MANAGEMENT BRIEF

Snorkeling-Based Fish Stock Assessment by Anglers—A Valuable Method for Managing Recreational Fisheries

Kurt Pinter,* Erwin Lautsch, and Günther Unfer

Institute of Hydrobiology and Aquatic Ecosystem Management, Department of Water, Atmosphere, and Environment, University of Natural Resources and Life Sciences, Vienna, Gregor-Mendel-Straße 33, 1180 Vienna, Austria

Daniel S. Hayes

Institute of Hydrobiology and Aquatic Ecosystem Management, Department of Water, Atmosphere, and Environment, University of Natural Resources and Life Sciences, Vienna, Gregor-Mendel-Straße 33, 1180 Vienna, Austria; and Forest Research Centre, Instituto Superior de Agronomia, University of Lisbon, Tapada da Ajuda, 1349-017, Lisboa, Portugal

Abstract

Periodic assessment of harvested fish populations is essential for their sustainable management. A potential alternative to costly and resource-intensive electrofishing estimates in clearwater streams is the noninvasive snorkeling method. To assess the utility of snorkeling for the angling community, we compared underwater fish counts carried out by novice snorkelers to state-of-the-art electrofishing depletion estimates. Over two consecutive years, we sampled subadult and adult Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* with both methods in a fourth-order mountain stream. In each year, a new team of novice snorkelers collected the data. In total, 12 riffle, pool, and run habitats were sampled, and the homogeneity of abundance and size-class distribution between the two methods was analyzed. Over both years, we could detect differences in 6 of 24 habitat × species configurations and in 10 of 72 habitat × species × size-class configurations. Species-specific behavioral traits and differences in the physical character of the habitats were responsible for a divergence in performance between the two methods. Overall, the observed effects were statistically interpreted as weak, as shown by local tests and the indicated low effect sizes. Snorkeling efficiency, however, remained affected by the effort and abilities of the team, as indicated by the year-by-year comparison. We conclude that in clearwater trout streams, snorkeling can be an appropriate substitute method for the widespread, autonomously organized angling community to gather data and build a sound foundation for fisheries-related decision making, if limitations are considered.

The growing threat to freshwater ecosystems (Vörösmarty et al. 2010) and the need to protect and restore them present a major challenge of the 21st century (Dudgeon et al. 2006). A multitude of impacts on freshwater biodiversity has been identified (Dudgeon et al. 2006), including recreational angling, which plays an influential (Cooke and Cowx 2004) and versatile role in the global fish crisis. Although anglers contribute to the conservation of freshwater fish and their habitats (Cooke et al. 2016), anglers' responsibility for biological impacts is increasingly recognized (Lewin et al. 2006). Both aspects frame anglers' area of influence and emphasize their obligation to actively participate in the application of ecosystem-based management practices (Arlinghaus et al. 2002; Pikitch et al. 2004; Hughes et al. 2005). In doing so, the study of quantitative data and life history parameters is crucial for the exploration, monitoring, assessment, and sustainable management of wildlife populations (Lebreton et al. 1992; Ludwig et al. 1993; Post et al. 2002). Especially in Europe, fishing

rights owners, recreational fishermen, fishing clubs, associations, or reach stewards are responsible for managing the fisheries resources themselves (Arlinghaus et al. 2002). Contrary to their responsibility and due to the elaborate acquisition of data with conventional methods, such as electrofishing (Reynolds 1996), representatives of the angling community often refrain from collecting data on managed (i.e., harvested) fish stocks.

Electrofishing has many advantages, such as the precise measurement of individuals and applicability under a broad spectrum of environmental conditions. However, electrofishing also includes associated disadvantages, such as size selectivity (Mullner et al. 1998; Reynolds and Kolz 2012), the potential for lethal or sublethal harm to the fish (Nielsen 1998; Schreer et al. 2004; Reynolds and Kolz 2012), high cost, and the need for specially trained personnel to achieve safe and effective application (Hankin and Reeves 1988). An alternative method is direct observation by snorkeling. The potential benefits of this survey method include cost and time reductions for acquiring and maintaining equipment (Hankin and Reeves 1988; Thurow et al. 2012), lowering physical disturbance to and impact on the observed populations (Thurow et al. 2012), simultaneous observations of associated microhabitat characteristics (Heggenes et al. 1991), and easier application in remote locations (Dolloff et al. 1996). Considering the lower costs and practicability, counting game fish populations by snorkeling may be a well-suited tool for the angling community to easily acquire data that are relevant for management actions. The knowledge of some stock parameters, such as stock density and population structure, can already be sufficient to provide decision-making aids necessary to implement and adapt fishing regulations, especially if these parameters are regularly monitored (Unfer and Pinter 2018).

