Snorkelers’ In-Water Observations Can Alter Salmonid Behavior

William R. Brignon,* M. Brian Davis, Douglas E. Olson, Howard A. Schaller, Carl B. Schreck

W.R. Brignon, M.B. Davis, D.E. Olson, H.A. Schaller
U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, 1211 SE Cardinal Court, Suite 100, Vancouver, Washington 98683

W.R. Brignon, C.B. Schreck
Oregon Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, Department of Fisheries and Wildlife, Oregon State University, 104 Nash Hall, Corvallis, Oregon 97331

Abstract

Direct underwater observation techniques (e.g., snorkel surveys) are widely used in fisheries science. Data collected from these surveys are used to estimate species abundance, detect presence and absence, and construct statistical models that predict microhabitat use and nonuse. To produce an unbiased estimate or model, fish should ideally behave as if there were no observer present. We conducted a study using underwater video to test whether snorkeling can elicit a change in fish behavior. Four behavioral metrics were measured: upstream movement, downstream movement, total movement, and number of fish in the field-of-view. Significant differences were detected in upstream, downstream, and total movements as a function of the in-water observer. These results suggest that an in-water observer can disturb fish, resulting in altered behavior, which in turn may bias study results. We suggest researchers use caution in making inferences to an entire population when data-collection methods have potential to bias fish behavior.

Keywords: fish behavior; salmonids; snorkel survey

Introduction

Direct underwater observation techniques (e.g., snorkel surveys) are widely used in fisheries science. Researchers use snorkel surveys to estimate fish abundance (e.g., Schill and Griffith 1984; Hankin and Reeves 1988), detect presence or absence (e.g., Watson and Hillman 1997; Peterson et al. 2002), measure meso- and microhabitat selection, and predict habitat use (e.g., Gries and Juanes 1998; Healy and Lonzarich 2000; Al-Chokhachy and Budy 2007). Studies designed to predict habitat use are conducted at a variety of spatial scales. Ideally, when conducting habitat-use studies, fish behavior as it relates to habitat selection would remain unaffected by the presence of an in-water observer. While conducting research on brown trout Salmo trutta and Atlantic salmon S. salar, Heggenes et al. (1990) found that they were able to almost touch a fish before eliciting a fright response. Conversely, Peterson et al. (2005) documented both upstream and downstream movements by bull trout Salvelinus confluentus during snorkel surveys when an in-water observer approached to within 10–20 m of the fish. Avoidance responses by fish also vary depending on their size (Grant and Noakes 1987). Displacement of fish caused by an in-water observer can bias data and influence interpretation of study results. For example, small-scale (e.g., microhabitat) movement or displacement of fish caused by the presence of an in-water observer may have no effect on a study focused at larger spatial scales (e.g., mesohabitat). However, results...
of habitat use studies at the microhabitat scale may be highly biased by small displacements (e.g., 1 m) of fish under observation.

Researchers have used various statistical methods to analyze microhabitat use data collected during snorkel surveys. Such methods have included 2-way analysis of variance (ANOVA) to determine differences in microhabitat use (e.g., Moyle and Baltz 1985; Lohr and West 1992) and more recently, logistic regression modeling (Hosmer and Lemeshow 2000) to predict microhabitat use (e.g., Guay et al. 2000; Maki-Petays et al. 2002; Turgeon and Rodriguez 2005; Al-Chokhachy and Budy 2007). Although researchers differ in the statistical methods used to analyze microhabitat data, their methods are similar in that they collect data from what they classify as “undisturbed” fish (e.g., Guay et al. 2000; Maki-Petays et al. 2002). However, these fish may not be representative of the entire population prior to the sampling disturbance. Inferences from these types of studies may have limited applicability to all fish within the study site (Peterson et al. 2005). Gatz et al. (1987) correctly acknowledged that the microhabitat data they collected using electrofishing most likely included undisturbed fish and fish that were frightened into refuge habitats. Al-Chokhachy and Budy (2007) made a similar acknowledgement in their study conducted using snorkel surveys.

In addition to biasing microhabitat use studies, a change in fish behavior caused by an in-water observer may bias the results of studies that employ a multiple-pass snorkel technique. For example, researchers may use a multiple-pass snorkel survey, with bounded counts (Routeledge 1982) to estimate species abundance. This requires multiple snorkel passes in the same stream section to acquire point estimates of fish sighted. If the number of visible fish in the study reach varies among snorkel passes as a function of the in-water observer, then the point estimates derived from each pass may be biased.

