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The effects of an underwater fish observation technique on stream macroinvertebrates at two spatial scales

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Abstract – We examined the effects of snorkeling, a commonly used fish observation technique, on the distribution and abundance of benthic macroinvertebrates at both the reach (i.e., 10 m) and patch scale (i.e.,< 1 m) within a southern Appalachian stream (North Carolina, USA). At the reach scale, we quantified increases in macroinvertebrate drift rates associated with snorkeling and used these values to calculate the percentage of the macrobenthos that drifted out of snorkeled reaches. We also used a simple decay model of macroinvertebrate drift to quantify patch scale effects of snorkeling. The model incorporated size specific macroinvertebrate settling rates to estimate the total number of benthic macroinvertebrates that entered the drift in response to snorkeling disturbance. We found that snorkeling consistently produced significant increases in the number of drifting macroinvertebrates. Nevertheless, these increases comprised a very small percentage (<1%) of the total number of organisms in the benthos, suggesting that snorkeling probably did not strongly affect macroinvertebrate assemblages at either the reach or patch scale. However, our analyses also indicated that snorkeling had a disproportionate effect on the drift of small ephemeropterans (4–5% entered the drift in response to snorkeling) relative to other macroinvertebrate taxa. Consequently, the microdistribution of early instar mayflies may have been altered within snorkeled reaches. We conclude that snorkeling related disturbance to the benthos should have a minimal effect on the behavior and distribution of most stream fishes at either the reach or patch scale. However, because snorkeling had a substantial effect on the drift of small mayflies, snorkeling may influence the behavior of fishes that depend on early instar mayflies as a primary food resource.

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Key words: observation technique; macroinvertebrate; stream

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Un resumen en español se incluye detrás del texto principal de este artículo.

Stream ecologists use a variety of techniques to sample fishes, including seining, electrofishing and traps (Murphy & Willis 1996). Increasingly, however, researchers are using direct observational techniques (i.e., snorkeling and SCUBA) to quantify a variety of biological characteristics of stream fishes (Dolloff et al. 1996). For example, underwater observations have been used to estimate fish abundance (Hankin & Reeves 1988) and to characterize microhabitat use and foraging behavior of stream fishes (Moyle & Baltz 1985; Rincón & Lobón-Cerviá 1993; Petty & Grossman 1996). The primary advantage of snorkeling is that it enables the observer to identify the exact locations of individual fishes within the stream with little apparent effect on their behavior (Heggenes et al. 1990).

Although underwater observational techniques such as snorkeling may not directly affect fish behavior, snorkeling may have an indirect effect by altering the distribution and abundance of fishes' benthic macroinvertebrate prey. The potential effect of snorkeling on macroinvertebrates in small, shallow streams is particularly high. In these habitats, a snorkeler may physically disturb the stream benthos by coming into direct contact with the substratum or by altering stream flow. Because benthic macroinvertebrates often respond to physical disturbance by entering the drift (Poff et al. 1991), snorkeling may indirectly affect stream fishes in two ways. First, at the reach scale (i.e., stream segments typically >10 m in length), if a large number of macroinvertebrates enter the drift and ultimately drift out of a stream reach, then snorkeling may lead to a significant reduction in the density of benthic macroinvertebrate prey within the snorkeled area. Furthermore, because certain species and size classes are more prone to drift (Waters 1962; Allan 1978), disturbance to the benthos may alter the size and taxonomic composition of macroinvertebrate assemblages within snorkeled reaches. The second manner in which snorkeling may affect the behavior of stream fishes occurs at the microhabitat or patch scale (i.e., areas <1 m^2 used by an individual). Our studies of patch selection by mottled sculpin, a predatory benthic stream fish, indicate that sculpin foraging behavior is strongly affected by the microdistribution (i.e., within reach distribution) of their invertebrate prey (Petty & Grossman 1996; Petty 1998). Consequently, patch use by this species, and other benthic fishes, may be affected if snorkeling activities alter the microdistribution of benthic macroinvertebrates.

Although snorkeling could conceivably produce changes in the distribution and abundance of stream fishes via an effect on the benthos, to our knowledge there are no studies that have attempted to quantify the impact of snorkeling on benthic stream macroinvertebrates. Given the increasing importance of direct observational techniques in stream fish ecology, we decided to conduct a short-term experiment to evaluate the effects of snorkeling on benthic macroinvertebrates at both the reach and patch scales. Specifically, our study addressed three questions: 1) Does snorkeling affect the number and composition (size and taxonomic) of macroinvertebrates drifting out of sampled reaches? 2) Does snorkeling affect the density and composition (size and taxonomic) of benthic macroinvertebrates within sampled reaches? and 3) Does snorkeling affect the microdistribution of benthic macroinvertebrates within sampled reaches? We then used answers to these questions to assess the likelihood that snorkeling would produce behavioral changes in fishes via its effects on macroinvertebrate drift.