In the present study, we compare abundance estimates and the size distribution of Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* sampled by electrofishing and snorkeling from three habitat types in a clearwater stream. It is often claimed that the efficiency of an assessment relies on the training and expertise of the snorkelers (Chamberland et al. 2014; Macnaughton et al. 2015). Our snorkeling counts were performed by surveyors with no previous snorkeling experience; this allowed us to test whether inexperienced individuals can generate good-quality data.

METHODS

Study area.— The study river is a fourth-order, prealpine trout stream (Ybbs River) draining off the Northern Limestone Alps in Austria. To determine representative sampling units, we assessed basic habitat characteristics according to Frissell et al. (1986) and Jowett (1993) in September during low-discharge conditions of 2.0 m³/s

between the town of Maierhoefen and the mouth of Seebach, a small tributary (Figure 1). The reach morphology corresponds to the pool–riffle river type described by Montgomery and Buffington (1997). The catchment size at the lower end of the pool–riffle section amounts to 117.9 km², with a mean annual discharge of about 4.5 m³/s. For the method comparison, we chose 12 habitat units (4 pools, 4 riffles, and 4 runs; Figure 1) located within the pool–riffle system; their elevation ranged from 641 to 624 m above sea level. The investigated habitat units had a total length of 1,051 m and were distributed over a range of 5.5 km (Figure 1). The lower six habitats are subject to long-term monitoring (20 years) in which the fish stock is sampled every year using electrofishing (Unfer et al. 2011). The water depth varied between a few centimeters in riffle habitats and up to 4 m in pools. The mean length ± SD of the 12 habitats was 93.1 ± 47.2 m for run units, 81.7 ± 61.4 m for riffles, and 53.1 ± 16.4 m for pools. The habitat widths ranged from 9 to 19 m (Table 1).

Complex cover (e.g., woody debris and root wads) is rare in the stream. The present fish species are the Brown Trout, European Bullhead *Cottus gobio*, European Grayling *Thymallus thymallus*, and nonnative Rainbow Trout. Although the entire fish community is of interest, Brown Trout and Rainbow Trout are of special relevance for recreational fishing.

Electrofishing.— In late September 2012 and 2013 at base flow conditions, we conducted multiple-pass depletion surveys in each of the 12 selected habitat units by following the national guidelines for fish sampling (Haunschmid et al. 2010). We installed a block net at the upper end of each habitat unit to prevent fish from escaping upstream before electrofishing was conducted. Beginning downstream of each habitat, three to four anode handlers waded upstream in a line, with a maximum distance of 4 m between two anodes, to cover the entire cross section. Pool habitats were sampled over the total length, whereas riffle and run habitats were sampled over a representative length (average sampled length of the total habitat lengths for both years was 78% for riffles and 58% for runs), but at least covering a minimum of 50 m, according to the requirements of the European Standard for the sampling of fish with electricity (CEN 2003). Gasoline-powered backpack electrofishing units were used with unpulsed DC (300–600 V; 1.5–2.5 kW). In pools, we additionally used a boat equipped with a 5-kW DC generator to sample deep areas. All units were equipped with a 30-cm hoop anode and a cable cathode. Fish captured from each pass were held separately in live wells at the stream margin. After the last pass of each habitat unit, we identified all fish to the species level and measured them to the nearest millimeter (TL) before returning them to the river. Population estimates were obtained using the maximum-likelihood solution for the two-run removal estimator (Seber and Le Cren 1967). In one
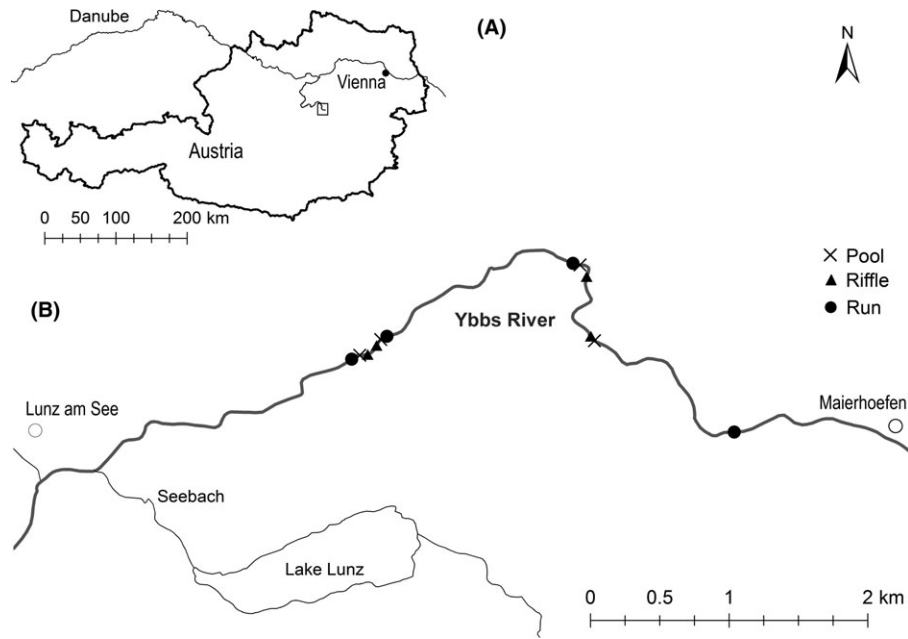
FIGURE 1. Location of **(A)** the Ybbs River in Austria and **(B)** the investigated habitats within the river.

