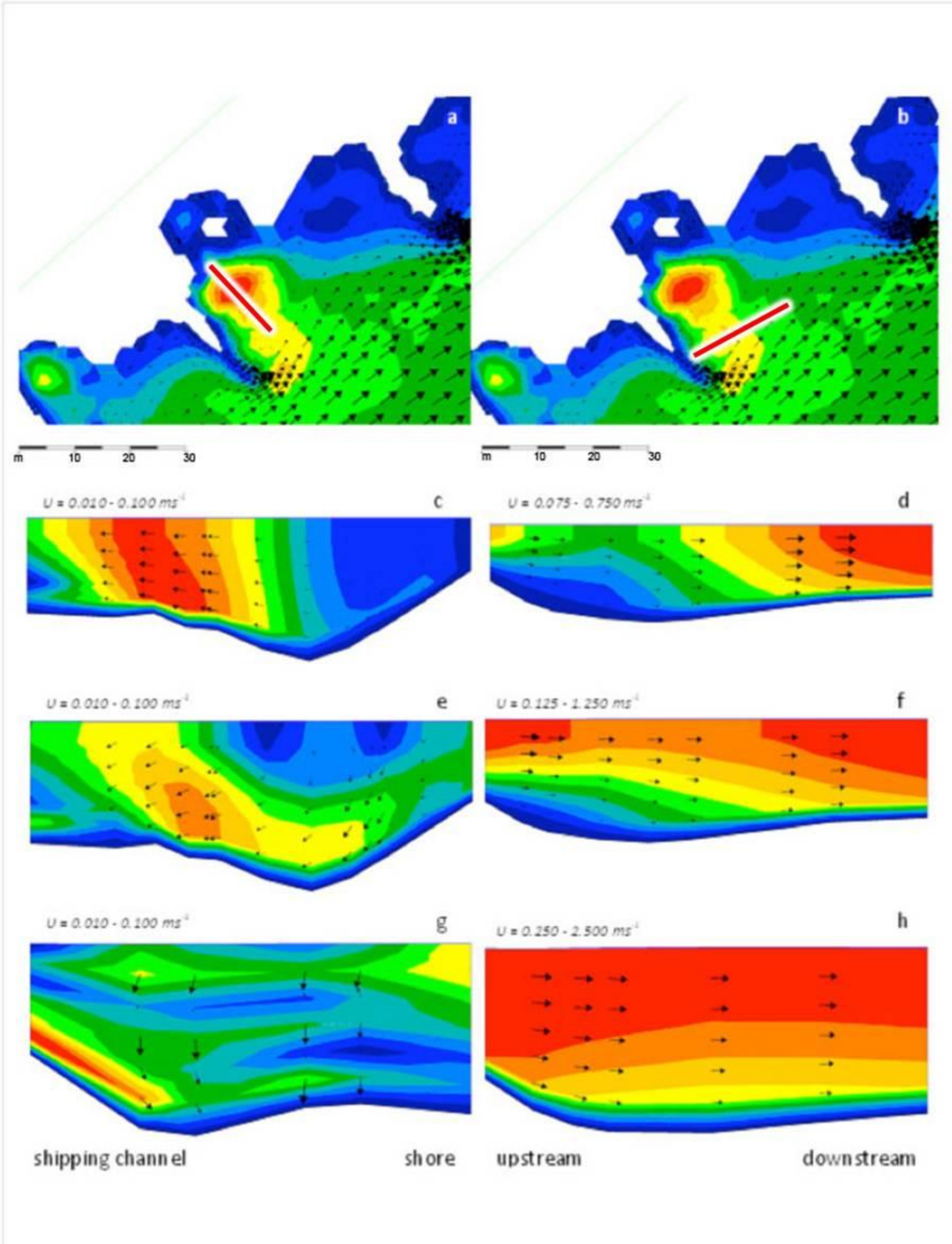

Figure 2 Top view of the transversal (red Line in a) and longitudinal (red line in b) flow velocity profile of the overfall pool. Side view of the flow conditions at different discharges along the transversal (c, e, g) and the longitudinal (d, f, h) profile based on the three-dimensional hydrodynamic model by Tritthart et al., (2009).

The pool at the Danube River kilometer 1885.6 was hydraulically classified as 'groyne-head' pool due to its position downstream the stream-edge of the groyne and its hydraulic characteristics of a turbulent whirlpool at any water level. It is characterized by an offshore position nearby the shipping channel. At low water level (LQ_{Hainburg}= 1543m³s^{-1}) the maximum depth is 11.4 m. At standard low water discharge (*SLQ*) and beyond a topographical water depth of -5 m the volume of the groyne-head pool is 11930.35 m³. At *SLQ* (*U*= 0.224 – 2.018 ms^{-1}) the transversal profile of the groyne-head pool shows a slight horizontal flow velocity aiming to the shipping channel. At the rim of the pool the flow direction is aimed to the ground (Fig.3 c). At mean water discharge (*MQ*) (*U*= 0.237 – 2.137 ms^{-1}) the flow conditions of the transversal profile are the same as the conditions at norm low water discharge (Fig.3 e). At high water discharge (*HQ10*) (*U*= 0.274 – 2.470 ms^{-1}) the horizontal flow direction is changing from offshore to inshore. Furthermore, is the flow displayed a turbulent and digging direction aiming vertically to the ground (Fig.3 g). At a longitudinal profile the water velocity constantly high, only slightly increases from *SLQ* (*U* = 0.241 –2.167ms^{-1}) to *MQ* (*U* = 0.252 – 2.271 ms^{-1}) to *HQ* (*U* = 0.281 – 2.525 ms^{-1}) and shows a uniform flow direction (Fig.3 d, f, h).

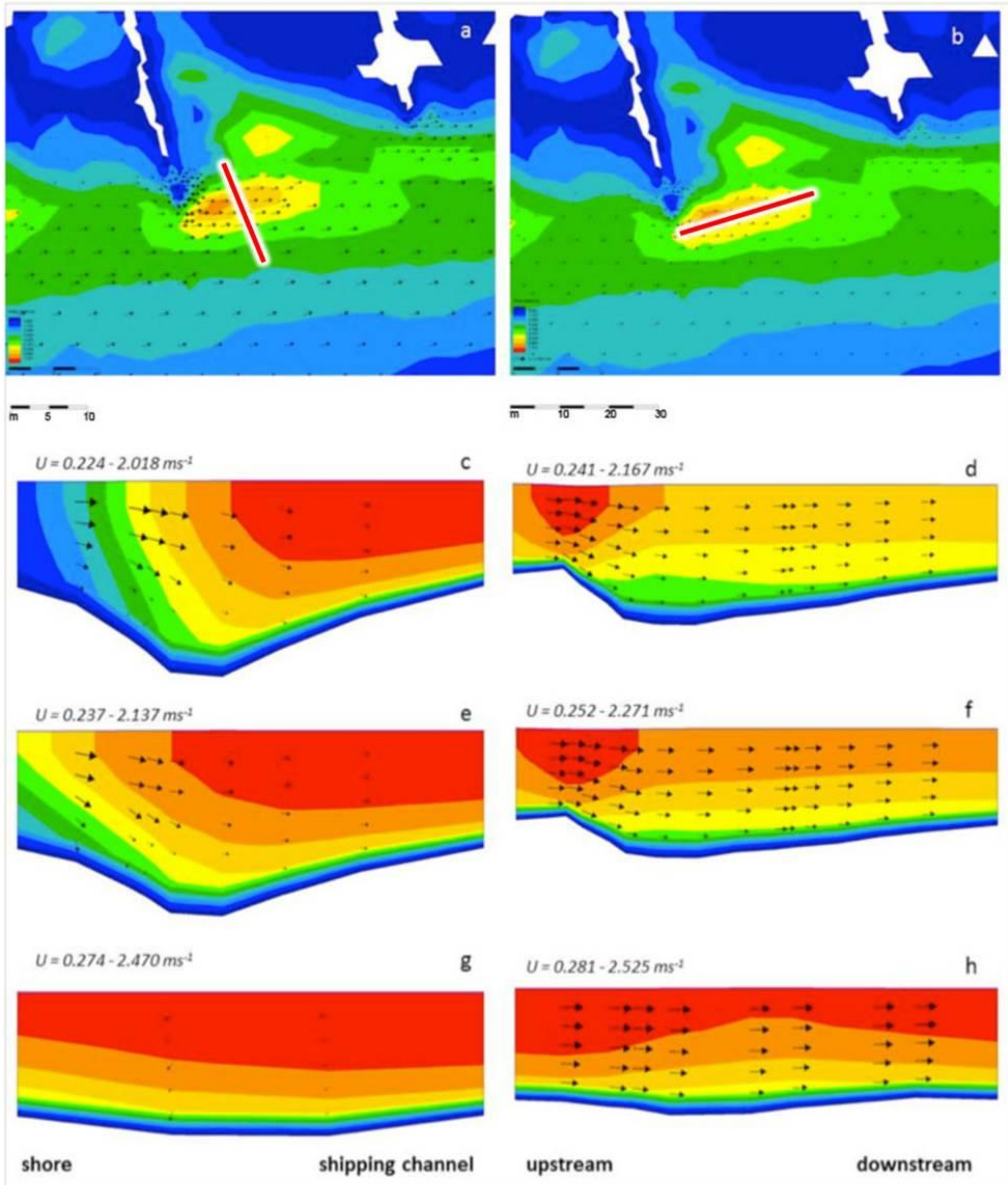

Figure 3 Top view of the transversal (red line in a) and longitudinal (red line in b) flow velocity profile of the groyne-head pool. Side view of the flow conditions at different discharges along the transversal (c, e, g) and the longitudinal (d, f, h) profile based on the three-dimensional hydrodynamic model by Tritthart et al., (2009).

2.2 Hydroacoustic comparison:

2.2.1. Split beam vs. multi beam sonar system

In table 2 illustrate the technical features as well as the field settings during the investigation of the different sonar systems.

Table 2 Characteristics of the two different sonar systems and their adjustments during the recordings.

Technical features and field settings	Split beam Sonar	Multi beam Sonar
Manufacturer	Simrad	Soundmetrics
Sonar type	EK 60	DIDSON
Frequency mode (kHz)	120 kHz	1800 kHz or 1100 kHz
No. of beams	1	96 or 48
Type of beam	split beam	single beam
Beam width (two-way) - horizontal (°)	8.8°	0.3° or 0.6°
Beam width (two way) - vertical (°)	4.4°	12°
Beam spacing (°)	-	0.3° or 0.6°
Field-of-view	8.8° x 4.4°	29° x 12°
Beam shape of single beams	elliptical	elliptical
Power consumption (Watt)	60 W	30 W
Pings s^{-1} or Frames s^{-1}	0.1 s^{-1}	7 - 8 s^{-1}
Pulse length (ms)	0.064 ms	0.032 ms
Receiver Gain (dB)	22.56 dB	36 - 40 dB
Echo length	0.8 - 1.8	-
Noise threshold (dB)	-70 dB	-
Maximum Phase Deviation	10	-
Maximum Gain Compensation (one-way) dB	6 dB	-
File size (total pings or frames)	6145	4930
Tilt angle (°)	25 - 50°	
Beam Range_winter_Overfall Pool/Groyne-head Pool (m)	20.19 m/ 10.09 m	
Beam Range_spring_Overfall Pool/Groyne-head Pool (m)	10.09 m/ 10.09 m	
Beam Range_summer_Overfall Pool/Groyne-head Pool (m)	20.01 m/ 20.01 m	
Beam Range_autumn_Overfall Pool/Groyne-head Pool (m)	20.32 m/ 20.32 m	

2.2.2. Field survey setting

At each sampling date the survey boat with the hydroacoustic equipment was fixed to an anchored buoy with two ropes at the bow and stabilized by an anchor at the stern at a suitable position which enabled an optimal performance of the hydroacoustic systems. Both sonar systems were mounted on a mechanically adjustable pan and tilt unit at the bow of the boat. Both transducers' depths were -0.85 m. The submerged sonars were protected from damage by floating objects by a metal-shroud.