Methods

Study site and sampling regime

We examined the effects of snorkeling on macroinvertebrate drift in Shope Fork, a fourth-order stream located on the USDA Forest Service Coweeta Hydrologic Laboratory. The laboratory is situated in the Blue Ridge Province of the southern Appalachian Mountains in western North Carolina. Our study was conducted in September 1994 during a period of normal, late summer baseflow (i.e., 0.23 m^3/s). During summer months, benthic invertebrate densities and invertebrate drift rates are significantly lower than during other seasons (e.g., Ealy Spring) (Stouder 1990). However, macroinvertebrate assemblages in September are representative of assemblages present in this system throughout much of the growing season (i.e., June–October) (Petty & Grossman 1996). We conducted our study in late summer because we felt that snorkeling effects on the benthos would be most likely during low-water periods. We snorkeled and collected drift and benthic samples during daylight hours (11:00 am–4:00 pm). This sampling regime was chosen because it is typical of the observation schedules used in most studies of fish microhabitat use (Paine et al. 1982; Moyle & Baltz 1985; Grossman et al. 1998). This seemed reasonable given that our objective was to evaluate the potential indirect effects of snorkeling on fish behavior in streams. Nevertheless, because macroinvertebrate drift rates often follow a distinct diel periodicity (i.e., drift rates are generally low during the day and peak at dusk; Waters 1962), we recognize that our results are most applicable to snorkeling studies conducted during daylight hours only.

The study site consisted of three 10-m reaches located just downstream of a gaging weir at ≈700 m elevation. At this elevation, Shope Fork has an average width of 5.2 m (range=3.9–6.0 m) and the substratum is dominated by cobble and gravel. The three 10 m reaches that we selected were physically similar, each consisting of a single, continuous riffle. We selected reaches of this length, because 10 m is the approximate average length of riffles within Shope Fork at this elevation (Petty 1998). Furthermore, we selected reaches that contained only riffles, because the potential effects of snorkeling probably are greater in these habitats than in deeper pools and runs. Hence, our estimates of snorkel effects on the benthos probably are higher than they would be if we had included a variety of habitat types.

Reach-scale effects of snorkeling

Our first objective was to determine whether snorkeling had a significant effect on the number and composition (size and taxonomic) of macroinvertebrates drifting out of sampled reaches. We began by making control observations, which consisted of three 15-minute-long drift samples collected during a time in which no snorkeling activities were conducted. At the downstream end of each riffle, we placed three drift nets (30×30 cm frames fitted with 250-μm mesh) at equal distances across the width of the stream. The nets sampled the entire water column from substratum to surface. After 15 minutes elapsed, the contents of each net were emptied into separate bags and preserved with a 10% formalin solution for processing in the lab. Immediately following the control sets, the drift nets were reset in the same locations, and a snorkeler began searching for fishes in a 10-m section of stream directly upstream of the drift nets (see Grossman et al. (1998) for snorkeling methods). This process took between 12 and 15 minutes. When the snorkeler reached the upper boundary of the study reach, he carefully exited the stream and waited to remove the nets at the end of the 15-minute period. After collecting drift samples, we measured the depth and average current velocity (cm/s) at the location of each drift net. Depth was measured using a meter stick and current velocity was measured with a Marsh-McBirney Model 201 electronic flow meter. We then took identical measurements at 10 randomly selected locations within each reach. For comparative purposes, we collected five benthic samples taken from an adjacent segment of Shope Fork with a modified Hess sampler (0.1 m^2 opening, 250-μm mesh). Previous research has indicated that five samples are sufficient to describe benthic macroinvertebrate density and composition on a given date within this system (Stouder 1990).

In the laboratory we identified macroinvertebrates to family. We also classified individuals as being either small or large on the basis of head capsule size (HCSZ) (small: HCSZ <1.0 mm; large: HCSZ $\geqslant 1.0$ mm). Estimates of macroinvertebrate drift rates for both the control and snorkel treatments were defined as the total number of macroinvertebrates captured in drift nets per minute. Because we set the drift nets in the same positions for both the control and the snorkel treatments, we did not standardize drift rates on the basis of current velocity or depth. To determine the effects of snorkeling on the drift rates of macroinvertebrates in Shope Fork, we used paired *t*-tests to test the null hypothesis that macroinvertebrate drift rates did not differ significantly between control and snorkel treatments. We conducted separate analyses on large and small macroinvertebrates.