TABLE 1. Habitat characteristics and dimensions of the 12 investigated habitats sampled through electrofishing and snorkeling in the Ybbs River, Austria.

Habitat	Habitat type	Total length (m)	Mean width (m)	Mean maximum depth (cm)	Maximum depth (cm)
1	Pool	51	14	121	>150
2	Pool	27	15	115	>150
3	Pool	56	14	130	>150
4	Pool	55	13	133	>150
5	Riffle	130	18	38	48
6	Riffle	61	19	41	57
7	Riffle	93	15	40	53
8	Riffle	77	16	41	49
9	Run	145	12	71	145
10	Run	94	9	73	91
11	Run	124	13	52	73
12	Run	138	13	55	75

habitat, the catch per pass declined by less than 50%, and a third pass was needed to estimate the population following DeLury (1947).

Snorkeling.— We based the snorkeling procedure, including lateral visibility measurements, on the methodological approach illustrated by Thurow (1994) and conducted the underwater fish counts on the days before the electrofishing surveys. Each year before data collection started, a new team of two novices to snorkeling was briefed on the methodology. During a short training session with an experienced snorkeler, they made themselves familiar with the upstream movement in the water, the identification of fish, and the length size estimation using a known distance (e.g., index finger to thumb; Thurow 1994) until they showed proficiency in these tasks. Their equipment consisted of a diving mask, a snorkel, a dry suit, and an underwater recording board. Block nets were not used. Snorkeling counts were carried out on dry days with good daylight conditions (1000–1600 hours). The underwater visibility allowed for spotting fish at all positions in the river

transects and to see the river banks from the position of the snorkelers. To identify fish outside of the range where exact species identification was possible, it was imperative to move toward the individuals and confirm the observation. We followed the protocol of Thurow (1994) to measure the average distance within which a fish could be clearly identified (mean = 3.8 m). Snorkelers carefully entered each sampling site at the lower end and then moved upstream in the middle of the stream, searching for Brown Trout and Rainbow Trout. Each snorkeler counted fish in separate halves of the river cross section. Snorkelers did not proceed shoulder to shoulder but left a gap in between themselves to cover the whole river width. Species and size-class were recorded when a fish passed the observer in the downstream direction. To avoid double counts of fish passing in between the snorkelers, hand signs were used to signal the recording. Due to high fish densities in the pools, the methodology had to be adapted in a way that each snorkeler counted the specimens of one species only. Pool units were counted twice to minimize error related to double-counting fish or missing fish that were present. Riffle and run habitats were snorkeled only once. Pools were snorkeled over the total length. In conformity with the electrofishing standards, a minimum length of 50 m in riffle and run habitat units was sampled in 2012 (average sampled length of the total habitat lengths was 80% for riffles and 64% for runs). In 2013, we sampled their total lengths.

Based on available length-frequency data (Unfer et al. 2011), we distinguished three size-classes: small (<200 mm), medium (200–320 mm), and large (>320 mm). Young of

the year were not recorded, as snorkeling had proven to be less effective in accurately counting this age-class (Heggenes et al. 1990; Thurow 1994). In some habitats (e.g., pools), high numbers of fish were present. In such cases, the total number of each species was counted first, and then the percentage distribution of size-classes was estimated and recorded for each species separately. To correctly assign size-classes, snorkelers had to consider an underwater magnification of 25% (Thurow et al. 2012). After a section was completed, data were transferred to a standard data sheet.

Data processing and analysis.— We standardized stock data for each habitat, method, species, and year to 100 m (Figure 2) and created a data set wherein all fish were itemized by habitat, sampling method, species, and assigned size-class and were differentiated by year, resulting in a table of 4,757 lines.

To test the homogeneity of abundance and size-class between the two sampling methods, we established two hypotheses (H_0 = total independence of all variables). Regarding both, it should be noted that the independent variables did not have the same status as the year, which was defined as a control variable (i.e., all tests were separately applied for 2012 and 2013).