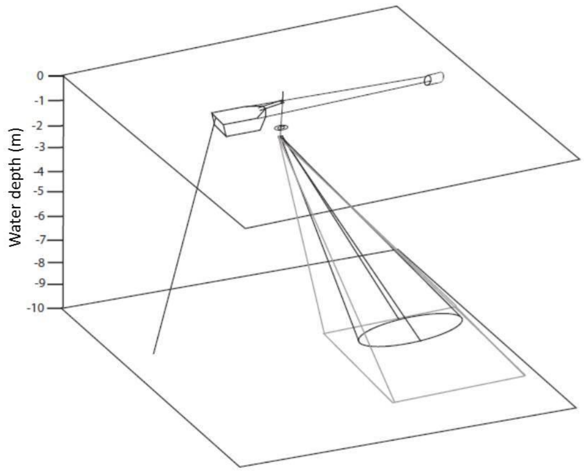

Figure 4 A schematic view of the setup during the field survey. The Graph shows the beam volume of the EK 60 (elliptical beam, black) and the DIDSON (quadratic beam, grey) Differences between the two volumes are due to different horizontal and vertical beam widths. The transducer of the EK 60 was arranged in a way that its beam was entirely contained within the sampling volume of the DIDSON. The boat was stabilized by an anchor at the stern and fixed by two lines to an anchored buoy.

2.3 Data analysis:

The field data were recorded directly to an external hard disk for further analysis.

2.3.1 EK 60

The split beam data were analyzed with Sonar5-Pro post-processing software version 5.9.9. (Balk and Lindem, 2010). For improved fish abundance estimates and separating individual fish in dense fish aggregations in the split beam data the cross- filter (CF) option of Sonar5-Pro was applied. The CF-settings we used were pre operating parameters activated (TS- domain; filter= mean); Foreground filter= 1, 3; Background filter= mean 55, 1; Offset dB= +6. Single echoes of a fish were tracked by freehand mode and merged together for fish abundance estimates as well as for the individual total length and biomass estimates based on the echo intensities. The mean Target Strength (TS) (Lilja et al., 2004) as well as the 95% percentile (Rakowitz et al., 2008b) of the echo intensities of tracked fish were taken as basis to calculate the total length. In order to analyze acoustic split beam data within a sufficient time interval randomly selected 20 minutes per hour subsamples were extrapolated by multiplying the manually counted fish-numbers by three to achieve the whole fish abundance assessment per hour (Lilja et al., 2008). The program was updated regularly.

2.3.2 DIDSON

The multi beam data were analyzed with DIDSON post-processing software version 5.16 (Hanot, 2008). In the DIDSON data each fish was individually marked and the total length was measured manually from snout to tail. For calculating the fish weight we used the

e^{y} Function.

The basis e represents the Euler´sche number and y equates the function

$$y = a + b * ln\, x$$

where y is the weight, x is the total length (TL) and $ln\, x$ is the natural logarithm of TL. The slope $b = 3.28$ and the intercept $a = -5.56.$ This function is based on a length-weight regression calculated with data from electro- fishing in the Danube in 2006 and 2007. The dataset consists of 5381 fish out of 34 different spices (Keckeis). We used this function to convert total length measurements into weight for the DIDSON recordings as well. Till recently no appropriate relationship based on acoustic intensities between total length and fish weight has been established in the DIDSON software.

To compare the mean biomass calculated with the different methods (mean TS, 95% percentile TS, length-weight regression) we determined the average weight (g) per hour. With the 24 values the average weight of the respective recording was calculated.

For the statistical analysis we used SPSS® 16. To compare the abundances and the estimated fish length of single recordings we run a Mann-Whitney U-test and a Wilcoxon signed-rank test respectively. To compare the fish length frequency based on the different acoustic methods a Kruskal- Wallis- test was performed. For showing the difference between the average fish length estimated at the single seasons we used a median test (Fig. 14 a, b). To show which influence the different factors (site, season and soar system) had on the results of the abundance estimation and the fish length estimation we run a general linear model (GLM). The graphs were created with SigmaPlot® 10.

2.4 Acoustic size vs. measured size

We compared our data with catch data of the sublithoral inshore zone of the Danube to prove if the fish length achieved by the acoustic sizing reflects the measured fish length. This data contained numerous measurements of bleaks (*Alburnus alburnus*). The bleak is a pelagic fish species occurring in the upper layers of the water column. As a consequence of its preferred habitat close to the surface we excluded the size-measurements of this species from our comparisons because of a system immanent blind zone of approx. 1.0 m below the water surface. It was assumed that there were none bleak in the deeper parts of the pools, which were investigated in this study. The data set contained 5381 single fish length measurements. 4061 of the collected fish were bleaks. So we had 1320 measured fish length to compare with the length estimations of the different sonar systems.

In the text we used the expressions winter, spring, summer and autumn when discussing seasonal data. This data related to on 24-hour recording taken at the different seasons (see Tab. 1 column ‘season’ and ‘date of recording’).

3 Results:

3.1 Total fish abundance:

A comparison of the total fish abundance is shown in Fig. 5, a Wilcoxon- test indicated that the abundance estimations of the two different sonar systems differ highly significant (n =; $p < 0.001$).

Fig 6).

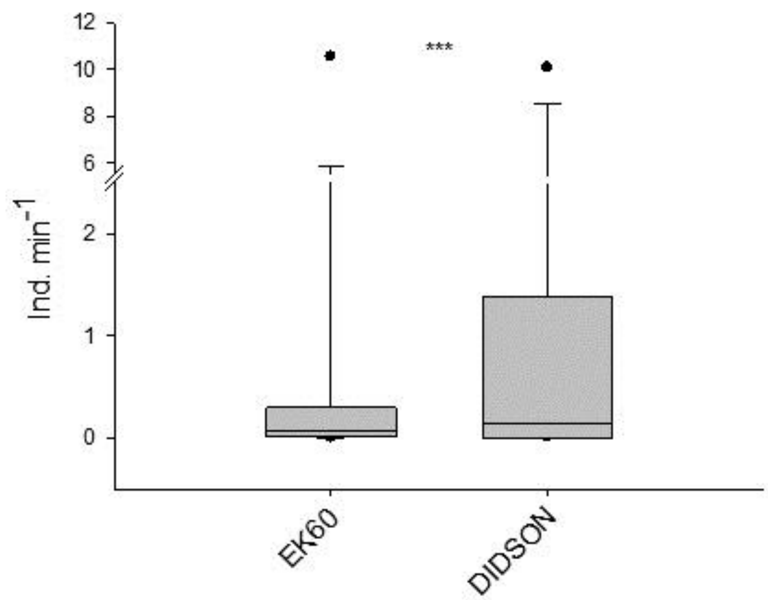

Figure 5 Comparison of the total fish abundance estimates derived from the two sonar systems, the lower end of the box describe the 25th percentile whereas the upper end of the box describe the 75th percentile; the line in the box symbolize the 50th percentile (median); the lower whisker describe the 5th percentile and the upper whisker the 95th percentile; the dots above the boxes represent outliers; the stars indicate highly significant differences.

A high correspondence of the estimates of fish abundance expressed as Ind. per minute between the two different sonar systems was observed. In Fig. 6 the correlation between the log-transformed hourly means (Individuals min^{-1}) between all values of the EK 60 and the DIDSON, irrespective of site and time, are shown. The results are best described by a linear regression

($y = a + b * x$; $R^2 = 0.81$, $p < 0.001$). The slope (b=0.901, lower $C.I._{95\%}$= 0.827, upper $C.I._{95\%}$= 0.975) of the regression differs highly significant from 1 (p<0.001), the intercept (a= 0.182, lower $C.I._{95\%}$= 0.103; upper $C.I._{95\%}$= 0.260) differs highly significant (p< 0.001) from zero. This means that the abundance estimates of the recordings from the two sonar systems are not directly proportional, at lower estimates of the EK 60 the abundances of derived from the DIDSON are slightly higher, and at high values of the EK 60 the estimates of the DIDSON are lower than those from a 1:1 relationship (see Fig 6).

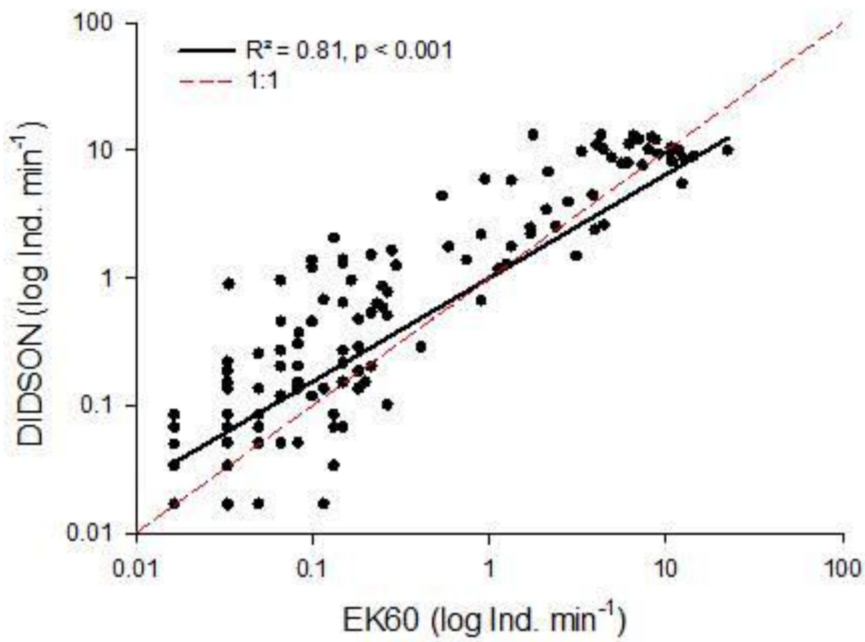

Figure 6 Relationship between $\log_{10}$ transformed abundance estimates derived from EK 60 and DIDSON recordings. Pooled data from both sites and all sampling dates (n= 192). The 1:1 proportionality is indicated by the dashed line. The relationship is described by a linear regression: logY = log a + b log X; log = logarithm to the base 10; Y = abundance estimate DIDSON; X = abundance estimate EK 60; a = intercept, b = slope. The regressione coefficients are given in the text.

The relationship between the abundance estimates of the two systems was also affected by sampling site. There is a better correspondence of the data from the two different sonar systems in the overfall pool than in the groyne-head pool. In the overfall pool (Fig. 7a) the correlation coefficient (R^2) is 0.86 whereas it is 0.75 in the groyne-head pool (Fig 7b). Low fish densities detected with the EK 60 correspond with slightly higher fish densities detected with the DIDSON in the overfall pool, and low abundance estimates in EK 60 correlate with high abundance estimates in DIDSON in the groyne-head pool. The intercept of the regression showed that the divergence between the EK 60 and the DIDSON decrease with higher abundances detected in the pool. The slope (b=0.091, lower $C.I._{95\%}$= 0.015, upper $C.I._{95\%}$= 0.167) of the regression of the overfall pool is significant different from 1 (p=0.02), intercept (a=0.993, lower $C.I._{95\%}$= 0.852, upper $C.I._{95\%}$= 1.014) differs highly significant (p< 0.001) from zero. The regression of the groyne-head pool has a slope of b= 4.564(lower $C.I._{95\%}$= 3.746, upper $C.I._{95\%}$= 5.383) which is highly significant different (p< 0.001) from 1, the intercept (a=-0.026, lower C.I.$_{95\%}$= -0.102, upper C.I.$_{95\%}$= 0.50) differs highly significant (p< 0.001) from zero.