We initiated a study to predict microhabitat selection of age 0 and age 1 winter steelhead *Oncorhynchus mykiss* and age 0 coho salmon *O. kisutch* in the presence of residual hatchery winter steelhead using logistic regression modeling. During snorkel surveys it became obvious that in-water observers were having a large effect on fish behavior, in particular fish movement. Regardless of the speed at which we maneuvered in the stream, or the amount of time we waited for the fish to return to what we perceived as a natural state, we were concerned that our data were incorporating erroneous microhabitat use and nonuse data. Due to this concern we shifted our focus to gain a better understanding of this unexpected outcome. We revisited the literature and with the exception of Peterson et al. (2005) we were unable to locate peer-reviewed literature documenting movement of juvenile salmonids during snorkel surveys and how this may affect habitat use and behavior of fish. Therefore, the objective of this study was to determine whether the presence of an in-water observer influences fish behavior, particularly movement.

### Methods

We conducted this study in Eagle Creek, a fourth-order stream in the Clackamas River watershed near Portland, Oregon. Eagle Creek originates in the Mount Hood National Forest and is fed primarily by snowmelt. We chose the upper section of Eagle Creek because previous snorkel surveys suggested juvenile coho salmon and winter steelhead would be present. We conducted the study in August and September 2008 when the stream was at base flow and water clarity was optimal (approximately 3 m).

We selected 10 sample sites in upper Eagle Creek based on stream characteristics that would allow for the maximum field-of-view and highest clarity when using underwater video. The selected locations were essentially pool habitats, characterized by a lack of turbulence (i.e., bubbles), moderate depth (~1 m), and few obstructions in the field-of-view (i.e., large woody debris and boulders). The upstream and downstream boundaries of each sample site occurred where stream morphology characteristics were no longer classified as pool habitat.

We placed an underwater video camera perpendicular to the stream flow, approximately in the middle of the length of the site, with minimal disturbance (i.e., taking a few steps into the stream and reaching a hand into the water). The underwater camera was fully submerged on the stream bottom and placed as close to the bank as possible in order to provide a maximum field-of-view of the opposite stream bank. The camera was powered with a 12-V deep-cycle battery and connected to a digital video camera recorder that allowed for real-time viewing and recording. With the digital video camera recorder connected to the underwater camera, we verified that the field-of-view was clear of any major obstructions and began recording. The camera’s field-of-view was conical in shape, projecting 3 m from its apex (at the camera lens) to its base. The maximum diameter at the base of the conical field-of-view was 3 m.

Immediately after the camera was placed in the stream at each site, 10 min of video were recorded before the observer entered the stream. However, only the 2 min of video directly preceding the observer entering the stream were reviewed and used in the data analysis. The observer traveled downstream of the camera without entering the water, until the downstream end of the pool habitat was reached, approximately 7 m from the underwater camera. At this point, the observer entered the middle of stream with as little disturbance as possible and slowly traveled upstream parallel to the flow, past the underwater camera, and exited the stream at the upstream end of the pool habitat, approximately 5 m from the camera. The duration of video taken while the observer was in the stream varied from 60 to 90 s, depending on the length of the site. This entire section of video during the in-water observation was reviewed and included in the data analysis. Video recording continued for 5 min after the observer exited the stream. We included the first 2 min of this footage in the video review and subsequent data analysis. Therefore, the video footage used in the data analysis varied from 300
to 330 s among sites. Before removing the camera from the stream, we used an incremented wading staff to measure the dimensions of the camera’s field-of-view, and the maximum distance to the camera lens from which we were unable to confidently differentiate fish from other in-water structures. After sampling all 10 sites, we archived videos on digital video discs and later reviewed them.

We divided the three video periods (before, during, and after the observer entered the water) into 5-s intervals and reviewed them to document changes in four metrics: upstream movements, downstream movements, total movements, and number of fish in the field-of-view. We tallied upstream and downstream movements at both sides of the video screen for each 5-s interval. For example, a fish traveling upstream and entering the field-of-view and a fish traveling upstream and leaving the field-of-view would each be classified as upstream movements. The opposite holds true for downstream movements. Total movements were calculated as the combined number of upstream and downstream movements. The average number of fish visible during each 5-s interval was recorded. Because we were unable to confidently differentiate between coho salmon and steelhead in the video recordings, our observations reflected the combined movement and number of both species.

To detect differences between periods, average number of fish movements and average number of fish in the field-of-view (Supplemental Material, Table S1, http://dx.doi.org/10.3996/052010-JFWM-012.S1) were analyzed using ANOVA. We included sample site as an independent variable to account for variation among locations. Pair-wise differences between periods were tested using the least-square means method with a Bonferroni adjustment. The null hypotheses were that no significant differences ($\alpha = 0.05$) in average number of fish movements or average number of fish in the field-of-view occurred between periods.