The first hypothesis assumed that fish abundance did not differ between the sampling methods, whereby we considered the independent variables of fish species and habitat type. We used cross-table analyses through chi-square and residual tests. Cramér's V was used to indicate the effect size. The first dimension of the cross-table was the sampling method, and the second dimension was a
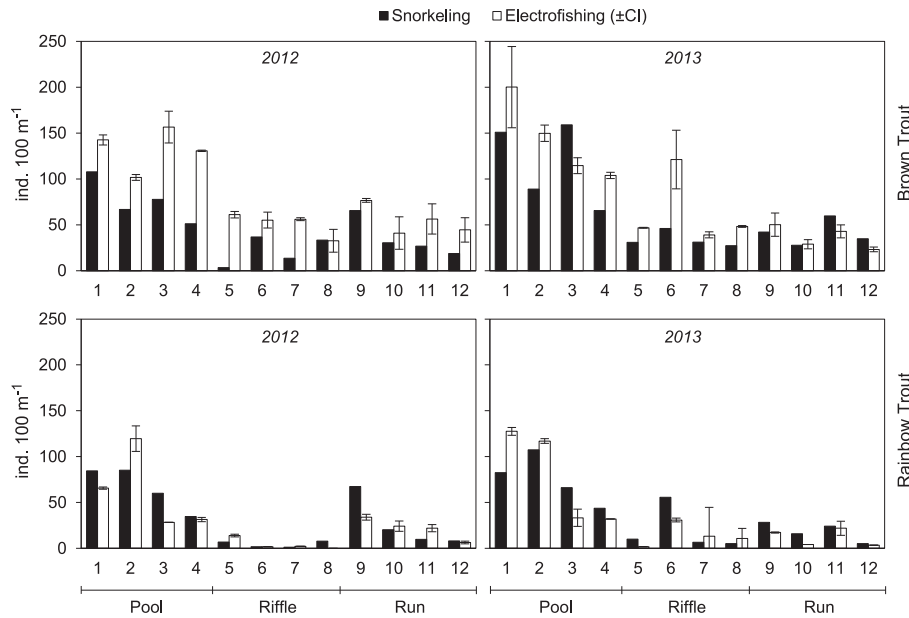

FIGURE 2. Comparison of fish abundance (individuals [ind.]/100 m) by gear type in the 12 investigated habitats separated by year (2012 and 2013) and fish species (Brown Trout and Rainbow Trout). Electrofishing estimates are presented with 95% confidence intervals (CIs). All fish data exclude young-of-the-year individuals.

TABLE 2. Cross-table results for tests of homogeneity of abundance in 2012. The species and habitat variables were grouped in a profile and tested versus the sampling method. Global chi-square test results (χ^2 = 67.88, df = 5, P = 0.000; Cramér's V = 0.137) and post hoc asymptotic binomial residual tests are shown (Obs. = observed cell counts; Exp. = expected cell counts; P' = alpha level for Holm's correction; T = typical/overfrequented; AT = atypical/underfrequented).

Species × habitat	Sampling method	Obs.	Exp.	Asymptotic binomial test	P	P'	T|AT[a]
Brown Trout × Pool	Snorkeling	304	342	−2.21	0.014	0.008	
Brown Trout × Pool	Electrofishing	533	495	1.91	0.028	0.010	
Brown Trout × Riffle	Snorkeling	87	126	−3.58	0.000	0.005	AT
Brown Trout × Riffle	Electrofishing	222	183	3.02	0.001	0.006	T
Brown Trout × Run	Snorkeling	143	150	−0.57	0.284	0.013	
Brown Trout × Run	Electrofishing	224	217	0.48	0.315	0.017	
Rainbow Trout × Pool	Snorkeling	264	206	4.23	0.000	0.004	T
Rainbow Trout × Pool	Electrofishing	241	299	−3.60	0.000	0.005	AT
Rainbow Trout × Riffle	Snorkeling	18	17	0.31	0.378	0.025	
Rainbow Trout × Riffle	Electrofishing	23	24	−0.26	0.398	0.050	
Rainbow Trout × Run	Snorkeling	105	81	2.74	0.003	0.006	T
Rainbow Trout × Run	Electrofishing	93	117	−2.30	0.011	0.007	

[a]Following Krauth (1993): result for the binomial test using Holm's correction (Von Eye et al. 2010).

combination of the following factors: fish species (1 = Brown Trout, 2 = Rainbow Trout) and habitat (1 = pool, 2 = riffle, 3 = run). We generated a two-digit profile variable (so-called "metavariable") from two solitary, single-digit variables. The first hypothesis was tested globally by chi-square tests. Locally, we examined which of the observed cell frequencies in the cross-table were compatible with the hypothesis of total independence. The local tests were post hoc tests and were described under the designation residual test or configuration frequency analysis (Von Eye et al. 2010; Stemmler 2014). We performed all analyses with the "cfa" package (Mair and Funke 2017). All tests were Holm corrected (α = 0.05).