(a) (b)

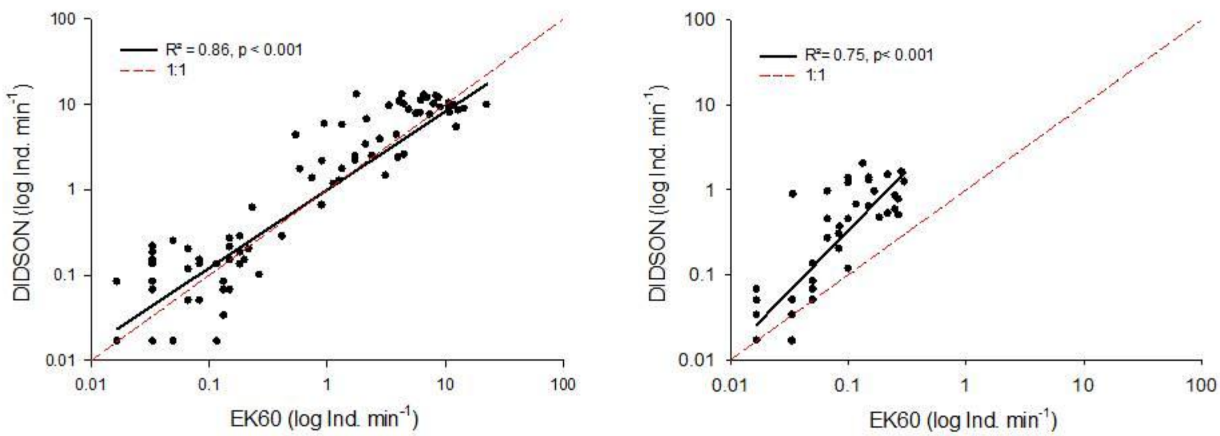

Figure 7 Relationship between DIDSON based abundance estimation and EK 60 based abundance estimation in (a) the overfall pool and (b) the groyne-head pool (both n=96). The 1:1 line highlights the variability of the abundance estimates in both systems.

3.2 Seasonal fish abundance – EK 60 vs. DIDSON

The expressions winter, spring, summer and autumn as used below is related to one 24-hour recording taken at the different seasons. In general we observed higher fish abundance in the overfall pool than in the groyne-head pool irrespective of the measuring device. In the overfall pool we recorded on average 3783 ± 4231 fish with the EK 60 and 4967 ± 5503 fish with the DIDSON respectively. In the groyne-head pool we detected on average 82 ± 99 fish with the EK 60 and 339 ± 616 fish with the DIDSON respectively.

The results of a general linear model (GLM) with the estimated abundance as dependent variable and the sonar systems, site and season as main factors revealed that all three factors have a highly significant influence on the abundance estimation. The factor with the highest effect on the estimations was the sampling site (MS= 73.25, p <0.001) followed by the factor season (MS= 35.65, p <0.001) and the sonar system (MS= 3.87; p <0.001).

3.2.1 Overfall pool:

The recordings of both sonar systems show is a high abundance at the sampling date in winter. In spring, summer and autumn the abundances detected by the EK 60 were much lower compared to the values observed from DIDSON. In the overfall pool (Fig. 8 a) the mean abundance differ from 6.27 ± 5.36 (EK 60) to 6.96 ± 4.07 (DIDSON). In spring the mean of EK 60 estimates was 0.04 ± 0.04 and the mean of the DIDSON is 0.10 ± 0.22. The means of the estimated abundances in summer are 0.15 ± 0.08 (EK 60) and 0.19 ±0.12 (DIDSON). In autumn there was a strong deviation between the means of the abundances recorded by the EK 60 (0.15 ± 4.10) and by DIDSON (6.54 ± 3.77).

3.2.2 Groyne-head pool:

There were nearly equal mean abundances in winter, spring and summer. In autumn the abundance is slightly higher than compared to the other sampling dates. In the groyne-head pool (Fig. 8 b) the means of the winter recordings are 0.02 ± 0.02 (EK 60) and 0.02 ±0.05 (DIDSON). In spring the means are 0.03 ± 0.02 (EK 60) and 0.03 ± 0.06 (DIDSON). The mean abundances of the summer are 0.02 ± 0.02 (EK 60) and 0.01 ± 0.03 (DIDSON). In autumn the means are 0.16 ± 0.08 (EK 60) and 0.88 ± 0.48 (DIDSON).

(a) (b)

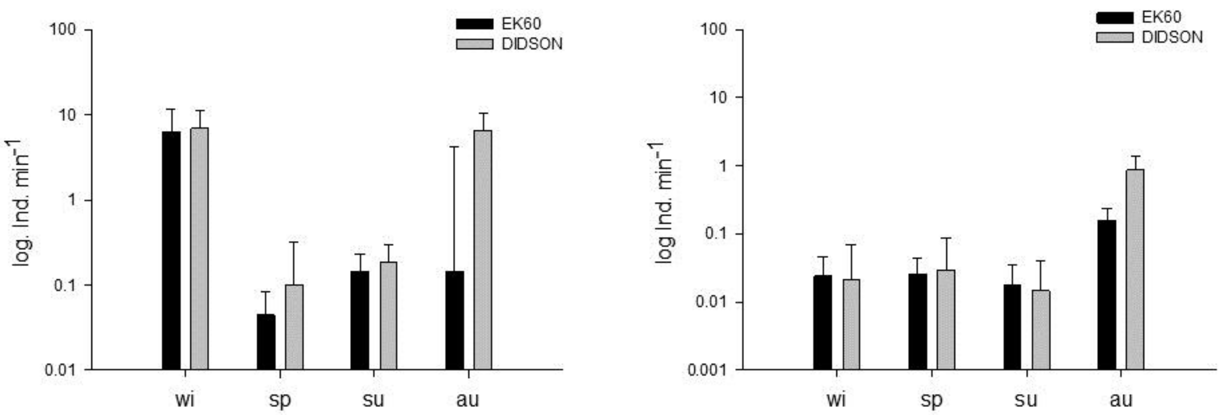

Figure 8 Comparison of seasonal average abundance (wi…winter; sp…spring; su…summer; au…autumn) estimates measured by two hydroacoustic devices at two different sampling sites. (a) overfall pool (b) groyne-head pool. Error bars show standard deviation (SD).

Figure 9 shows the differences of the detected abundance by the different sonar systems for each sampling date. A pairwise comparison of pooled data of each sampling date of both sampling sites indicated no significant difference of the abundance estimations between the two measuring devices in winter, spring and summer (Wilcoxon-test: winter p= 0.678; spring p= 0.725, summer p= 0.300), whereas a highly significant difference between the abundance estimations of the two sonar systems (Wilcoxon-test: p< 0.001) was found for autumn.

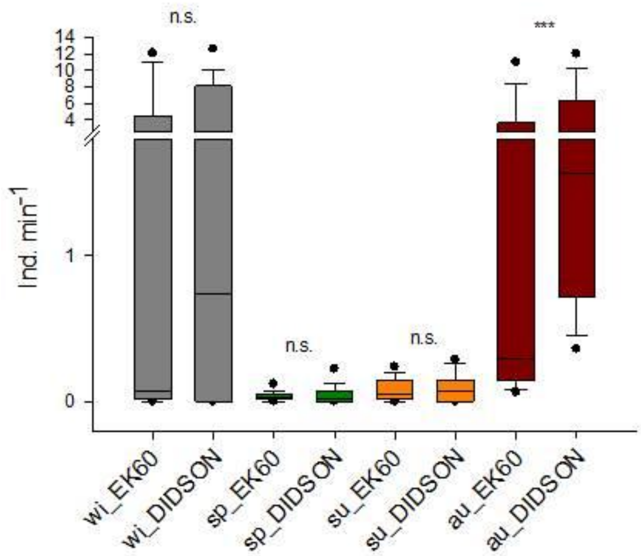

Figure 9 Comparison of the seasonal abundance derived from two sonar systems. Pooled datasets (overfall pool + groyne-head pool). Stars indicate significant differences of pairwise comparisons. n.s. = not significant.

Figure 10 shows the comparison of the fish abundances between the sonar systems and the sampling dates during the different seasons. In general the fish density was much higher in the overfall pool than in the groyne-head pool in both systems. In the overfall pool (Fig. 10 a) there was high abundance in winter and autumn and low abundance in spring and summer. A Mann- Whitney test (winter p= 0.427, spring p= 0.525, summer p= 0.185, autumn p= 0.62) revealed no significant differences between any measurement. At the groyne-head pool (Fig. 10 b) in winter, spring and summer there were low abundances whereas in autumn there were higher abundances. A Mann-Whitney test showed that there was no significant differences between the two sonar systems in spring and summer (spring p= 0.229, summer p= 0.091). In contrast in winter there was a high significant (winter p= 0.009) and in autumn a highly significant difference between EK 60 estimates and DIDSON estimates (autumn p< 0.001).

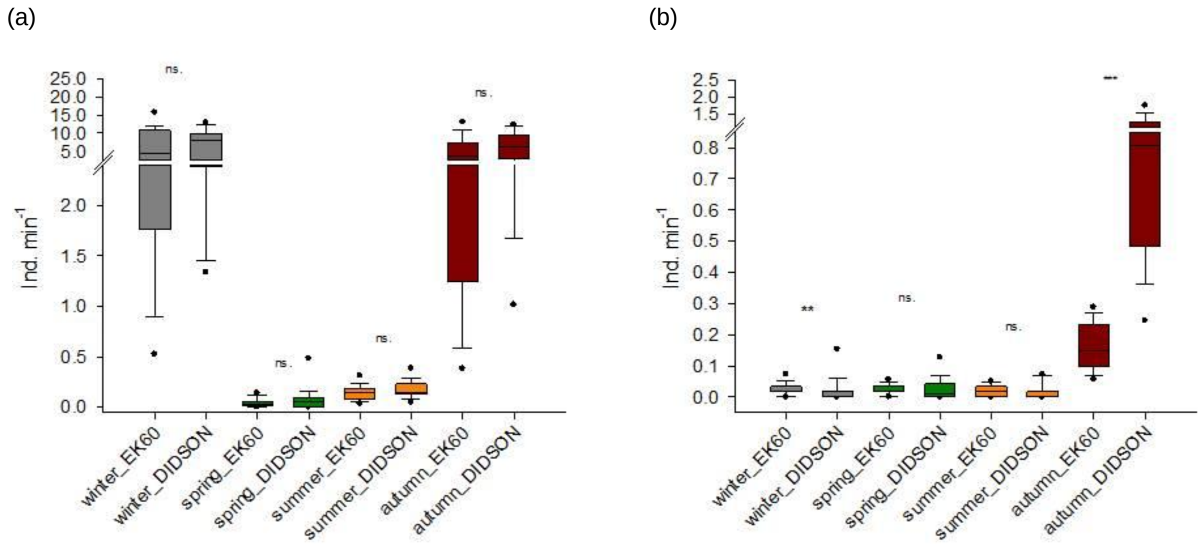

Figure 10 Comparison of the seasonal abundance estimates measured by two sonar systems at two sampling sites and different sampling dates (a) overfall pool, (b) groyne-head pool. The stars and the n.s respectively mark the significant differences between the pairwise comparisons of the abundance estimated by the different devices detected at the respective season.

3.3 Diel fish abundance:

The diel fish abundance distribution of both sonar systems displayed a similar pattern in both pools. At the overfall pool (Fig. 11) a Mann-Whitney test showed no significant differences between the hourly abundances detected by the different sonar systems (winter EK 60 vs. DIDSON: p= 0.427; spring EK 60 vs. DIDSON: p= 0.525; summer EK 60 vs. DIDSON: p= 0.158; autumn EK 60 vs. DIDSON: p= 0.062). However at the groyne-head pool (Fig.12) the abundance estimations between winter and autumn were significant different (winter EK 60 vs. DIDSON: p= 0.009; autumn EK 60 vs. DIDSON: p< 0.001) whereas in spring and summer there were no significant differences (spring EK 60 vs. DIDSON: p=0.229; summer EK 60 vs. DIDSON: p=0.091).