To assess the effects of snorkeling on the size and taxonomic composition of drift from disturbed reaches, we tested two separate null hypotheses. First, we tested the null hypothesis that the size and taxonomic composition of macroinvertebrate drift in the control samples was not significantly different from the composition of macroinvertebrates present in the benthos. Second, we tested the null hypothesis that the composition (size and taxonomic) of the drift from the snorkel samples did not differ significantly from that of the control. We compared the relative abundance of major macroinvertebrate taxa (i.e., macroinvertebrate orders) and size classes (i.e., small and large) in the different sampling categories (i.e., benthos, control drift, and snorkel drift) with partitioned chi-square goodness-of-fit tests.

The second objective of our reach scale analysis was to determine whether snorkeling had a significant effect on the density and composition of benthic macroinvertebrates within snorkeled reaches. We used benthic samples taken in adjacent reaches along with estimates of "snorkel effect" to estimate the proportion of benthic macroinvertebrates that drifted out of a reach as a result of snorkeling activities. We defined the snorkel effect as the total number of macroinvertebrates drifting out of a reach in response to snorkeling disturbance and calculated its magnitude by subtracting the number of drifting macroinvertebrates captured in control samples from the number captured in the snorkeling samples. Snorkel effect estimates were then standardized by the area sampled. We assumed that each drift net sampled from an area of 3 m^2, an area that corresponds to the width of a single net (0.3 m) multiplied by the total distance snorkeled (10 m). The proportion of the macrobenthos that drifts out of the study site due to snorkeling equals the area standardized snorkel effect divided by the density of macroinvertebrates in the benthos. We calculated this proportion separately for each taxon and size class. We also estimated the expected change in the composition of the benthos as a result of macroinvertebrates drifting out of a snorkeled reach. We used chi-square analysis to test the null hypothesis of no significant differences in the composition (size and taxonomic) of benthic macroinvertebrates in the control and snorkeled benthos.

Patch-scale effects of snorkeling

A potentially important effect of snorkeling on the stream benthos involves the redistribution of benthic macroinvertebrates within a reach as disturbed individuals enter the drift and resettle in other areas. Consequently, quantifying patch scale effects requires an estimate of the total number of individuals that enter the drift in response to snorkeling activities, an estimate that includes individuals that drift completely out of a reach as well as individuals that resettle before reaching the downstream border. We used a model originally developed by McLay (1970) to estimate the total number of macroinvertebrates entering the drift in response to snorkeling activities. Under this model, a pulse of organisms enters the drift after a disturbance and then subsequently returns to the substratum according to the simple negative exponential relationship:

$$N_x = N_0 e^{-RX} \qquad (1)$$

where: N_0 is the number of macroinvertebrates that initially enter the water column, N_x is the number of individuals remaining in the drift at distance X from the point of introduction, and R is a constant reflecting the rate of settling to the substratum by drifting macroinvertebrates.

Previous applications of this model either have sought to estimate the number of macroinvertebrates remaining in the drift (N_x) based on initial abundance (N_0) and drift distance (X), or they have used estimates of N_x and N_0 to estimate taxon-specific settling coefficients (R) (Elliott 1971; Allan & Feifarek 1989). In contrast, we used the model to estimate the initial number of macroinvertebrates entering the drift (N_0) on the basis of the number of macroinvertebrates remaining in the drift (N_x) and drift distance (X). To derive these estimates, we employed three simplifying assumptions. First, each sample reach was viewed as a series of 1-m-wide cross-sections, and all points within a given section were assumed to be the same distance from the drift nets downstream. For example, all locations within the 0- to 1-m cross-section were considered to be 1 m from the nets. Second, we assumed that the initial number of macroinvertebrates entering the drift from each cross-section was equal. (Note: failure to meet this assumption does not affect our estimates of N_0 as long as the true N_0 does not consistently increase or decrease with distance.) Third, we assumed that flows were constant across each of the 1-m cross-sections. Again, failure to meet this assumption should not affect our estimates as long as there was no consistent variation in flows as a function of distance from the drift nets. Given these assumptions, the number of insects that reach the downstream nets from cross-section X equals N_x from equation 2. Furthermore, the total number of insects that reach the downstream nets from all sections combined equals the sum of the N_x's across all sections. The general form of this relationship can be written as:

$$\sum_{x=1}^{n} N_x = \sum_{x=1}^{n} N_0^{(x)} e^{-Rx} \qquad (2)$$

where: n equals the number of cross-sections ($n=10$ in our study). Because we assumed that N_0 is constant across sections (i.e., $N_0^{(1)}=N_0^{(2)}=\ldots=N_0^{(n)}$), we could easily solve for N_0.