The second hypothesis extended the first hypothesis by the size-class variable. The first dimension of the cross-table was the sampling method, and the second dimension was a combination of the three factors: species (1 = Brown Trout, 2 = Rainbow Trout), habitat (1 = pool, 2 = riffle, 3 = run), and size-class (1 = small, 2 = medium, 3 = large). We conducted global and local testing, as described above.

RESULTS

We recorded a total of 4,757 fish in both years: 2,134 were detected in the snorkeling surveys, and 2,623 were detected through electrofishing (Tables 2, 3). Both sampling methods indicated that Brown Trout were the dominant species in all habitat types. We documented the highest fish abundance for both species in pool habitats, typically followed by run and riffle habitats. The assessment of fish abundance with electrofishing data yielded higher Brown Trout numbers than the snorkeling method.

In contrast, snorkeling data yielded higher Rainbow Trout numbers than electrofishing, although on a lower level (Tables 2, 3).

Global tests of the sampling method and species × habitat combination showed a statistically significant influence for both years (2012: P = 0.000; 2013: P = 0.000; Tables 2, 3). The test results further indicated that the model could only explain the observed differences very weakly (2012: Cramér's V = 0.173; 2013: Cramér's V = 0.115). Extending the test procedure to the performance of local tests showed that in 2012, 7 of the 12 cells fulfilled the hypothesis of total homogeneity (Table 2). Deviations from the homogeneity hypothesis were found for Brown Trout in riffles, whereby snorkel counts underrepresented and electrofishing results overrepresented Brown Trout. The opposite deviation was found for Rainbow Trout in pools. Snorkeling overrepresented Rainbow Trout in runs. In 2013, we only observed local differences for the snorkeling method in riffles, with Rainbow Trout being overrepresented (Table 3), indicating that the two sampling methods should be regarded as equivalent in their performance.

Global tests of the sampling method and species × habitat × size-class combination showed a statistically significant influence for both years (2012: P = 0.000, Cramér's V = 0.294; 2013: P = 0.000, Cramér's V = 0.227; Table 4). Local tests highlighted the positioning of the differences; in 2012, 4 of 18 contrasts showed statistically relevant divergences: two contrasts referred to Brown Trout in pools, one referred to Brown Trout in riffles, and one referred to Rainbow Trout in pools. In 2013, one profile showed statistically significant differences regarding large Brown Trout in pool habitats. In total, the local tests from

TABLE 3. Cross-table results for tests of homogeneity of abundance in 2013. The species and habitat variables were grouped in a profile and tested versus the sampling method. Global chi-square test results ($\chi^2 = 32.86$, df = 5, $P = 0.000$; Cramér's $V = 0.115$) and post hoc asymptotic binomial residual tests are shown (Obs. = observed cell counts; Exp. = expected cell counts; P' = alpha level for Holm's correction; T = typical/overfrequented; AT = atypical/underfrequented).

Species × habitat	Sampling method	Obs.	Exp.	Asymptotic binomial test	P	P'	T|AT[a]
Brown Trout × Pool	Snorkeling	464	484	−1.02	0.153	0.013	
Brown Trout × Pool	Electrofishing	534	514	1.00	0.158	0.017	
Brown Trout × Riffle	Snorkeling	135	162	−2.20	0.014	0.005	
Brown Trout × Riffle	Electrofishing	199	172	2.14	0.016	0.006	
Brown Trout × Run	Snorkeling	165	150	1.27	0.102	0.008	
Brown Trout × Run	Electrofishing	144	159	−1.24	0.108	0.010	
Rainbow Trout × Pool	Snorkeling	299	300	−0.08	0.467	0.025	
Rainbow Trout × Pool	Electrofishing	320	319	0.08	0.468	0.050	
Rainbow Trout × Riffle	Snorkeling	77	57	2.64	0.004	0.004	T
Rainbow Trout × Riffle	Electrofishing	41	61	−2.56	0.005	0.005	
Rainbow Trout × Run	Snorkeling	73	59	1.82	0.035	0.006	
Rainbow Trout × Run	Electrofishing	49	63	−1.76	0.039	0.007	

[a]Following Krauth (1993): result for the binomial test using Holm's correction (Von Eye et al. 2010).

TABLE 4. Global chi-square tests and selected post hoc asymptotic binomial residual test results for tests of the homogeneity of size-class abundance in 2012 and 2013 (2012: $\chi^2 = 194.49$, df = 17, $P = 0.000$, Cramér's $V = 0.294$; 2013: $\chi^2 = 128.93$, df = 17, $P = 0.000$, Cramér's $V = 0.227$). Only statistically significant cells (10 of 72) are presented here. For 2013, only the post hoc test assignments are shown. The species, habitat, and size-class variables were grouped in a profile and tested versus the sampling method (Obs. = observed cell counts; Exp. = expected cell counts; P' = alpha level for Holm's correction; T = typical/overfrequented; AT = atypical/underfrequented).