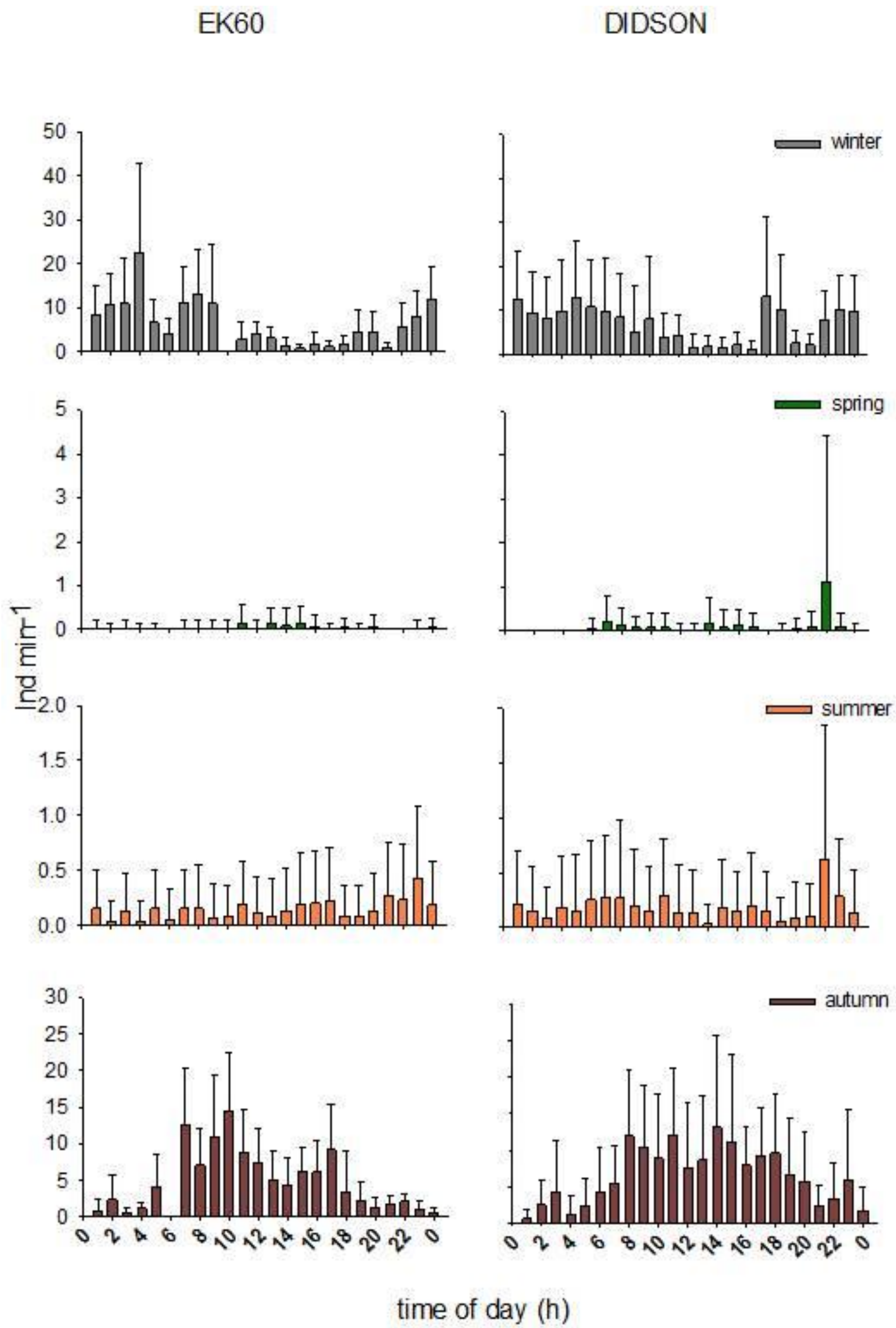

Figure 11 Diel fish abundances recorded by the different sonar systems at the overfall pool in different seasons (4 sampling dates).

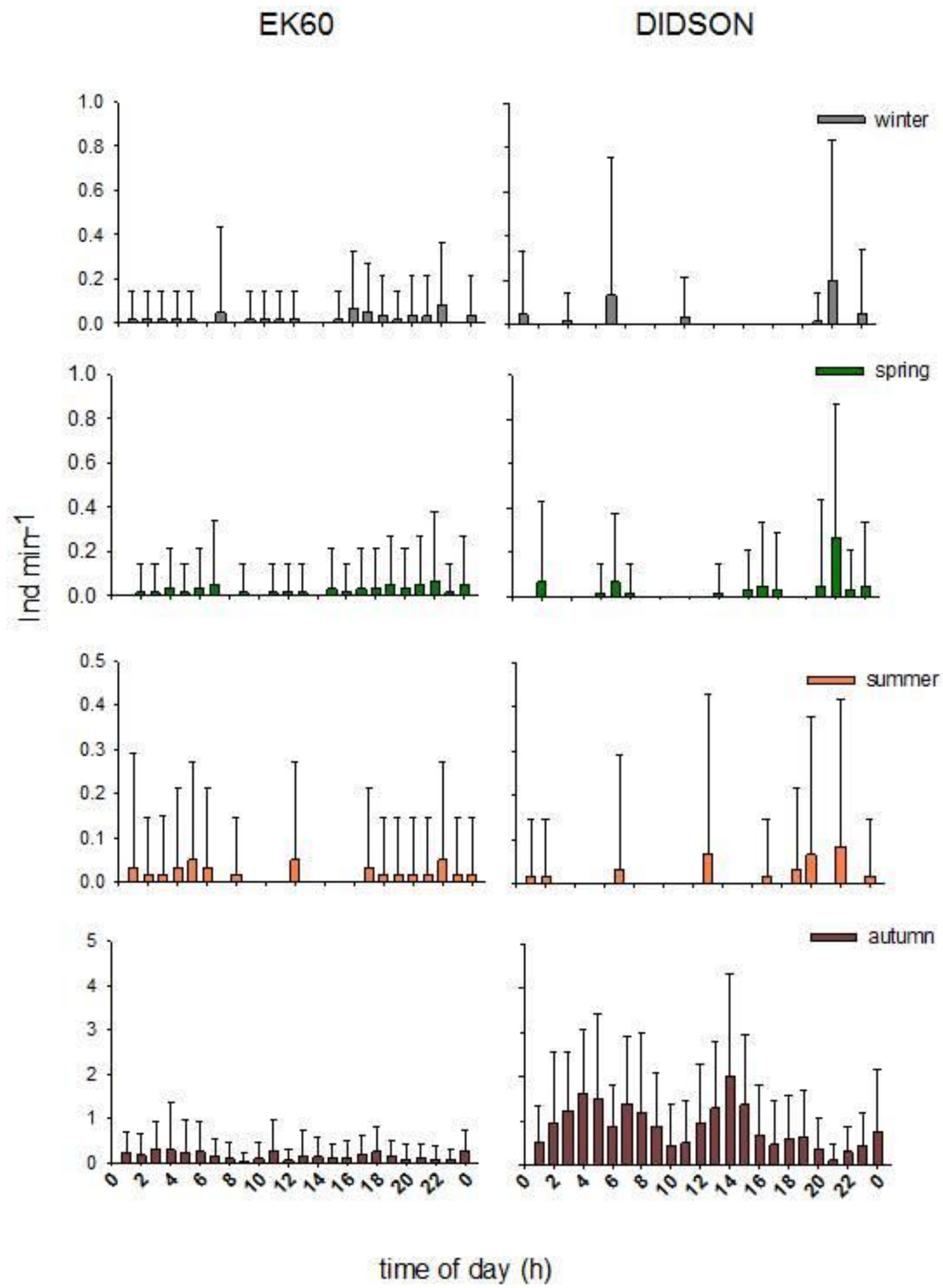

Figure 12 Diel fish abundance recorded by the different sonar systems at the groyne-head pool in different seasons (4 sampling dates).

3.4.1 Fish size estimates

Figure 13 shows a comparison of all fish length estimated by three different methods and two measuring devices. A Wilcoxon test showed that all methods are highly significant different from each other (EK 60 mean vs. EK 60 95%: $p < 0.001$; EK 60 mean vs. DIDSON: $p < 0.001$; EK 60 95% vs. DIDSON: $p < 0.001$).

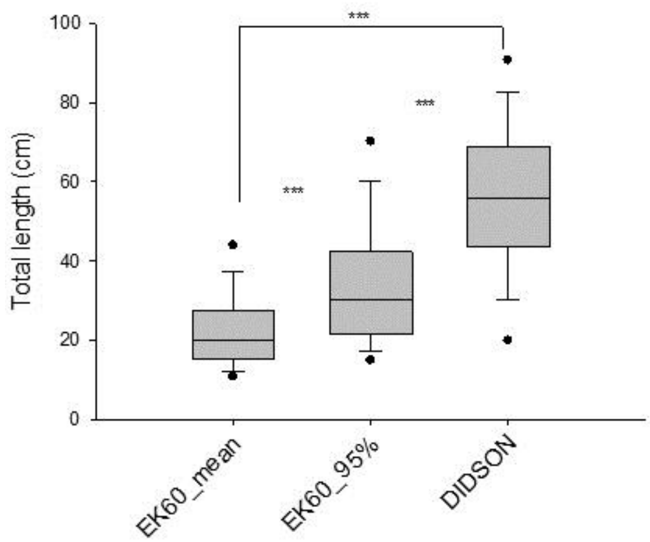

Figure 12 Comparison of fish total length estimates based on the three different sizing methods and two measuring devices. The stars indicate highly significant differences; the lines between the DIDSON box plot and the EK 60_mean box plot and the stars above the line show the significant between these two sizing methods.

3.4.1.1 Overfall pool:

Figure 14 shows a comparison of the average total-length estimated with three different methods at four sampling dates. With the exception of spring the total length estimates of the DIDSON sonar were larger than the estimates of the two EK 60 methods. A highly significant difference of the average total-length of fish between seasons was observed within each method. A median test showed that the average fish length within seasons differed highly significant between the two methods ($p < 0.001$). In the overfall pool the average total-length of the winter recordings was 22.9 ± 6.1 cm (EK 60_mean), 39.6 ± 18.6 cm (EK 60_95%) and 58.8 ± 4.7 cm (DIDSON). In spring the average total length was 16.3 ±7.8 cm (EK 60_mean) 25.8 ± 13.8 cm (EK 60_95%) and

22.3 ± 17.4 cm (DIDSON). In summer the average total length was 18.4 ± 3.6 cm (EK 60_mean) 25.63± 9.1 cm (EK 60_95%) and 48.7 ± 8.8 cm (DIDSON). In autumn the average total length was 17.0 ± 4.2 cm (EK 60_mean) 27.5 ± 13.0 cm (EK 60_95%) and 61.5 ± 3.8 cm (DIDSON).

3.4.1.2 Groyne-head pool:

In the groyne-head pool (Fig. 14 b) the average total length of fish did not show a pronounced seasonal variability. A median test showed that the average fish length within seasons differed highly significant between the two methods ($p < 0.001$). The average total-length in winter was 12.8 ± 8.1 cm (EK 60_mean), 24.1 ± 14.5 cm (EK 60_95%) and 11.4 ± 18.3 cm. In spring the average total-length was 10.0 ± 5.8 cm (EK 60_mean), 16.8 ± 10.5 cm (EK 60_95%) and 13.0 ± 16.1 cm (DIDSON). In summer the average total-length was 8.3 ± 6.5 cm (EK 60_mean), 16.7 ± 4.7 cm (EK 60_95%) and 15.2 ± 22.5 cm (DIDSON). In autumn the average total-length was 13.8 ± 2.4 cm (EK 60_mean), 19.6 ± 8.5 cm (EK 60_95%) and 22.5 ± 4.6cm (DIDSON).

(a) (b)

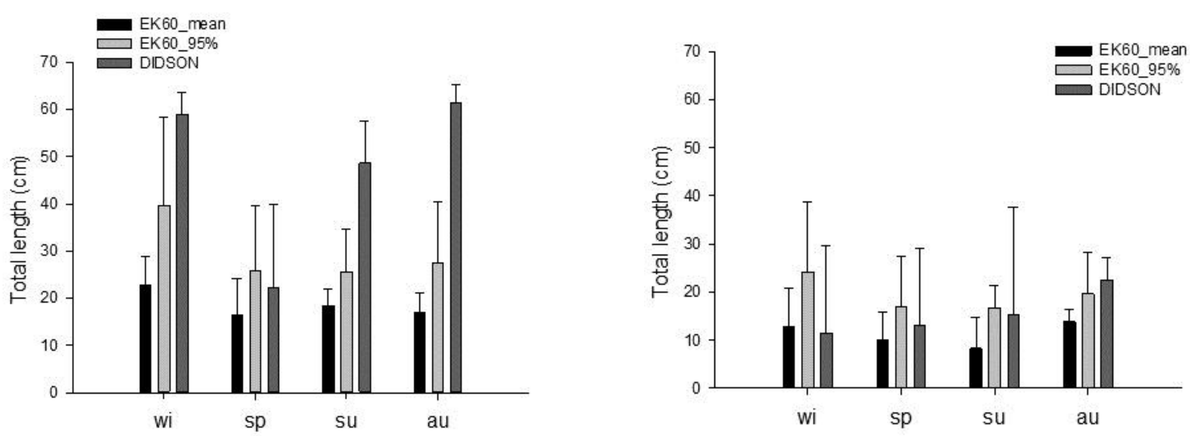

Figure 14 Total length estimates (+SD) derived from three different methodes. (a) overfall pool (b) groyne-head pool.