We used published relationships between settling rate and current velocity to estimate reach specific settling coefficients (i.e., R) for both small and large macroinvertebrates (Table 1). Because small ephemerellid and heptageniid mayflies dominated our drift samples, we used settling relationships for *Cinygmula* (see Allan & Feifarek 1989), a morphologically generalized heptageniid, to estimate settling coefficients for small and large macroinvertebrates in Shope Fork (small macroinvertebrates: $a=11.5$, $b=-1.09$; large macroinvertebrates: $a=45.68$, $b=-1.306$). Note that the rate at which drifting macroinvertebrates settle to the substratum increases with decreasing current velocity and increasing macroinvertebrate size (Table 1).

Estimates of N_x were based on estimates of the snorkel effect (see above) from each sample reach. This provided an estimate of the total number of macroinvertebrates remaining in the drift that initially entered the drift in response to snorkeling disturbance. We then used reach specific estimates of N_x and R to calculate the total number of individuals from each taxon and size class that enter the drift in response to snorkeling activities (i.e., size- and taxon-specific N_0). Finally, we used area standardized estimates of N_0 and estimates of benthic macroinvertebrate densities to quantify the proportion of macroinvertebrates within the benthos that enter the drift as a result of snorkeling activities. These estimates were made for each taxon and size class separately. If snorkeling has a significant effect on the microdistribution of macroinvertebrates within disturbed reaches, then a relatively large percentage of the macrobenthos should enter the drift in response to snorkeling activities. Alternatively, if snorkeling effects at the microhabitat scale are insignificant, then a relatively small percentage of the macrobenthos is expected to enter the drift.

Table 1. Reach- and size-specific settling coefficients (R) used in calculating N_0 (i.e., the patch scale effect of snorkeling). Settling coefficients were determined on the basis of mean average current velocity (cm/s) in each reach and relationships between settling rate and current velocity developed by Allan & Feifarek (1989) for *Cinygmula* of the form $R=aV^{-b}$.

		Settling coefficient	
Reach	Average current velocity	Small macroinvertebrates	Large macroinvertebrates
1	28.6	0.297	0.572
2	22.3	0.390	0.792
3	23.5	0.368	0.740

Results

Reach-scale effects of snorkeling

Snorkeling within Shope Fork had a significant effect on the drift rates of both large and small macroinvertebrates. The drift of small macroinvertebrates increased significantly ($t=-5.63$; d.f.=8; $P<0.001$) from an average baseline rate of 5.5±1.4 individuals/min to a rate of 57.8±11.1 individuals/min during snorkeling activities. Similarly, snorkeling within the study site caused a significant ($t=-3.0$; d.f.=8; $P=0.02$) increase in the drift rate of large macroinvertebrates (control drift=0.10±0.02 individuals/min; snorkel drift=0.32±0.14 individuals/min).

Snorkeling also had a significant effect on the size and taxonomic composition of the macroinvertebrate drift. The relative abundance of small macroinvertebrates in the drift increased significantly ($\chi^2=22.9$; d.f.=1; $P<0.01$) from 98.2% in the control samples to 99.5% in the snorkel samples. In addition, there was a shift in the taxonomic composition of the drift as a result of snorkeling disturbance (Fig. 1). Specifically, the relative abundance of ephemeropterans within the drift increased significantly during snorkeling activities (Fig. 1).

Comparison of drift samples with benthic samples taken in Shope Fork indicated that the most important effect of snorkeling was to increase the drift of macroinvertebrates with a naturally high propensity to drift. For example, the relative abundance of small macroinvertebrates within control drift samples (97.8%) was significantly higher than expected based on the composition of the benthos (96.2%) ($\chi^2= 7.81$; d.f.=1; $P<0.05$), suggesting a naturally high propensity to enter the drift for these macroinvertebrates. Previous analyses indicated that the primary effect of snorkeling was to intensify the drift rates of small macroinvertebrates. Differences in the taxonomic composition of drift samples and the undisturbed benthos demonstrated a similar pattern (Fig. 1). Under natural conditions, ephemeropterans exhibited an extremely high propensity to drift relative to other taxa (Fig. 1). Differences between snorkel and control drift samples further demonstrated that the high propensity of small mayflies to drift under normal conditions was intensified by snorkeling activities (Fig. 1).