Species × habitat × size-class	Sampling method	Obs.	Exp.	Asymptotic binomial test	P	P'	2012 T|AT[a]	2013 T|AT[a]
Brown Trout × Pool × Large	Snorkeling	42	45	−0.49	0.310	0.006		AT
Brown Trout × Pool × Large	Electrofishing	69	66	0.41	0.340	0.007		T
Brown Trout × Pool × Medium	Snorkeling	81	160	−6.48	0.000	0.001	AT	
Brown Trout × Pool × Medium	Electrofishing	311	232	5.47	0.000	0.001	T	
Brown Trout × Pool × Small	Snorkeling	181	136	3.95	0.000	0.001	T	
Brown Trout × Pool × Small	Electrofishing	153	198	−3.33	0.000	0.002	AT	
Brown Trout × Riffle × Small	Snorkeling	44	74	−3.57	0.000	0.002	AT	
Brown Trout × Riffle × Small	Electrofishing	138	108	2.99	0.001	0.002	T	
Rainbow Trout × Pool × Large	Snorkeling	80	54	3.60	0.000	0.002	T	
Rainbow Trout × Pool × Large	Electrofishing	52	78	−3.01	0.001	0.002	AT	

[a]Following Krauth (1993): result for the binomial test using Holm's correction (Von Eye et al. 2010).

both years ($n = 72$) showed that the homogeneous length-class assignments ($n = 62$) predominated, with a share of around 86% (78% in 2012; 94% in 2013).

DISCUSSION

The objective of the present study was to test whether inexperienced snorkelers were capable of gathering reliable data on fish abundance and the size-class distribution of trout populations in a clear, fourth-order stream in Austria by comparing snorkeling and electrofishing data. We conducted cross-table analysis comparing observed and expected frequencies to test for homogeneity. Considering both years, our results demonstrated that the hypothesis of equivalence between the two methods can be maintained since fish abundance proved to be independent of the sampling method in 18 of 24 configurations (Tables 2, 3). For the size-class distribution, the hypothesis of homogeneity could not be rejected in either year, which was also considered to be statistically supported (Table 4).

However, differences between the years can be seen, with 2013 showing higher consistency in results.

Our observations are broadly consistent with other studies that have assessed the suitability of the snorkeling method for depicting the densities or structure of salmonid populations. Mullner et al. (1998), for example, compared electrofishing and snorkeling by counting Brook Trout *Salvelinus fontinalis*, Rainbow Trout, and Cutthroat Trout *O. clarkii*, and they achieved high correlations ($R^2 \geq 0.90$) for the abundance estimates. Adjusting the frequencies in three length-classes, they also obtained similar results for the length-frequency comparisons (see also Wildman and Neumann 2003 for data on Brook Trout and Brown Trout). Studying Bull Trout *Salvelinus confluentus* stocks, Thurow and Schill (1996) found that size structure estimates were similar between the two methods and that daytime snorkeling produced abundance estimates equivalent to 75% of the electrofishing abundance estimates.

Strengths and weaknesses of the two investigated sampling methods were observed when detailed local tests were applied to identify single effect combinations (Tables 2–4). In our study, conspicuous differences emerged in the case of Brown Trout, whereby the snorkeling method often yielded lower observed frequencies than the electrofishing depletion estimates. This pattern was most evident for riffle habitats during 2012 (Table 2) but also for large- and medium-sized trout in pools. In this context, snorkelers reported a well-known difficulty in locating Brown Trout due to their cryptic coloration and hiding behavior (Pert et al. 1997; Joyce and Hubert 2003). Brown Trout often used interstitial spaces between boulders to hide, which caused sighting difficulties. Low snorkeling detection rates of small Brown Trout in riffles during 2012 may have been due to the difficulty in carefully searching a shallow area of high flow velocity and coarse substrates. Based on similar experiences, Heggenes et al. (1990) emphasized the advantages of the electrofishing method in such habitats. Species-specific behavior may further explain the higher performance of the snorkeling method for Rainbow Trout in pool and run habitats during 2012 and in riffle habitats during 2013. Several authors have reported that variation in observability due to interspecific differences is an essential factor in the success of sampling campaigns (Hankin and Reeves 1988; Pert et al. 1997; Chamberland et al. 2014). Pert et al. (1997) ascribed the higher success in counting Rainbow Trout than Brown Trout to the less-secretive nature of Rainbow Trout. From our observations, we can confirm that Rainbow Trout tended to occupy midwater positions and showed a higher level of activity than Brown Trout.