Figure 15 shows the comparison of estimated fish lengths between the two sampling sites derived from three different sizing techniques and the two sonar techniques. All three sizing methods showed a similar pattern, the median fish size in the overfall pool was generally higher than in the groyne-head pool, irrespective of sizing technique and hydroacoustic device. A Wilcoxon-Test showed that the size estimates of all three methods differed highly significantly between the overfall pool and the groyne-head pool (EK 60_mean, EK 60_95%, DIDSON p <0.001). A GLM showed that both factors ‘sonar systems’ and ‘site’ (OP and GP) have highly significant effects on fish size estimates (both p< 0.001). The mean squares of the factor ‘site’ have a higher influence on the model (MS= 507 509.613) than the different sonar systems (309 441.956).

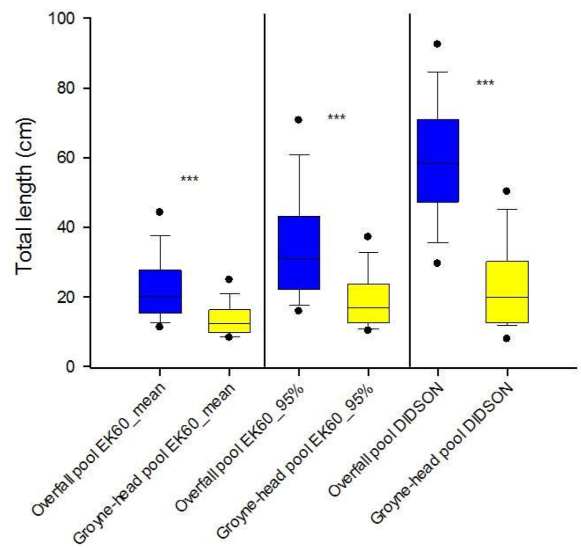

Figure 15 Comparison of the total length in the overfall pool and the groyne-head pool based on three different sizing methods and two measuring devices.

3.4.1.3 Overfall pool:

In the overfall pool the size distribution regarding the different estimation methods showed that in the majority of the cases the DIDSON estimations produce the largest results. In winter the sizing conducted by the EK 60 95% percentile TS and the DIDSON result in a similar median fish length whereas in spring the median fish length achieved with the DIDSON approximate the length measured by the EK 60 mean TS. However the fish length based on the mean TS (EK 60) always result in the smallest median sizes. The two EK 60 methods showed the highest fish length in winter. In summer and autumn the DIDSON detected very large fish in comparison to the EK 60 methods. Figure 16 (a) shows the fish length distribution of the three different size estimations at the overfall pool. A Wilcoxon Single Ranks test showed that there were highly significant differences between winter EK 60 mean and DIDSON ($p < 0.001$) as well as between winter EK 60 95% and DIDSON ($p < 0.001$). In spring EK 60 mean and DIDSON there was a highly significant difference ($p < 0.001$) but between EK 60 95% and DIDSON there was no significant difference ($p = 0.654$). In summer there were highly significant differences between EK 60 mean and DIDSON (Wilcoxon $p < 0.001$) as well as EK 60 95% and DIDSON ($p < 0.001$). In autumn both EK 60 mean – DIDSON ($p < 0.001$) and EK 60 95% – DIDSON ($p < 0.001$) were highly significant different.

3.4.1.4 Groyne-head pool:

In the groyne-head pool the size distribution between the single seasons was more heterogeneous. The two EK 60 methods show a trend that there were larger fish in winter and autumn whereas the DIDSON estimation showed the opposite trend. Here the length estimations of the winter spring and summer recordings involved the largest fish. However the DIDSON length estimation was the highest in all four seasons. Figure 16 (b) shows the fish length distribution of the three different size estimations at the groyne-head pool. A Wilcoxon Single Ranks test showed that in winter EK 60 mean and DIDSON differed highly significantly ($p < 0.001$) whereas EK 60 95% and DIDSON differed high significantly ($p = 0.002$). The same pattern was observed during the spring recordings (EK 60 mean – DIDSON; $p < 0.001$) (EK 60 95% – DIDSON; $p = 0.024$). In summer both EK 60 mean – DIDSON ($p < 0.001$) and EK 60 95% – DIDSON ($p < 0.001$) were highly significant different. In autumn the difference between EK 60 mean and DIDSON was high significant ($p = 0.015$) and the difference between EK 60 95% and DIDSON was highly significant ($p < 0.001$).

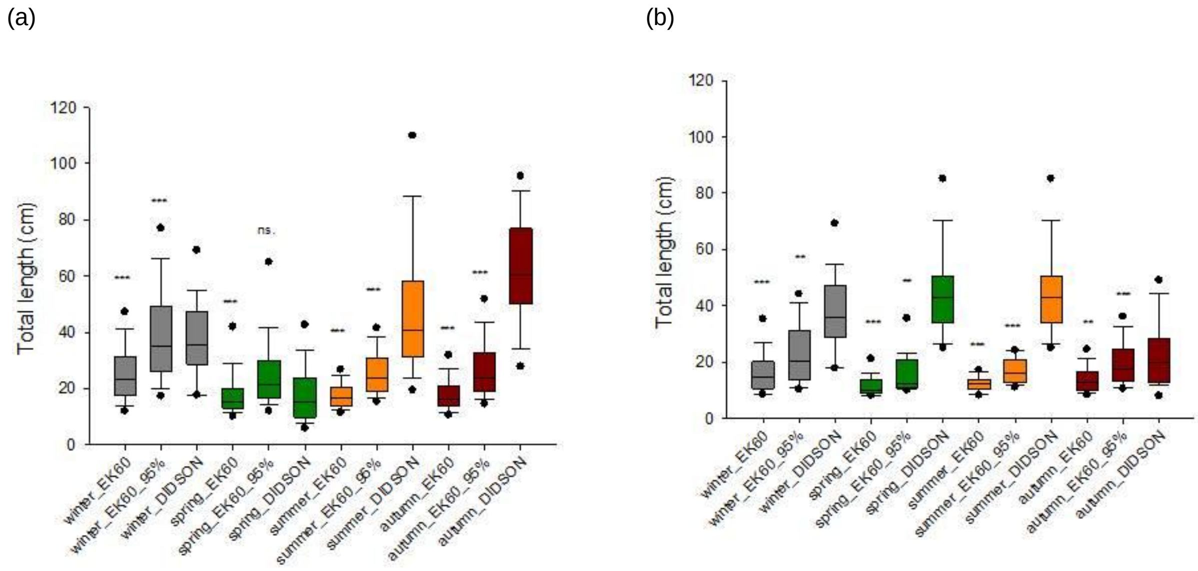

Figure 16 Comparison of the estimated total length of (a) overfall pool and (b) groyne-head pool based on three different sizing methods and two measuring devices.

3.4.2 Acoustic size vs. measured size

The comparison of the acoustic size estimates achieved from different sizing techniques with size measurements from electro fishing in the River Danube in 2006 and 2007 displayed that there is a highly significant difference between the sonar data and the catch data (Fig. 17) (Wilcoxon Signed Ranks, electro fishing – electro fishing $_{\text{excl. }bleak}$ ($p < 0.001$)*;* EK 60_mean – electro fishing $_{\text{excl. }bleak}$ ($p < 0.001$); EK 60_95% – electro fishing $_{\text{excl. }bleak}$ ($p < 0.001$); DIDSON – electro fishing $_{\text{excl. }bleak}$ ($p < 0.001$)). A comparison of the medians of the single groups showed that the median of the DIDSON based estimates is closest to the median of the catch $_{\text{excl. }bleak}$ (median $_{\text{e-fishing excl. }bleak}$ = 47.30; median $_{\text{e-fishing}}$=14.00; median $_{\text{EK 60\_mean}}$=19.85; median $_{\text{EK 60\_95\%}}$=30.21; median $_{\text{DIDSON}}$=56.40).

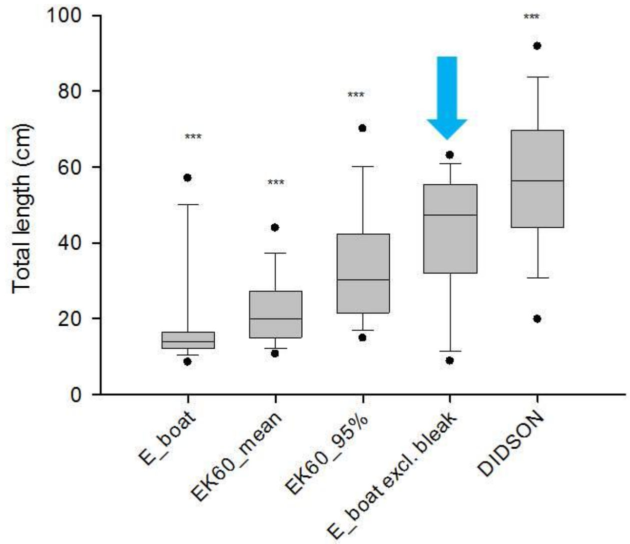

Figure 17 Comparison of acustic total length estimations (EK 60_mean, EK 60_95% and DIDSON) and catch data of the Danube River (E_boat and E_boat $_{\text{excl. bleak}}$).

3.2.4.1 Overfall pool:

To show if there is a difference between the lengths frequency determined by the three different methods (Fig. 18) a Kruskal- Wallis- test was performed. It shows that in winter and spring the averages of the frequency distribution did not differ significantly (winter: p= 0.127, spring: p= 0.910). In summer (p< 0.001) and in autumn (p= 0.013) the results derived from different sizing methods differ significantly.

3.2.4.2 Groyne-head pool:

The analyses of the length frequency distribution between the three different methods at the groyne-head pool (Fig. 19) indicated no significant differences in winter, spring and summer (Kruskal- Wallis- test: winter: p= 0.344, spring: p= 0.616, summer: p= 0.057). In autumn the average of the length frequencies differ high significant (Kruskal- Wallis- test: p= 0.002).