Although snorkeling increased macroinvertebrate drift rates and altered the size and taxonomic composition of the drift, our analyses indicated that snorkeling did not have a significant effect on either the density or composition of the macrobenthos at the reach scale (Table 2). The percentage of the total macrobenthos that drifted out of

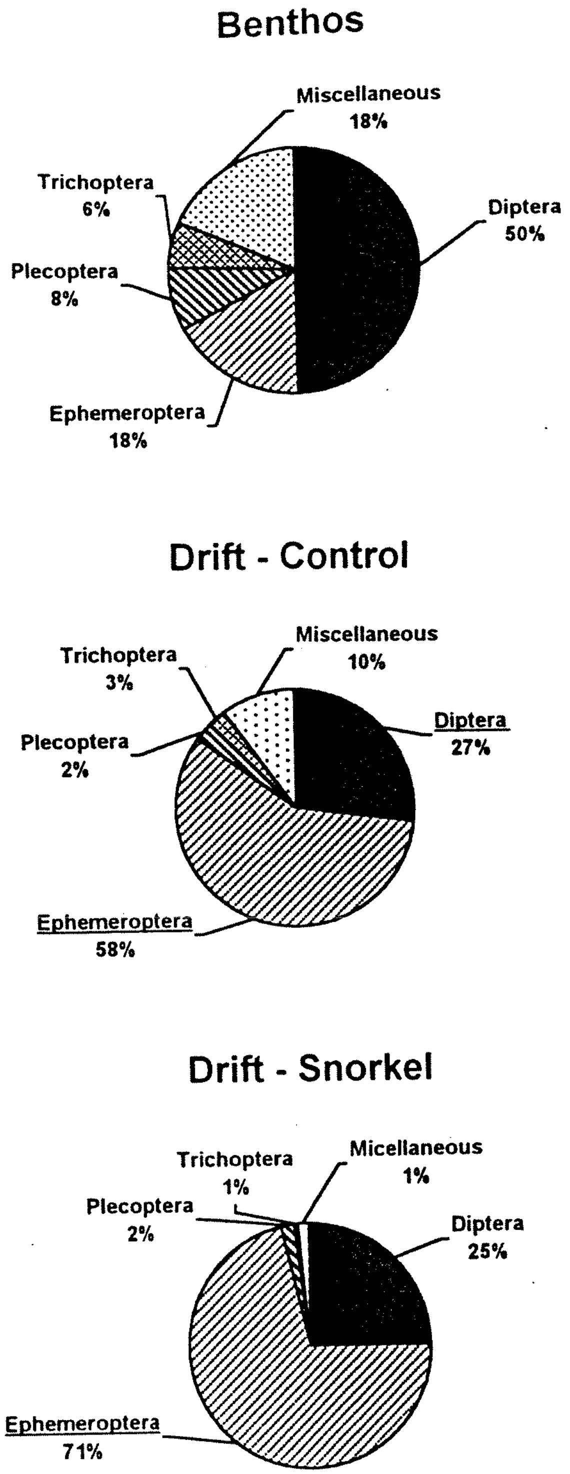

Fig. 1. Percentage composition of major macroinvertebrate taxa in benthic and drift samples. We made statistical comparisons between the benthos and control drift samples and between the control drift and snorkel drift samples. Partitioned χ^2 analyses indicated significant differences ($P<0.05$) in the percentage contribution of the underlined taxa (benthos *vs* control drift: $\chi^2=193$, d.f.=4, $P<0.01$; control drift *vs* snorkel drift: $\chi^2=217$, d.f.=4, $P<0.01$).

Table 2. Effect of snorkeling disturbance on benthic macroinvertebrates at the reach scale. The snorkel effect (mean±SE) is the total number of macroinvertebrates drifting out of a reach in response to snorkeling, standardized by the area sampled. Also presented is the percentage of each taxon and size class that drifted out of reaches in Shope Fork in response to snorkeling.