## Results

With Eagle Creek at base flow and no precipitation events around the time our observations were made, water clarity was high and remained constant throughout the study. Juvenile coho salmon and winter steelhead were observed at all sample sites. Few fish were present in some sites, whereas in other sites, fish densities were notably greater. The 10 sample sites had an average depth of 0.99 m (range, 0.60–1.41 m), a mean width of 7.91 m (range, 5.1–14.0 m), and a mean water temperature of 11.5 °C (range, 10.6–12.3 °C).

A significant difference in upstream movements occurred between periods ($F = 11.77, P < 0.001$). Pair-wise comparisons detected an increase in upstream movements both during and after the in-water observation period compared to the period before the in-water observations (Figures 1 and 2).

A significant difference in downstream movements occurred between periods ($F = 10.06, P = 0.001$). Pair-wise comparisons detected an increase in downstream movements during the period of in-water observation compared to both the period before and the period after in-water observations (Figure 1 and 2).

A significant difference in total movements occurred between periods ($F = 12.39, P < 0.001$). Pair-wise comparisons detected an increase in total movements both during and after the periods of in-water observation compared to the period before in-water observations (Figures 1 and 3).

Overall there was no significant difference in the number of fish in the field-of-view between periods ($F = 1.70, P = 0.21$; Figure 1); however, an interesting observation occurred at one site. There were no fish visible at site 4 before the in-water observation period or during the majority of the in-water observation period. However, after the in-water observer passed the underwater camera, there was an increase in the abundance of fish in the field-of-view for the remainder of time the observer was in the water, as well as during the 2-min period after the in-water observer exited the stream (Figure 4).

## Discussion

Our study provides evidence that in a stream with high water clarity, an in-water observer moving through a study reach disturbs fish and can influence fish behavior as it relates to juvenile salmonid movement. Such movements can affect, for example, results of a study that attempts to model preferred microhabitat use by juvenile coho salmon and winter steelhead. Data collected from a fish displaced or disturbed by a sampling method would result in models that more closely resemble cover habitat or refugia than true preferred habitat. Also, fish that appear to be “undisturbed” may be selecting habitat that is a comfortable distance from the observer. Upstream and downstream movements of fish were significantly greater during the time the observer was in the stream and upstream movements remained significantly elevated after the observer left the stream. In hindsight we should have captured video until the activity returned to the levels seen before the observer maneuvered the site. There was also a significant difference in the average number of total movements, which suggests the in-water observer influenced swimming intensity (i.e., chaotic or frenzied movement) as well as direction. However, the in-water observer had no effect on the number of fish in the field-of-view (for example, see Supplemental Material, Video S1, http://dx.doi.org/10.3996/052010-JFWM-012.S2).

Factors affecting fish behavior, and ultimately fish movement, are widespread and well-documented. Predator avoidance (e.g., fright response) has been observed in various species of trout (Brown and Moyle 1991; Campbell 1998) and Pacific salmon Oncorhynchus spp. (Berejikian 1995; Healey and Reinhardt 1995). Conversely, prey species conducting “predator inspections” have been documented for mosquito fish Gambusia spp. (George 1960), threespine stickleback Gasterosteus aculeatus (Godin and Crossman 1994), and minnow shools Phoxinus phoxinus (Magurran 1986). Presence of a predator can also cause distress in fish (Barton 2002).
and affect movement and habitat selection (Price and Schreck 2003). If juvenile coho salmon Oncorhynchus kisutch and winter steelhead O. mykiss view an in-water observer as a potential predator, the downstream movements observed are most likely a function of predator avoidance. Upstream movements that occurred after the perceived predator left the stream could be explained as predator inspections or simply a foraging behavior brought on when the in-water observer stirred up benthic food resources.

Unexpectedly, the in-water observer had no effect on the number of fish in the field-of-view. It is likely all fish are not readily available for observation during snorkel surveys; some may be using cover or other refugia. Because fish apparently moved from cover to inspect the