Table 3 Summary of the most frequent size-classes (cm) estimated by three different sizing methods (EK 60_mean = sizing using the mean TS; EK 60_95% = sizing using the 95% percentile; DIDSON= sizing by image analyses) from recordings of the two measuring devices at two sampling sites and the four sampling dates (wi= winter, sp= spring, su= summer, au= autumn).

season	pool	EK60_mean	EK60_95%	DIDSON
wi	OP	20-25	35-40	60-65
	GP	15-20	15-20	35-40
sp	OP	15-25	20-25	10-15
	GP	10-15	15-20	20-30
su	OP	15-20	20-25	40-45
	GP	15-20	15-20	50-55
au	OP	15-20	25-30	55-60
	GP	15-20	15-20	20-25

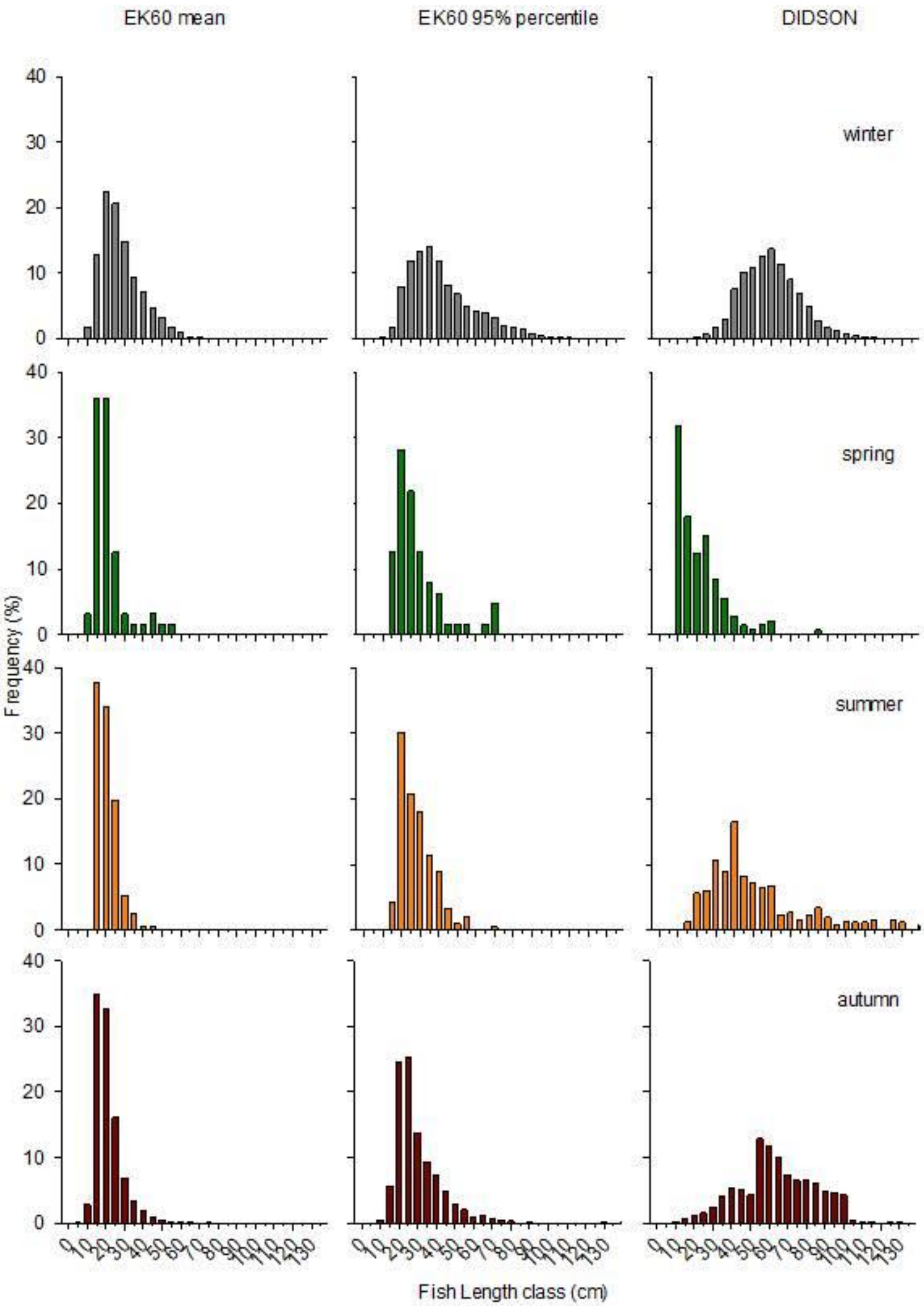

Figure 18 Comparison of fish lengths frequencies estimated with three different methods (DIDSON vs. EK 60 95% percentile vs. EK 60 mean) in the overfall pool at each sampling date.

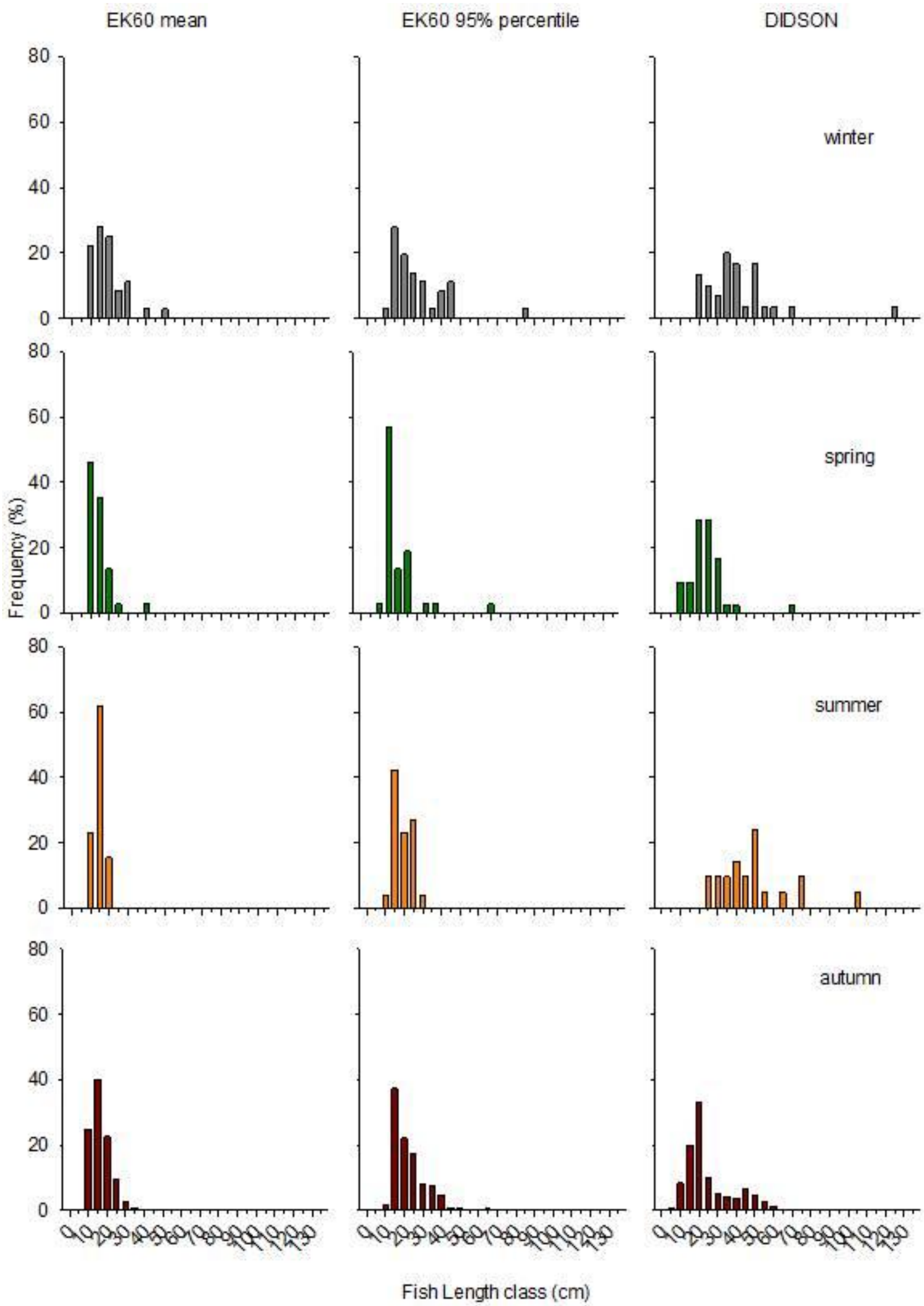

Figure 19 Comparison of fish lengths frequencies estimated with three different methods (DIDSON vs. EK 60 95% percentile vs. EK 60 mean) in the groyne-head pool at each sampling date.

3.5 Individual biomass estimates – EK 60 vs. DIDSON

3.5.1 Overfall pool:

The average individual biomass estimate in the overfall pool was higher than the average individual biomass in the groyne-head pool. Figure 20 shows the average weight converted on basis of the three different total length estimates. In the overfall pool (Fig 20 a) there was a higher average weight in winter and autumn than in spring and summer. However the DIDSON estimation of the summer recording was nearly as high as the average weight of winter and autumn. In winter the average weight was 263.02 ± 132.92 g (EK 60_mean), 1362.71 ± 2705.53 g (EK 60_95%) and 3178.42 ± 910.99 g (DIDSON). In spring the averages weight was 80.21 ± 117.16 g (EK 60_mean), 410.19 ± 920.06 g (EK 60_95%) and 342.93 ± 589.63 g (DIDSON). In summer the average weight was 108.97 ± 65.90 g (EK 60_mean), 251.31 ± 406.17 g (EK 60_95%) and 3067.26 ± 2047.72 g (DIDSON). In autumn the average weight was 109.74 ± 50.89 g (EK 60_mean), 468.12 ± 2182.06 g (EK 60_95%) and 4048.97 ± 693.99 g (DIDSON).

3.5.2 Groyne-head pool:

In the groyne-head pool (Fig. 20 b) average weight for the winter recording was 85.58 ± 134.97 g (EK 60_mean), 398.59 ± 1202.24 g (EK 60_95%) and 331.23 ± 699.13 g (DIDSON). In spring the average weight was 35.69 ± 51.27 g (EK 60_mean), 152.89 ± 600.96g (EK 60_95%) and 204.07 ± 733.25 g (DIDSON). In summer the average weight was 23.93 ± 22.26 g (EK 60_mean), 50.63 ± 43.75 g (EK 60_95%) and 450.49 ± 939.60 g (DIDSON). In autumn the average weight was 56.96 ± 28.65 g (EK 60_mean), 126.46 ± 257.51 g (EK 60_95%) and 296.67g ± 220.57 g (DIDSON).

(a) (b)

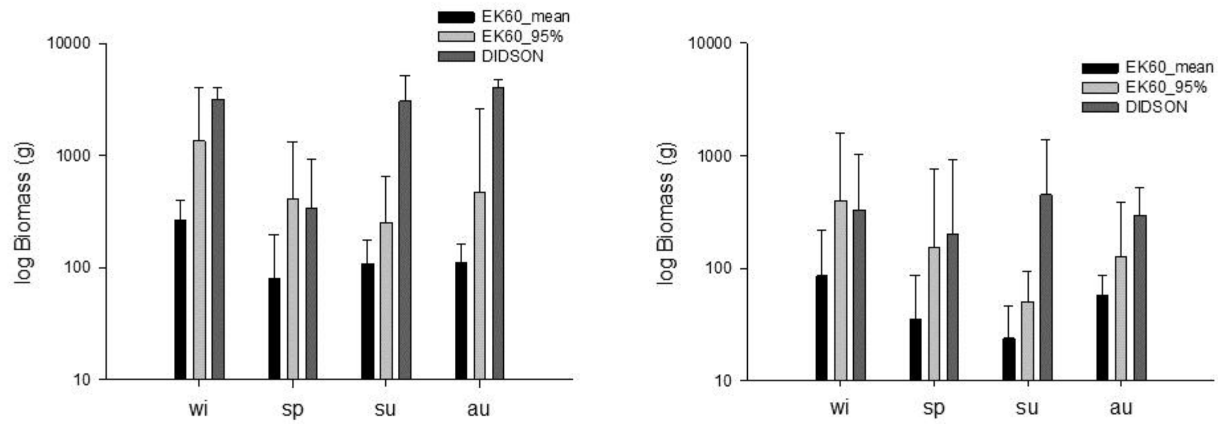

Figure 20 Biomass calculations (+SD) based on three different methodes. (a) overfall pool (b) groyne-head pool.

Figure 21 shows the weight calculation based on the three different methods of the size estimation of the overfall pool (a) and the groyne-head pool (b). The calculation of the overfall pool of the winter recordings showed that there were highly significant differences between both EK 60 mean and DIDSON and EK 60 95% and DIDSON (Wilcoxon Signed Ranks, $p < 0.001$). In spring the difference between EK 60 mean and DIDSON were highly significant (Wilcoxon Signed Ranks, $p < 0.001$) whereas the difference between EK 60 95% and DIDSON were not significant (Wilcoxon Signed Ranks, $p = 0.794$). In summer and autumn both EK 60_ mean – DIDSON (Wilcoxon Signed Ranks, summer: $p < 0.001$; autumn: $p < 0.001$) and EK 60_95% – DIDSON (Wilcoxon Signed Ranks, summer: $p < 0.001$; autumn: $p < 0.001$) were highly significant. In the groyne-head pool in winter there was a highly significant difference between EK 60 mean and DIDSON (Wilcoxon Signed Ranks, $p < 0.001$) and a high significant difference between EK 60 95% and DIDSON (Wilcoxon Signed Ranks, $p = 0.007$). In spring there was a highly significant difference between EK 60 mean and DIDSON (Wilcoxon Signed Ranks, $p < 0.001$) and a significant difference betweenEK 60 95% and DIDSON (Wilcoxon Signed Ranks, $p = 0.021$). In summer both EK 60 mean – DIDSON (Wilcoxon Signed Ranks, $p < 0.001$) and EK 60 95% – DIDSON (Wilcoxon Signed Ranks, $p < 0.001$) were highly significant. In autumn the differences between EK 60 mean and DIDSON (Wilcoxon Signed Ranks, $p = 0.016$) were significant whereas between EK 60 95% and DIDSON (Wilcoxon Signed Ranks, p <0.001) they were highly significant.