Taxon/size class	Snorkel effect (number per m^2)	% benthos leaving reaches
Diptera	43 (9)	0.13
Ephemeroptera	127 (56)	1.10
Plecoptera	3 (1)	0.06
Trichoptera	2 (1)	0.05
Miscellaneous	1 (1)	0.01
Small macroinvertebrates	175 (64)	0.27
Large macroinvertebrates	1 (1)	0.09
All macroinvertebrates	176 (65)	0.27

Table 3. Effect of snorkeling disturbance on benthic macroinvertebrates at the patch scale. We have presented the mean (±SE) number of macroinvertebrates per m^2 that entered the drift in response to snorkeling activities. Also presented is the percentage of the macrobenthos entering the drift for each taxon and size class.

Taxon/size class	Number per m^2 entering drift	% benthos entering drift
Diptera	188 (65)	0.57
Ephemeroptera	522 (217)	4.50
Plecoptera	11 (4)	0.20
Trichoptera	4 (3)	0.10
Miscellaneous	2 (4)	0.02
Small macroinvertebrates	722 (272)	1.13
Large macroinvertebrates	6 (4)	0.54
All macroinvertebrates	727 (275)	1.12

a reach as a result of snorkeling disturbance was much less than 1% (Table 2). In fact, with the exception of Ephemeroptera, the percentage of the benthos that left a reach due to snorkeling activities generally was less than 0.5% (Table 2). Given these findings, it is not surprising that we failed to detect significant differences in either the size or taxonomic composition of the macrobenthos of control or snorkeled samples (size: $\chi^2=0.02$, d.f.= 1, $P>0.5$; taxon: $\chi^2=0.1$; d.f.=4; $P>0.5$).

Patch-scale effects of snorkeling

Because most drifting macroinvertebrates resettled into the benthos before reaching the downstream border of snorkeled reaches, our patch-scale estimates of snorkeling disturbance were considerably higher than our reach-scale estimates. Application of McLay's (1970) model of invertebrate drift to our data indicated that the number of individuals entering the drift in response to snorkeling was approximately four times greater than our estimates of snorkel effect at the reach scale (Table 3). Nevertheless, the overall effect of snorkeling on macroinvertebrate distributions at the patch scale remained very small. Similar to our findings at the reach scale, the total number of macroinvertebrates entering the drift in response to snorkeling activities represented a very small percentage (approximately 1%) of the total macrobenthos (Table 3).

Although our results demonstrate that the effects of snorkeling on the distribution and abundance of macroinvertebrates in Shope Fork were minimal, they also suggest that this technique may have significantly affected the distribution of small ephemeropterans within reaches. The number of early instar mayflies that entered the drift in response to snorkeling was considerably higher than it was for other taxa and represented nearly 5% of mayflies present in the benthos (Table 3). Consequently, snorkeling may have altered the distribution of this taxon within snorkeled reaches, even though it is unlikely that snorkeling affected the microdistribution of the overall macrobenthic assemblage.

Discussion

Snorkeling consistently produced increases in the overall number of macroinvertebrates entering the drift (i.e., microhabitat-scale effects) and leaving the site (i.e., reach-scale effects). Nevertheless, the observed increases in the number of drifting macroinvertebrates represented a very low percentage of the macroinvertebrates found in the benthos. In fact, we found that only about 1% of all benthic macroinvertebrates entered the drift in response to snorkeling, and most of these organisms settled back into the substratum before drifting out of the affected reaches. Consequently, our data indicate that snorkeling did not significantly affect the density, composition, or size structure of the benthic macroinvertebrate assemblage present within sampled reaches. Furthermore, given the small percentage of macrobenthos entering the drift, it is unlikely that snorkeling affected overall benthic macroinvertebrate distributions at the patch scale.

Our results are very similar to those of other investigators who examined the effects of fish sampling procedures on macroinvertebrate drift rates in streams. Researchers have shown that, although a given fish sampling procedure may induce significant increases in macroinvertebrate drift rates, sampling activities generally have little effect on overall benthic macroinvertebrate densities or taxonomic composition (electrofishing: Elliott & Bagenal 1972; Bisson 1976; rotenone: Dudgeon &

Kong 1990). For example, Dudgeon & Kong (1990) reported that rotenone, a commonly used piscicide, induced an "immediate catastrophic" increase in total macroinvertebrate drift densities in two New Guinean streams. However, Dudgeon & Kong (1990) also found that rotenone applications failed to produce significant declines in benthic macroinvertebrate density despite increased drift rates (Dudgeon & Kong 1990). Similarly, investigators have reported that increased drift rates associated with electrofishing activities represent an extremely low percentage of the macroinvertebrates comprising the benthos (Elliott & Bagenal 1972).