Aside from biological factors, such as species or fish size, there also exists a broad consensus that the reliability of a sampling method can depend on environmental factors, including water transparency, water conductivity, or habitat complexity (Heggenes et al. 1990; Reynolds 1996), which must be carefully considered when determining the sampling design (Macnaughton et al. 2015). With increasing complexity of environmental parameters (e.g., high species diversity; nature of the physical habitat), reliable data collection becomes more complicated (Orell et al. 2011) and demands the use of more experienced snorkelers.

However, the employment of novice snorkeling crews showed that in the Ybbs River, inexperienced snorkelers were capable of gathering reliable data on trout abundance and size-class distribution, even under conditions of high fish abundance. Our results, therefore, do not concur with those of other authors, who have claimed that the efficiency of snorkeling counts relies heavily on sampling expertise (Chamberland et al. 2014; Macnaughton et al. 2015). The combination of few biotic instream structures (e.g., woody debris, macrophytes, and emergent plants) and high underwater visibility seemed to provide favorable conditions for snorkelers in the Ybbs River.

Ultimately, snorkeling efficiency remains affected by the effort and abilities of the team. The higher accordance of the sampling results in 2013 suggests that working as enthusiastically and carefully as possible is a necessity for high-quality data. We therefore recommend that researchers initially verify the accuracy of snorkel counts with other methods—for example, through electrofishing, repeated counts, or tagging (Orell et al. 2011). To maximize the comparability of data in early and late study years, we further recommend testing snorkeler experience levels to determine the most competent and accurate working team. Yearly repeated snorkel counts can increase experience and thus improve detection rates and enhance sampling efficiency (Orell et al. 2011). Therefore, it is desired to start perennial assessments with the most qualified team but also to conduct periodic validation to estimate reliability.

We conclude that snorkeling has the potential to provide an appropriate method for quantifying trout populations in clearwater streams, such as the Ybbs River, even if the surveyors have no previous snorkeling experience. For fisheries managers, the facilitated access to data acquisition allows for changing harvest regulations based on current production and is thus a promising tool for autonomous inland trout fisheries. Beyond that, snorkeling offers additional advantages over other sampling methods. For example, it provides the possibility to sample large or remote areas, allowing the development of a more holistic picture of underwater habitats. Finally, the direct observation of fish in their natural environment contributes to a better understanding of processes and life underwater, constituting a beneficial insight for conservation-based management of wild fish stocks.

REFERENCES

Arlinghaus, R., T. Mehner, and I. G. Cowx. 2002. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. Fish and Fisheries 3:261–316.

CEN (European Committee for Standardization). 2003. Water quality—sampling of fish with electricity (European Standard EN 14011:2003). CEN, Brussels, Belgium.

Chamberland, J. M., G. Lanthier, and D. Boisclair. 2014. Comparison between electrofishing and snorkeling surveys to describe fish assemblages in Laurentian streams. Environmental Monitoring and Assessment 186:1837–1846.

Cooke, S. J., and I. G. Cowx. 2004. The role of recreational fishing in global fish crises. BioScience 54:857–859.

Cooke, S. J., Z. S. Hogan, P. A. Butcher, M. J. Stokesbury, R. Raghavan, A. J. Gallagher, N. Hammerschlag, and A. J. Danylchuk. 2016. Angling for endangered fish: conservation problem or conservation action? Fish and Fisheries 17:249–265.

DeLury, D. B. 1947. On the estimation of biological populations. Biometrics 3:145–167.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observation. Pages 533–554 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Léveque, R. J. Naiman, A. H. Prieur-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163–182.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199–214.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Haunschmid, R., N. Schotzko, R. Petz-Glechner, W. Honsig-Erlenburg, S. Schmutz, T. Spindler, G. Unfer, G. Wolfram, V. Bammer, L. Hundritsch, H. Prinz, and B. Sasano. 2010. Leitfaden zur Erhebung der biologischen Qualitätselemente Teil A1—Fische. Bundesministerium für Land-und Forstwirtschaft, Umwelt und Wasserwirtschaft, Sektion VII, Vienna.

Heggenes, J., Å. Brabrand, and S. J. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young Brown Trout and Atlantic Salmon. Transactions of the American Fisheries Society 119:101–111.

Heggenes, J., Å. Brabrand, and S. J. Saltveit. 1991. Microhabitat use by Brown Trout, Salmo trutta L. and Atlantic Salmon, S. salar L., in a stream: a comparative study of underwater and river bank observations. Journal of Fish Biology 38:259–266.

Hughes, T. P., D. R. Bellwood, C. Folke, R. S. Steneck, and J. Wilson. 2005. New paradigms for supporting the resilience of marine ecosystems. Trends in Ecology and Evolution 20:380–386.