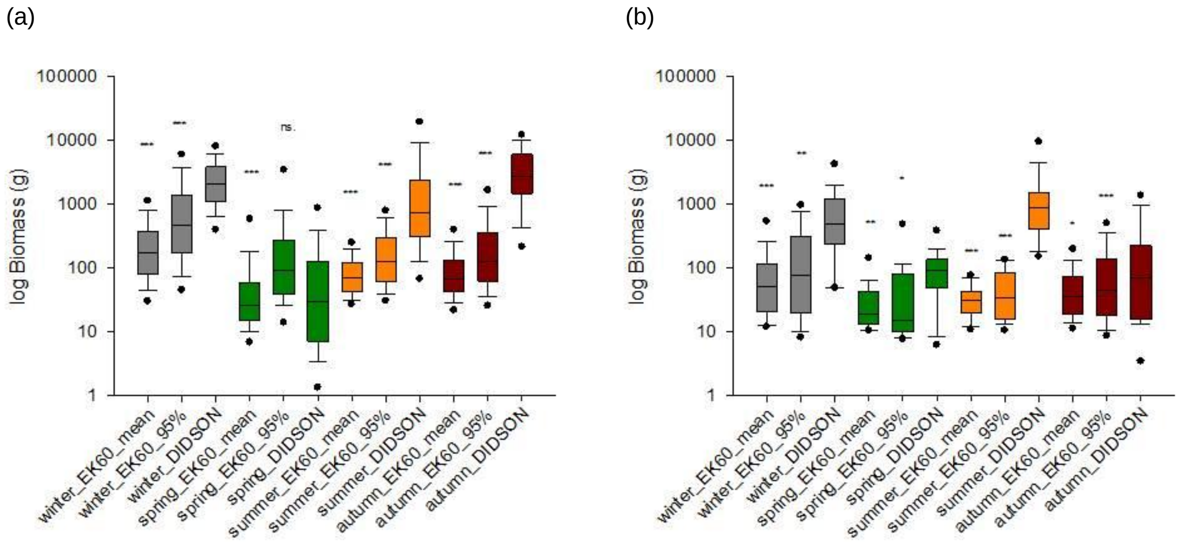

Figure 21 Comparison of the calculated biomass (EK 60_mean vs. EK 60_95% percentile vs. DIDSON) at the single recording dates (a) overfall pool (b) groyne-head pool.

4. Discussion

4.1 Fish abundance

The goal of our investigation was to show to which extent the abundance- and size estimates from recordings of two synchronized sonar systems (split beam EK 60 vs. multi beam DIDSON) differ in two hydraulic different pool habitats in a free-flowing stretch of the River Danube in Austria. The results are discussed in the light of the different features of the two sonar systems and how they possibly have an influence on the observed fish abundance patterns. In general the abundance estimates of the two systems did not differed significantly; however different seasonal abundance estimates between sampling sites and sampling dates were evident. Moreover, regression analyses of $\log_{10}$ transformed data of abundance revealed a highly significant relationship and explained 81 percent of the total variance, it indicated that the abundance estimates of the two methods are not direct proportional, as the slope of the regression was slightly below 1 and the intercept slightly above zero. Generally, this model enables the conversion of estimated abundances between the two systems with a reasonable accuracy. The intercept and the slope of the regression leads to a higher average abundance estimated by the DIDSON when the fish density of the EK 60 is low whereas at high fish densities of the EK 60 the abundance estimates from DIDSON are lower than it is predicted by direct proportional results. At the overfall pool high abundances estimate with the EK 60 correspond well with abundances estimated by the DIDSON although a detailed look on seasonal patterns shoed some significant differences as well. In groyne-head pool the highly significant difference between the abundance estimation achieved by the different sonar devices are reflected in lower coefficient of determination of 0.75 between the two different abundance estimations. The regression line at the groyne-head pool indicates that the average abundance estimated by the DIDSON were always higher than the one estimated by the EK 60. However, this effect seems to decrease with an increase of fish density. At high fish densities main divergent parameters of the sonar systems, beam volume (1:7) and frequency (1:10) have less effect on the results than when the fish densities are low like in the groyne-head pool. Densely packed fish aggregations like in the overfall pool in autumn and winter display similar fish abundance estimates in both sonar systems because fish are aggregated in a small area or volume respectively. Therefore beam volume has less effect on the abundance estimates. When fish are spread more widely in the water column like in the groyne-head pool beam volume is an issue.

The GLM showed that the factor ‘sampling site’ had the strongest effect on the abundance estimation. This can be explained for the highly different fish densities observed at the two pools (OP: wi. 7962° (EK 60), 10038 (DIDSON), sp. 64 (EK 60), 145 (DIDSON), su. 212 (EK 60), 267 (DIDSON), au. 6894° (EK 60), 9419 (DIDSON) vs. GP: wi. 36 (EK 60), 30 (DIDSON), sp. 37 (EK 60), 42 (DIDSON), su. 26 (EK 60), 21 (DIDSON), au. 231 (EK 60), 1264 (DIDSON)) (° subsampled data). This is given evidence by the fact that the abundance estimations contributed most to the overall abundance pattern of both pools. The high abundance in the OP especial in winter an autumn seems to explain the high influence of the factor ‘season’ since the detected seasonal abundances differed within a magnitude within and between pools. This circumstance is evident by comparing the abundance distribution pattern of the pooled data and the single pools. It is traceable that the much high abundance of the overfall pool covers the abundances of the groyne-head pool. This may explain why the different sonar systems seem to have less effect on the results. Differences of abundances between sites and seasons were much stronger than differences between the two sonar systems. This matter became obvious by looking at the seasonal abundance estimates of each pool. Since we observed no significant differences of the abundance estimates of the two different sonar systems in the hydraulically calm overfall pool we infer that high and packed fish densities have no effect on the recording capability of the sonar systems. Differences between the beam volume and the frequency used by the sonar systems may lead to different abundance estimates. However, our results seem to indicate no bias in the overall pattern of abundance. Maxwell and Gove (2007) proposed density-dependent effects on salmon counts achieved by different sonar systems like split-beam and multi-beam, but the fish densities during the salmon runs were one order of magnitude bigger than in the deep pools of the Danube River at least. Densely packed fish can cause shadowing of the sound on each other displayed as overlapping on the echograms which consequently can bias quantitative sampling. However this was not observed in our recordings. Particularly in split beam recordings single fish traces were nicely distinguishable even in high fish densities.

In the groyne-head pool the significant different fish abundance estimations in winter and autumn could probably be caused by different beam-volumes and frequencies between the two sonar systems, because fish were more spread in the water column and spilt beam was not able to detect small benthic fish due to bottom blind zone.

There are several possible explanations for the divergence in quantitative estimates between the two sonar systems in the groyne-head pool to be discussed. At the groyne-head pool we achieved high significant differences between the sonar systems in winter and highly significant differences in autumn. A possible explanation for the differences at the winter recordings could be counting false signals as fish signals in EK 60 due to noisy environment at the groyne-head pool. A high background noise can cause false fish echoes. The high frequency as used by the DIDSON sonar is more sensitive in terms of background noise like in the turbulent groyne-head pool than the low frequency used by the EK 60 split beam. As a consequence of this higher sensitivity towards high background noise like in the groyne-head pool the abundance estimates based on high frequency should be lower than the estimates based on the low frequency used by the EK 60. Our results showed that this was not the case. Hence, it seems more likely that high background noise cause false fish echoes in the split-beam than masking fish echoes in the DIDSON. The results achieved at the groyne-head pool that low fish densities in EK 60 corresponded with higher fish densities in DIDSON supports the argument that the bigger beam volume of DIDSON seems to be less affected by low fish densities in this pool. So it is possible that because of the larger beam volume of the DIDSON more fish could be detected which were not detected by the smaller beam of the EK 60. Due to large beam-volume and much higher resolution in DIDSON it was possible to detect even small benthic fish, which were very abundant in autumn whereas this was not possible with the EK 60 due bottom blind zone effects.

The overall pattern of the seasonal abundance was characterized by high abundances in winter and autumn and low abundances in spring and summer. This seasonal pattern was more pronounced in the overfall pool, which was possibly used by fish as retention area for hibernation due the low flow velocity in the pool. In spring and summer the fish may leave the pool in order to start their spawning migration and for migration to feeding grounds, respectively (Vehanen et al., 2005). In the Groyne-head pool a slightly different pattern was observed, the abundance was low in winter, spring and summer and higher in autumn. Therefore, pools with different hydraulic situations seem to reveal a different pattern of temporal habitat use by fishes.

4.2 Diel fish abundance

In general, the diel abundance within each seasonal 24 hour sampling corresponded well between the two sonar systems in both pools at all sampling dates. In the overfall pool in spring the abundance estimates from the DIDSON recordings were distinctly higher than those from the EK 60 data, hence, the diel abundance fluctuations were more pronounced The difference can be explained by differences in the sampling volume, it is very likely that the larger beam volume of DIDSON contained more fish than the smaller volume which was scanned by the EK 60. In the groyne-head pool the diel abundance patterns were different between the two sonar systems. In winter, spring and summer the abundances by the EK 60 were homogeneous distributed over the day whereas distribution of the DIDSON was patchier with higher abundances.

4.3 Acoustic fish sizing

In rivers, side-looking sonar applications are subject to a set of conditions, which make acoustic sizing difficult and cause bias. Main causes are: (1) low signal-to-noise ratios due to interference from acoustic boundaries (surface and bottom); or noisy environment like in turbulent pools, which lead to bias in 3D-position estimates of objects within the beam in split-beam estimates (Kieser et al., 2000; Mulligan, 2000) and TS (Fleischman and Burwen, 2000), particularly for fish located near the periphery of the beam. (2) Variability in fish’s aspect due to natural swimming causes profound changes in backscatter (Love, 1969; Dahl and Mathisen, 1983). Consequently, Target Strength (TS) turned out to be a poor predictor of fish size for side-looking sonar (Burwen et al., 2003).

Measurements based on echo envelope (= pulse length) provided better predictions for tethered fish, but this could not be conclusively verified for free-swimming fish (Burwen et al., 2007). Blurred fish images in the DIDSON recordings impede the exact identification of the end of the snout and the tail and can therefore lead to an overestimation of fish size due to adding of false non-fish pixels.

Fish sizing in this study was based on three different methods. Two methods were based on target strength (TS) and achieved from split-beam recordings namely mean-TS and 95%-percentile-TS (Rakowitz et al., 2008b). The third method was based on image analysis from DIDSON multi-beam recordings using manual fish-measuring features of the software. These results were compared with catch data of the sublittoral inshore zone of the main channel of the Danube to see which length estimation method reflects the measured size distribution best. The three different methods of fish length estimation resulted in three highly significant different length estimations. These length estimations were compared with the catch data without the sizes of a surface dwelling, small sized species like bleak.. In general, all acoustic sizing methods were significantly different from the catch data. Fish sized from DIDSON images were larger than the catch data, and TS based sizing methods (mean-TS, 95%-percentile-TS) underestimated the fish size of the catch. The underestimation of the two TS based methods is very likely caused by the high variability in the fish aspect due to the tilted downward looking split-beam and natural behavior. The strongest fish signal is usually received from the side aspect of the fish. With an increasing aspect angle of the fish the echo intensity is decreasing (Burwen et al., 2007). In our application the probability to record side aspects of fish was very low. Even the 95%-percentile-TS, which takes into account only the strongest fish echoes provided generally smaller fish size estimates than the measured individuals from the catched ones. The comparatively higher length estimations of the DIDSON could have two reasons: (1) a high background noise like in the Danube pools as well as densely fish aggregations (Maxwell & Gove, 2007; Berghuis, 2008) can lead to blurred or overlapping fish images. Differentiation of snout and tail becomes difficult (Burwen et al., 2010) and implication of enlarged pixels due to cross-range resolution especially at further ranges can cause overestimation of fish sizes. (2) The catch data were achieved from electro fishing in the River Danube in 2006 and 2007 including specimens from the littoral and sublittoral fish community. Since there exist no catch data from the fish community of 2008 the size distribution of the catch of 2006 and 2007 is the best available comparative data set of fish size distribution in the main channel of the River Danube in this region in 2008. Still, an underestimation of the sizes distribution of the real deep pool fish communities is probable, particularly since electro-fishing has a limited depth range. Therefore, the size distribution based on the DIDSON sonar images seems to come as close as possible to the size distribution of the deep pool fish community.