Figure 1. Box plots of average number of fish movements and number of fish in the field-of-view by period for juvenile coho salmon Oncorhynchus kisutch and winter steelhead O. mykiss at each of the 10 sample sites in Eagle Creek, Oregon, August and September 2008. Periods consist of before, during, and after the snorkeler sampled the site. The box represents the interquartile range of observations during each period, and the X line represents the median value. The whiskers represent 1.5 times the interquartile range and outliers are identified as open circles. Within panels, different lowercase letters above boxes represent statistically significant differences between periods as determined by pair-wise comparisons.
observer (i.e., predator inspection) or search for food stirred up by the observer, we expected to observe more fish in the field-of-view after the observer exited the stream. This may have occurred at site 4 (Figure 4) where the in-water observer turned what initially would have been classified as nonuse habitat into use habitat because abundance dramatically increased after the observer entered the reach. In instances where the presence of an in-water observer increases the number of visible fish, population estimates calculated from subsequent snorkel passes (i.e., the bounded-count method) may more closely resemble the true population and, therefore, reduce the bias of the estimate. On the contrary, if an in-water observer lowers the abundance of visible fish at a site, then subsequent snorkel passes may negatively bias of the population estimate. Depending on the system and species, there are alternative techniques to estimating population abundance that may be more appropriate (see Seber 1982, 1986, 1992; Schwarz and Seber 1999).

Due to uncertainty in accurately identifying all fish to species, we were unable to detect any potential interspecific differences in movements caused by the

![Figure 2](http://example.com/figure2.png)

**Figure 2.** Upstream and downstream movements of juvenile coho salmon *Oncorhynchus kisutch* and winter steelhead *O. mykiss* for each of the 10 sample sites in Eagle Creek, Oregon, August and September 2008. Upstream movements (blue bars) and downstream movements (red bars) are centered around zero. Each bar represents a 5-s interval. The scale of the x-axis is varied to account for varying time duration between sites during the in-water observation period. Periods consist of before, during, and after the snorkeler sampled the site.
in-water observer. It is our belief that the results would have been similar if this study were conducted in streams where these species live in allopatry. However, the more docile nature of coho salmon compared to that of steelhead trout may result in species-specific differences in their response to in-water observers.

Our study is one example of how underwater video can be used to address fisheries-related questions. The human eye possesses the ability to see in three dimensions and has a higher visual acuity compared to that of a camera lens. For these reasons, the human eye can see underwater with greater resolution and perception than a camera lens. However, the use of underwater video has other benefits. Underwater cameras appear to have less impact on fish behavior than an in-water observer in clear stream pools. Video footage can also be archived and reviewed if necessary to verify the findings or to add a posteriori analyses to

---

**Figure 3.** Total number of movements of juvenile coho salmon *Oncorhynchus kisutch* and winter steelhead *O. mykiss* for each of the 10 sample sites in Eagle Creek, Oregon, August and September 2008. Each bar represents a 5-s interval. The scale of the x-axis is varied to account for varying time duration between sites during the in-water observation period. Periods consist of before, during, and after the snorkeler sampled the site.
Figure 4. Number of juvenile coho salmon *Oncorhynchus kisutch* and winter steelhead *O. mykiss* in the field-of-view during sampling for each of the 10 sample sites in Eagle Creek, Oregon, August and September 2008. Each bar represents a 5-s interval. The scale of the x-axis is varied to account for varying time duration between sites during the in-water observation period. Periods consist of before, during, and after the snorkeler sampled the site.

The study. Depending on study objectives, underwater video technology may be a preferred method for observing fish in their natural habitat. At the very least, underwater video can be used to validate the data collected by in-water observers.

We conclude that in-water observations can influence juvenile salmonid behavior. Studies that use in-water observations to calculate population estimates and evaluate habitat use and selection are essential in managing certain fisheries resources. Due to the complexity of underwater habitats, there are biases and limitations associated with all methods used to observe fish in their natural habitat, and it is important to understand and acknowledge these limitations. We suggest that researchers take caution when collecting data specifically for “undisturbed” fish and acknowledge that any inferences drawn from this type of information cannot appropriately be extrapolated to the entire population.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author.
Table S1. Data used in study analysis, sample sites 1–10 in upper Eagle Creek, Portland, Oregon. Found at DOI: http://dx.doi.org/10.3996/052010-JFWM-012.S1 (13 KB DOCX).

Video S1. This short video from sample site 3 shows the reaction of juvenile salmonids to an in-water observer. Notation embedded in the video will direct the viewer as to the location of the in-water observer. Notice the fish respond well before the observer is within range of identifying the fish and their microhabitat. Also, there is increased activity well after the observer exits the stream. Found at DOI: http://dx.doi.org/10.3996/052010-JFWM-012.S2 (27810 KB WMV).

Acknowledgments

David L. G. Noakes, Timothy A. Whitesel, five anonymous reviewers, and the Subject Editor provided constructive comments that improved this manuscript. Henry Yuen and Steven Haesecker provided statistical assistance.

Any use of trade, product, website, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References


Berejikian BA. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (Oncorhynchus mykiss) to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences 52:2476–2482.