Jowett, I. G. 1993. A method for objectively identifying pool, run, and riffle habitats from physical measurements. New Zealand Journal of Marine and Freshwater Research 27:241–248.

Joyce, M. P., and W. A. Hubert. 2003. Snorkeling as an alternative to depletion electrofishing for assessing Cutthroat Trout and Brown Trout in stream pools. Journal of Freshwater Ecology 18:215–222.

Krauth, J. 1993. Einführung in die Konfigurationsfrequenzanalyse (KFA). [Introduction to configural frequency analysis (CFA)]. Beltz, Psychologie Verlags Union, Weinheim, Germany.

Lebreton, J. D., K. P. Burnham, J. Clobert, and D. R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67–118.

Lewin, W. C., R. Arlinghaus, and T. Mehner. 2006. Documented and potential biological impacts of recreational fishing: insights for management and conservation. Reviews in Fisheries Science 14:305–367.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Ecological Applications 3:547–549.

Macnaughton, C. J., S. Harvey-Lavoie, C. Senay, G. Lanthier, G. Bourque, P. Legendre, and D. Boisclair. 2015. A comparison of electrofishing and visual surveying methods for estimating fish community structure in temperate rivers. River Research and Applications 31:1040–1051.

Mair, R., and S. Funke. 2017. cfa: configural frequency analysis (CFA). R package version 0.10-0. Available: https://CRAN.R-project.org/package=cfa. (November 2018).

Montgomery, D. R., and J. M. Buffington. 1997. Channel reach morphology in mountain drainage basins. Geological Society of American Bulletin 109:596–611.

Mullner, S. A., W. A. Hubert, and T. A. Wesche. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18:947–953.

Nielsen, J. L. 1998. Scientific sampling effects: electrofishing California's endangered fish populations. Fisheries 23(12):7–12.

Orell, P., J. Erkinaro, and P. Karppinen. 2011. Accuracy of snorkelling counts in assessing spawning stock of Atlantic Salmon, Salmo salar, verified by radio-tagging and underwater video monitoring. Fisheries Management and Ecology 18:392–399.

Pert, E. J., J. M. Deinstadt, and D. C. Erman. 1997. Evidence of differential detectability of lotic adult Rainbow and Brown Trout: implications for habitat use inference from direct-underwater observation. Journal of Freshwater Ecology 12:359–365.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, and K. J. Sainsbury. 2004. Ecosystem-based fishery management. Science 305:346–347.

Post, J. R., M. Sullivan, S. Cox, N. P. Lester, C. J. Walters, E. A. Parkinson, A. J. Paul, L. Jackson, and B. J. Shuter. 2002. Canada's recreational fisheries: the invisible collapse? Fisheries 27(1):6–17.

Reynolds, J. B. 1996. Electrofishing. Pages 221–254 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Reynolds, J. B., and A. L. Kolz. 2012. Electrofishing. Pages 267–304 in A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Schreer, J. F., S. J. Cooke, and K. B. Connors. 2004. Electrofishing-induced cardiac disturbance and injury in Rainbow Trout. Journal of Fish Biology 64:996–1014.

Seber, G. A. F., and E. D. Le Cren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36:631–643.

Stemmler, M. 2014. Person-centered methods: configural frequency analysis (CFA) and other methods for the analysis of contingency tables. Springer, New York.

Thurow, R. E., and D. J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate Bull Trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16:314–323.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. U.S. Forest Service General Technical Report INT-GTR-307.

Thurow, R. F., C. A. Dolloff, and J. E. Marsden. 2012. Visual observation of fishes and aquatic habitat. Pages 781–817 in A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Unfer, G., C. Hauer, and E. Lautsch. 2011. The influence of hydrology on the recruitment of Brown Trout in an Alpine river, the Ybbs River, Austria. Ecology of Freshwater Fish 20:438–448.

Unfer, G., and K. Pinter. 2018. Fisheries management of stream-resident Brown Trout populations—possibilities and restrictions. Pages 649–665 in J. Lobón-Cerviá and N. Sanz, editors. Brown Trout: biology, ecology and management. Wiley, Hoboken, New Jersey.

Von Eye, A., P. Mair, and E. Y. Mun. 2010. Advances in configural frequency analysis. Guilford Press, New York.

Vörösmarty, C. J., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R. Liermann, and P. M. Davies. 2010. Global threats to human water security and river biodiversity. Nature 467:555–561.

Wildman, T. L., and R. M. Neumann. 2003. Comparison of snorkeling and electrofishing for estimating abundance and size structure of Brook Trout and Brown Trout in two southern New England streams. Fisheries Research 60:131–139.