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[Management Brief]

Accuracy of Aerial Telemetry in Fisheries Studies

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Abstract.—Radiotelemetry has become an important method for examining movement patterns of fishes. The use of aircraft allows transmitter-implanted fish to be tracked over long distances and in areas difficult to access on the ground. However, the accuracy of aerially determined locations can limit the types of conclusions one can draw about fish habitat use. We utilized aerial telemetry while studying the effects of irrigation canals on a population of cutthroat trout *Oncorhynchus clarkii*. To determine the accuracy of aerially determined locations, we used a method common in terrestrial studies whereby transmitters are placed at known locations and then located by a naïve pilot. These aerially determined locations were then compared with the known locations of transmitters to determine the mean error associated with aerial telemetry. In our study, we found that aerially acquired location errors ranged from 22 to 426 m and had a mean of 178 m. In a review of recent studies that used aerial telemetry, we found that 15 of 34 (44%) terrestrial studies but only 4 of 17 (24%) aquatic studies reported an estimate of the error associated with aerial telemetry locations. The overall mean location error of these studies was 158 m. We urge aquatic biologists to consider location errors when using aerial telemetry, especially when making inferences about fish habitat use or movement patterns.

Understanding movement patterns of stream-dwelling fishes is an important aspect of fisheries management. If fish are relatively stationary, then relatively short stream reaches may be sufficient to sustain a population (Gerking 1959). However, if long-distance migrations occur among widely separated habitat types, then barriers to movement can jeopardize the survival of a population (Gowan et al. 1994; Fausch et al. 2002). Recent studies have utilized radiotelemetry to show that many stream fishes exhibit extensive movement patterns (Clapp et al. 1990; Brown and Mackay 1995; Brunnellet et al. 1998; Jakober et al. 1998; Schrank and Rahel 2004). These studies of fish movement and habitat use in lotic systems have benefited greatly from the use of radiotelemetry to expand the spatial scale at which organisms can be studied.

Radiotelemetry using ground-based methods can be effective when organisms move distances on the order of several hundred meters, but becomes logistically difficult when movement distances span several kilometers or more. The use of aircraft becomes a method of choice for following transmitter-implanted fish over large distances (Tyus and McAda 1984; Bresser et al. 1988; Modde and Irving 1998; Harvey and Nakamoto 1999). Aerial telemetry also allows biologists to track fish in remote areas where access to study sites may be difficult, to locate fish on private land where landowners may not allow access, and to avoid disturbing fish from the presence of streamside trackers.

Aerial telemetry usually uses an airplane equipped with several antennas, a radiotelemetry receiver, and a global positioning system (GPS). When determining the position of a transmitter-implanted fish, pilots take a GPS reading when they determine that the signal from the transmitter is strongest, indicating the transmitter is directly below the aircraft. These techniques raise questions about the accuracy of positions obtained from an airplane. Sources of measurement error can include pilot judgment, accuracy of GPS equipment, weather, and environmental conditions of the study system. These environmental conditions include water conductivity, signal reflections, and extraneous noises (Hoskinson 1976; White and Garrott 1990; Priede and Swift 1992; Winter 1996).

Terrestrial researchers have long advocated testing the accuracy of aerial locations (White and Garrott 1990). In aquatic studies the accuracy of ground-based telemetry locations has been addressed (Simpkins and Hubert 1998; James et al. 2003), but the errors associated with aerial telemetry data have generally been ignored. The lack of information about the accuracy of aerially determined fish locations is especially problematic in studies of habitat use, where researchers are often interested in identifying macrohabitats (run, riffle, pool) or instream features (e.g., woody debris or other cover variables) important to fish. Our objectives were to estimate the accuracy of fish locations determined by aerial telemetry in a lotic system and to review the literature to determine

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the accuracy of aerial radiotracking in both aquatic and terrestrial environments.

Methods

Study site.—We measured the error associated with aerially determined telemetry locations as part of a study evaluating movement patterns of cutthroat trout *Oncorhynchus clarkii* in the Smiths Fork drainage, Lincoln County, Wyoming. The Smiths Fork originates in the Bridger Teton National Forest and is a tributary to the Bear River. There are 11 agricultural irrigation canals located in the lower portion of the Smiths Fork watershed. These irrigation canals have natural substrates and are routinely dredged. The largest is the Covey Canal where the aerial telemetry work was conducted in the summer of 2003.

Accuracy experiment.—We used two types of radio transmitters, an 8-g transmitter (model F1820) and a 3.1-g transmitter (Model F1570; Advanced Telemetry Systems, Insanti, Minnesota) both of which operated at 50 pulses/min and on frequencies between 150.000 and 151.999 mHz. The aerial portion of this study was contracted to a local specialist in natural resource aviation. Aerial tracking was conducted using a fixed-wing aircraft (Maule MX-235) equipped with three telemetry antennas (two directional H, and one forward Yaggi with a Telonics TAC-7 switch) mounted by brackets on the wing struts, a telemetry receiver (Telonics TR-2 with scanner), and a GPS (Apollo GX 55) having an accuracy of 15 m. The pilot located radio transmitters as he flew over the study area by using the telemetry receiver to scan the frequencies of the deployed transmitters. The two directional antennae were located separately on each wing. The pilot was able to use these directional antennae in unison or separately to determine where in relation to the airplane a transmitter was located. When a transmitter was heard on the receiver, an effort was made to determine its exact location. This involved making several passes over the area where the transmitter was emitting its signal. When the pilot was confident he had pin-pointed the transmitter's location directly below the plane, he recorded the GPS reading in Universal Transverse Mercator (UTM) coordinates that were saved in an onboard computer. This procedure continued until all the transmitters had been located. The average altitude above ground level (AGL) of the plane while locating transmitters was 136 m. The pilot was completely unaware of the accuracy experiment and treated each transmitter as if it had been implanted in a fish.