Although snorkeling did not appear to affect the distribution of the total benthic community, snorkeling may have had a significant effect on the distribution of early instar mayflies, especially at the patch scale. Despite a generally weak response of most macroinvertebrate taxa to snorkeling, we estimated that nearly 5% of ephemeropterans in the benthos entered the drift in response to snorkeling activities. This is a particularly interesting result given that small mayflies had a high propensity to drift even under undisturbed conditions. It is likely that mayflies, which are strong swimmers (Kohler 1985), respond to local perturbations by actively entering the drift in an effort to disperse from the disturbed area (Poff et al. 1991). In contrast, taxa that are less effective swimmers (e.g., Coleoptera and Trichoptera) may respond to disturbance by burrowing deeper into the substratum. Consequently, snorkeling may have produced significant changes in the patch-specific distributions of small mayflies within a reach, given that a relatively large number of individuals entered the drift and then resettled into other areas of the disturbed reach.

Direct underwater observation has been considered a versatile and relatively unbiased method for quantifying a variety of biological characteristics of stream fishes (Dolloff et al. 1996). Snorkeling techniques have been used successfully in studies ranging from large scale population and community surveys (Hankin & Reeves 1988; Ensign et al. 1995) to specialized observations of habitat use and foraging behavior (Petty & Grossman 1996; Grossman et al. 1998). To our knowledge, however, there are no published studies that have examined the potential indirect effects of snorkeling on the foraging behaviors of stream fishes.

Our results allow us to draw at least two conclusions regarding the potential impacts of snorkeling on fishes in Shope Fork. First, because such a small percentage of benthic macroinvertebrates drift completely out of snorkeled reaches, snorkeling should have a minimal impact on the behavior and distribution of stream fishes at the reach scale. Second, the effects of snorkeling on fish behavior at the patch scale probably will depend on the degree to which a particular species depends on small mayflies as a food resource. Because a relatively large number of small mayflies enter the drift, repeated snorkeling over a short time span might affect the short-term distribution of this taxon within a reach. Fishes that are generalist feeders such as mottled sculpin and other benthic fishes, however, may not be affected by changes in the distribution of any one particular prey taxon. In contrast, fishes that specialize on certain taxa or size classes may be indirectly affected by snorkeling if disturbance alters the distribution of their preferred prey.

Our study suggests that snorkeling during daylight hours in Shope Fork does not have a significant effect on the distribution of benthic macroinvertebrates at either the reach or the patch scale. We conducted this study during the day to coincide with the observation schedules used by many investigators who study fishes in streams (Paine et al.1982; Petty & Grossman 1996; Grossman et al. 1998). Because macroinvertebrate drift rates follow a diel periodicity (Waters 1962; Allan 1978), however, our results are applicable to daylight hours only. It is possible that snorkeling has a much greater effect on the benthos at night. Previous studies have shown that many macroinvertebrates drift further at night than during the day (Elliott 1971; Malmqvist & Sjöström 1987). Therefore, even if the same number of macroinvertebrates enter the drift at night, more will ultimately drift out of disturbed reaches leading to a greater effect of snorkeling at the reach scale. Furthermore, many macroinvertebrates have an increased tendency to drift at night. This is especially true for larger organisms that do not drift during the day to avoid predation by drift feeding fishes (Allan 1978). Consequently, because snorkeling increases the drift rates of taxa and size classes with a high propensity to drift, snorkeling effects may be intensified at night possibly leading to a greater effect at both the reach and the patch scales.

Resumen

1. En un río de los Apalaches (Carolina del Norte, USA) hemos estudiado el efecto del buceo, técnica de observación de peces usada de forma habitual, sobre la distribución y abundancia de los macroinvertebrados bentónicos, a dos escalas distintas: mesohábitat (tramos de río de 10 m) y microhábitat (áreas <1 m usadas por un individuo). En el mesohábitat cuantificamos el aumento en las tasas de macroinvertebrados que derivan asociado al buceo y utilizamos estos valores para calcular el porcentaje de macrobentos que derivó fuera de las localidades de buceo.

2. Para comprobar los efectos del buceo en el uso del microhábitat, utilizamos un modelo de desaparición de macroinverte-

brados. Para estimar el número total de macroinvertebrados bentónicos que derivaron como respuesta a las molestias provocadas por el observador, dicho modelo incorporó clases de tamaño de macroinvertebrados y comprobamos que el buceo produjo un aumento significativo en el número de macroinvertebrados de deriva. Sin embargo, estos aumentos afectaron a un procentaje muy pequeño (<1%) del número total de organismos bentónicos, lo que indica que, con toda probabilidad, la observación subacuática no afecta a los ensamblajes de macroinvertebrados en ninguna de las dos escalas estudiadas, aunque sí influyó de manera desproporcionada sobre los efemerópteros (4–5% derivaron como respuesta al buceo) en comparación con otros taxones.