A detailed look on each pool type revealed that on average fish were significantly larger in the overfall pool than in the groyne-head pool, which can be seen in the results by all three sizing methods. A possible explanation for these differences might be that the hydraulically calm overfall pool functions as an in stream overwintering habitat for the fish assemblage of the main channel, indicated by high fish abundances and a wide range of sizes in winter and autumn. Especially in spring but also in summer the size range was lower than in autumn and winter. Low fish abundance due to highly turbulent hydraulic conditions, high number of small benthic fish as well as only occasional occurrence of large top predators (e.g. catfish) have probably caused the smaller average fish size and a different fish size distribution in the groyne-head pool.

The general pattern displayed by the comparison of sizing methods (largest sizes from DIDSON, 2^{nd}-largest from 95%-percentile-TS and 3^{rd}-largest from mean-TS) also held true at all sampling dates and in each pool. Since the biomass calculation is based on the seasonal fish length estimates the biomass distribution shows the same pattern as the length estimates. Nevertheless the seasonal biomass distribution displayed very high values in the inshore-sited overfall pool, particularly in autumn and winter. The offshore-sited groyne-head pool showed one magnitude lower biomass values. This biomass divergence between inshore and offshore pools is in good concordance with findings from Walter and Fryhof (2004) showing significant differences in diel biomass distribution pattern between inshore and offshore habitats in lower Oder River.

The investigation showed generally higher abundance estimations by the DIDSON sonar. Patterns of abundance between sites and different sampling dates were similar in both systems. A higher conformity between abundance estimates of the two systems was observed at higher fish densities. A comparison of the fish length showed that the size estimations of the DIDSON were higher than the estimations derived from two different methods applied to the EK 60 fish recordings (Fig. 13). The comparison of the size distribution of the two different sonar devices with catch data from the Danube indicated that the size distribution of the DIDSON sonar seems to overestimate measurements from actual catches whereas the EK 60 sizing methods seems to underestimate the fish length from the catch.

It can be concluded that the hydroacoustic is very value to achieve reliable seasonal abundance estimates. Particularly in so far uninvestigated habitats like deep whirl pools in a large river. The observed variability in the seasonal pool specific abundance estimates provide us a new insight in the ecological function of these valuable habitats for the instream fish community of a large river. The results fill a lack of knowledge regarding quantitative fish assessment in rivers. Although the sonar systems delivered comparable quantitative estimates especially at high fish densities, new acoustic devices like DIDSON with high frequency and high resolution display a methodical advantages in acoustically inconvenient riverine habitats like turbulent deep pools with high back ground noise.

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6. Zusammenfassung

Vergleich der Abundanz Schätzungen von Fischen in Donaukolken mittels zweier unterschiedlicher Echolotsysteme.

Kolke in großen Flüssen wie der Donau stellen in Hinblick auf die Nutzung durch Fische wenig untersuchte Habitate dar. Der Grund hierfür liegt darin, dass herkömmliche Methoden zur Erfassung von Fischzönosen wie Fischen mit elektrischem Strom, Langleinen oder der Einsatz von Netzen methodisch bedingt nicht ausreichen, um ein genaues Bild der Fischabundanz dieser Bereiche zu liefern. Der Wirkungsbereich des elektrischen Feldes ist auf die oberen Bereiche beschränkt, und nimmt mit der Wassertiefe ab (Zalewski and Cowx 1990). Mittels Langleinen werden hauptsächlich benthische Fischarten mit einer räuberischen Ernährungsweise erfasst (Bammer, 2010). Der Einsatz von Kiemennetzen ist aufgrund der herrschenden Strömungen und Turbulenzen nur in einem sehr eingeschränkten Maße möglich (Goffaux et al., 2005). Eine adäquate Methode um das Vorkommen und die Abundanz von Fischen in Kolken zu erfassen ist daher der Einsatz von Echoloten (Kolding, 2002). Ein großer Vorteil der Anwendung von Echoloten besteht darin, Messungen der Verteilung und der Abundanz von Fischen über beliebig lange Zeiträume durchführen zu können.

Im Zuge der vorliegenden Studie wurden zwei hydrologisch unterschiedliche Kolke in der freifließenden Donau östlich von Wien erstmalig untersucht. Ein Kolk befand sich direkt stromab hinter einer transversalen Buhne (Überfallskolk). Bei erhöhtem Wasserstand, wird die Buhne vom Wasser überflutet und es entsteht eine zum Grund gerichtete, grabende Strömung. Der zweite Kolk befand sich am Ende einer transversalen Buhne (Buhnenkopfkolk). Beim Auftreffen des Wassers auf den Kopf der Buhne entstehen turbulente Strömungen die sich in das Bachbett graben und so einen Kolk entstehen lassen. Im Zuge dieser Untersuchung wurden gleichzeitig durchgeführte Aufnahmen von verschiedenen Echolotsystemen miteinander verglichen (z.B. Maxwell and Gove, 2007; Berghuis, 2008). Die zwei verwendeten Systeme waren das „Split - beam“ Echolot EK 60 von Simrad® und das „Multi- beam Dual Frequency Identification

Sonar“ Echolot (DIDSON) von Soundmetrics®. Das EK 60 verwendet eine Frequenz von 120 kHz während das DIDSON mit 1,1 oder 1,8 MHz arbeitet. Die höhere Frequenz ermöglicht es dem DIDSON feinere Aufnahmen zu machen, wodurch kleinere Objekte erfasst werden können. Die Aufnahmen wurden zeitlich synchronisiert, von einem Boot, dass über den Kolken im Fluss verankerten war, durchgeführt. Insgesamt wurden acht 24 stündige Aufnahmen (4 vom Überfallkolk und 4 vom Buhnenkopfkolk) saisonal über das Jahr verteilt, ausgeführt.

Im Überfallskolk waren generell höhere Fischdichten zu beobachten, als im Buhnenkopfkolk. Weiters war ein saisonaler Trend bezüglich der Fischdichte im Überfallskolk erkennbar, es wurden hohe Dichten im Winter und Herbst und geringere Dichten im Frühjahr und Sommer festgestellt. Im Buhnenkopfkolk wurden niedrige Abundanzen im Winter, Frühjahr und Sommer beobachtet, während im Herbst leicht erhöhte Fischdichten vorhanden waren. Der Vergleich der Aufnahmen beider Systeme ergab, dass das DIDSON Sonar höhere Fischdichten aufzeichnete als das EK 60. Die Differenzen zwischen den Systemen zeigten auch Unterschiede zwischen den Probestellen, ebenso waren saisonale Effekte gegeben. Die Abundanz im Überfallskolk zeigte keine signifikanten Unterschiede zwischen den Echolotsystemen. Im Buhnenkopfkolk waren im Winter hohe und im Herbst höchst signifikante Unterschiede zwischen den erfassten Fischabundanzen zu beobachten, während im Frühjahr und Sommer keine signifikanten Unterschiede auftraten.

Ein weiteres Untersuchungsziel war der Vergleich der Längenbestimmung der beiden Echolotsysteme. Die Längenbestimmung des EK 60 erfolgte indirekt durch die Umrechnung der reflektierten Signalstärke in die Fischlänge, während beim DIDSON die Messung der Länge von Individuen direkt mittels Bildanalyse durchgeführt wurde. Die mittels des EK 60 beziehungsweise DIDSON ermittelten Längenverteilungen wurden mit Fangdaten der Freiwasserzone der Donau aus den Jahren 2006 und 2007 verglichen. Zur Längenbestimmung mittels EK 60 wurden zwei unterschiedliche Methoden, unter Verwendung der mittleren Signalstärke (Lilja et al., 2004; Love, 1969; Love, 1977) bzw. des 95% Perzentils der Signalstärkeverteilung (Rakowitz et al., 2008b), verwendet. Die Ergebnisse, der Längenverteilung aller Methoden ergaben, dass sich im Überfallskolk größere Fische aufhielten als im Buhnenkopfkolk. Die DIDSON Längenbestimmung lagen immer über der beiden EK 60 Methoden. Der Vergleich der Längenbestimmung der Echolotsysteme mit den Fangdaten aus der Donau zeigte eine leichte Überschätzung der Längen durch das DIDSON und eine leichte Unterschätzung der EK 60 Längen ermittelt mit der 95%-Perzentil Methode. Die Längenbestimmung mittels der mittleren Signalstärke unterschätze die Fischlängen, verglichen mit den Fangdaten am stärksten.

Zusammenfassend lassen sich folgende Schlussfolgerungen ziehen. Die Ergebnisse der zwei Echolotsysteme (Simrad® Split - beam EK 60 und DIDSON® Multi - beam) korrelierten nicht direkt proportional miteinander, eine logarithmische Transformation der Werte zeigte eine hochsignifikanten linearen Zusammenhang der geschätzten Abundanzen beider Messsysteme. Die zu den unterschiedlichen Terminen aufgenommenen Abundanzen der zwei synchronisierten Echolotsysteme ergaben ähnliche Verteilungsmuster der saisonalen Fischdichten. Die Längenberechnung mittels DIDSON liegt näher an den Messungen von Fangdaten, als die aus den reflektierten Signalstärken berechneten Längen durch das EK 60 Echolot.

7. Abstract

The goal of our research was to compare fish abundances of two large pools in the free-flowing Danube by different sonar systems, a split beam (Simrad® EK 60; 120 kHz) and a multi beam (DIDSON®; 1.1- 1.8 MHz). The pools under investigation were distinctly different regarding their hydraulic properties. We were interested how far the different recording sensitivities of these two devices are reflected in the results of the abundance estimations at a lower flowing, less turbulent habitat and of a faster flowing, more turbulent habitat, respectively. Moreover we were interested in the size estimations from the two systems and how these results deviate from catch data from the Danube River. The recordings showed that the DIDSON detected more fish than the EK 60. The

comparison of the size distribution showed that the estimations of the DIDSON were generally higher than the estimations of the EK 60. In comparison with the fish total-length measurements of catch data the DIDSON estimation revealed larger sizes whereas the EK 60 estimations were distinctly lower. The reason for the observed differences of abundance and fish-size estimates may be that both, fish density and hydraulic conditions had an influence on the signal type and signal quality of different sonar. The size estimation from the EK 60 is strongly influenced by the tilt angle and the fish aspect; whereas the size estimation from DIDSON is influenced by overlapping signals due to low individual distances (fish shoal) or miss-tracking of signals due to turbidity leading to blurs at the signal starting and ending points.

8. Lebenslauf

Persönliche Daten

Vorname: Stefan

Nachname: Singer

Geboren an: 02.05.1983 in Baden bei Wien, Niederösterreich

Adresse: Josefstädterstraße 74/41 1080 Wien

Kontakt: e-mail: singer.stefan@gmx.at

Schulausbildung

1989 - 1993 Volksschule Pfeilgasse, 1080 Wien

1993 - 2002 BG/BRG Rahlgasse, 1060 Wien; Naturwissenschaftlicher Zweig

Studium

2002 - 2011 Diplomstudium Biologie, Stzw. Ökologie mit Schwerpunkt Limnologie an der Universität Wien

2010 - 2011 Diplomarbeit