3. En conclusión, el buceo tendría un efecto mínimo sobre el comportamiento y la distribución de las mayoría de las comunidades de peces de agua dulce en meso y microhábitat, si bien, dado que esta técnica afecta de manera sustancial la deriva de efemerópteros, también influirá sobre el comportamiento de los peces que tienen en estos pequeños insectos su fuente principal de alimento.

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References

Allan, J.D. 1978. Trout predation and the size composition of stream drift. Limnology and Oceanography 23: 1231–1237.

Allan, J.D. & Feifarek, B.P. 1989. Distances traveled by drifting mayfly nymphs: factors influencing return to the substratum. Journal of the North American Benthological Society 8: 322–330.

Bisson, P.A. 1976. Increased macroinvertebrate drift in an experimental stream caused by electrofishing. Journal of the Fisheries Research Board of Canada 33: 1806–1808.

Dolloff, A., Kershner J. & Thurow R. 1996. Underwater observation. In: Murphy, B.R. & Willis, D.W. eds. Fisheries techniques. 2nd edn. Bethesda, Maryland: American Fisheries Society, pages 533–554.

Dudgeon, D., & Kong, H. 1990. Benthic community structure and the effect of rotenone piscicide on macroinvertebrate drift and standing stocks in two Papua New Guinea streams. Archiv für Hydrobiologie 119: 35–53.

Elliott, J.M. 1971. The distances traveled by drifting macroinvertebrates in a Lake District stream. Oecologia 6: 191–220.

Elliott, J.M. & Bagenal, T.B. 1972. The effects of electrofishing on the macroinvertebrates of a Lake District stream. Oecologia 9: 1–11.

Ensign, W.E., Angermeier, P.L. & Dolloff, C.A. 1995. Use of line transect methods to estimate abundance of benthic stream fishes. Canadian Journal of Fisheries and Aquatic Sciences 52: 213–222.

Grossman, G.D., Ratajczak, R.E. Jr., Crawford, M. & Freeman, M.C. 1998. Assemblage organization in stream fishes: effects of environmental variation and interspecific interactions. Ecological Monographs 68: 395–420.

Hankin, D.J., & Reeves, G.H. 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.

Heggenes, J., Brabrand, A. & Saltveit, S.J. 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.

Kohler, S.L. 1985. Identification of stream drift mechanisms: an experimental and observational approach. Ecology 66: 1749–1761.

Malmqvist, B., & Sjöström, P. 1987. Stream drift as a consequence of disturbance by macroinvertebrate predators. Oecologia 74: 396–403.

McLay, C.L. 1970. A theory concerning the distance travelled by animals entering the drift of a stream. Journal of the Fisheries Research Board of Canada 27: 359–370.

Moyle, P.B. & Baltz, D.M. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114: 695–704.

Murphy, B.R. & Willis, D.W. eds. 1996. Fisheries techniques. 2nd edn. Bethesda, Maryland: American Fisheries Society.

Paine, M.D., Dodson, J.J. & Power, G. 1982. Habitat and food resource partitioning among four species of darters (Percidae: *Etheostoma*) in a southern Ontario stream. Canadian Journal of Zoology 60: 1635–1641.

Petty, J.T. 1998. Mottled sculpin in a dynamic landscape: linking environmental heterogeneity, individual behaviors, and population regulation in a southern Appalachian stream. PhD dissertation. Athens: University of Georgia.

Petty, J.T. & Grossman, G.D. 1996. Patch selection by mottled sculpin (Pisces: Cottidae) in a southern Appalachian stream. Freshwater Biology 35: 261–276.

Poff, N.L., DeCino, R.D. & Ward, J.V. 1991. Size-dependent drift responses of mayflies to experimental hydrologic variation: active predator avoidance or passive hydrodynamic displacement? Oecologia 88: 577–586.

Rincón, P.A. & Lobón-Cerviá, J. 1993. Microhabitat use by stream-resident brown trout: bioenergetic consequences. Transactions of the American Fisheries Society 122: 575–587.

Stouder, D.J. 1990. Dietary fluctuation in stream fishes and the effects of benthic species interactions. PhD dissertation. Athens: University of Georgia.

Waters, T.F. 1962. Diurnal periodicity in the drift of stream macroinvertebrates. Ecology 43: 316–320.