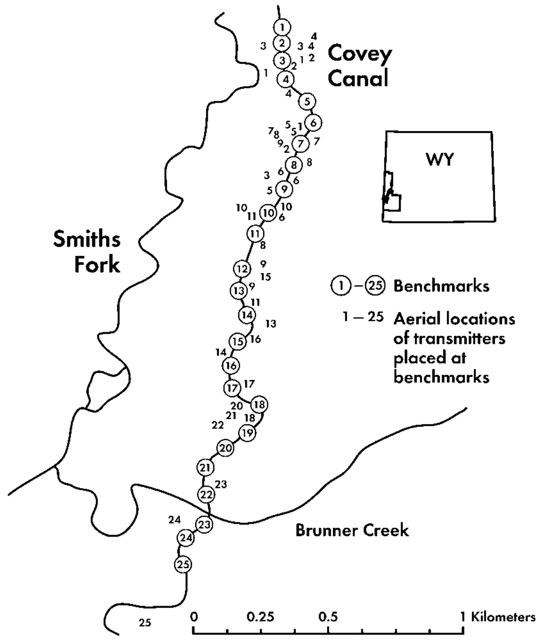

FIGURE 1.—Study area where the accuracy of aerial telemetry for locating fish was assessed, showing the Smiths Fork of the Bear River and the Covey Canal in Lincoln County, Wyoming. Circled numbers indicate the locations of 25 benchmarks (known locations of placed transmitters) that aerial telemetry sought to identify, and uncircled numbers refer to the aerially determined location of a given transmitter with the same benchmark number.

To test the accuracy of aerial telemetry, we established the location of 25 benchmarks on the ground using a Trimble Geo XP GPS unit (Figure 1). These GPS points were used to test the accuracy of transmitter locations determined by the aerial method. Because the location accuracy of these benchmarks was paramount to our study, the GPS locations of the benchmarks were postprocessed and differentially corrected so that location errors due to the GPS were less than 1 m. This amount of accuracy was possible because our study was conducted after the selective availability was deactivated by the U.S. Government in May 2000. The location of the airplane and, subsequently, the aerially determined locations of the transmitters were assessed by aeronautical GPS, which has an accuracy of 15 m. We were not able to postprocess the aeronautical GPS data to improve the accuracy.

The 25 benchmarks were sequential numbers; benchmarks 1–9 were placed underwater in the Covey Canal, and benchmarks 10–25 were placed out of the water on the banks of the canal. The location of each benchmark was marked by a stake

(Figure 1). The transmitters placed underwater were located in the deepest part of the canal and were submerged no deeper that 1 m. When flights were made to relocate transmitter-implanted fish, unused transmitters were attached to some of these benchmarks. Having some of the transmitters in the water and others on land allowed us to determine if their being underwater influenced the accuracy of aerially determined locations.

To prevent loss or damage to the radio transmitters, a sheath was placed over those deployed at the aquatic benchmarks. This sheath consisted of 3 cm of 1.91-mm polyvinyl chloride (PVC) piping that covered the body of the transmitter. The body of the transmitter was secured to the sheath via cable ties (10 × 2 mm), and the whip antenna of the transmitter was allowed to hang freely out the back of the sheath.

Transmitters were placed at bench marks to test aerial accuracy during three flights in the summer of 2003. The first flight was on 17 June and involved 23 transmitters placed at benchmarks 1–11, 13–18, and 20–25. The second flight took place on 13 July and involved 11 transmitters placed at benchmarks 1–11. The third flight took place on 20 July and involved 8 transmitters placed at benchmarks 1–9, excluding benchmark 7.

The aerially determined location of each experimental transmitter was then compared with the location of the benchmark where the transmitter was placed during the flight. To compare these locations, GIS (geographic information system) software (ArcView 3.2 © ESRI, Redlands, California) was used in conjunction with Animal Movement (an ArcView extension produced by the USGS-BRD, Alaska Biological Science Center and available at www.absc.usgs.gov/glba/gistools/animal_mvmt.htm). These tools were used to calculate the distance between the actual location of the experimental transmitter (benchmark) and the location produced from aerial surveys. The statistical package MINITAB© (Version 12.21, State College Pennsylvania) was used to perform a *t*-test comparing the locations of underwater versus bank benchmarks.

Literature review.—We assessed aerially determined measurement errors from studies done in aquatic versus terrestrial environments. The Fish and Fisheries Worldwide database (National Inquiry Services Centre [NISC], Grahamstown, South Africa) was searched for peer-reviewed aquatic studies (1994–2003), and the Wildlife & Ecology Studies Worldwide database (NISC Baltimore, MD) was searched for peer-reviewed terrestrial studies (2000–2003). Because aerial telemetry was used in relatively few aquatic studies, we extended the literature search to cover a longer period than for terrestrial studies.

TABLE 1.—Aerial location errors for radio transmitters placed at known, benchmark locations in the Covey Canal, Wyoming. Up to three flights were done for some of the benchmark locations.

Benchmark number	Mean location error across flights (m)	Location errors (m) by flight		
		Flight 1	Flight 2	Flight 3
1	219	372	105	179
2	209	104	425	97
3	203	426	97	86
4	114	40	141	161
5	200	359	124	117
6	246	190	351	200
7	46	46	46	
8	145	49	79	307
9	272	293	381	143
10	42	35	49	
11	159	49	269	
13	173	173		
14	163	163		
15	268	268		
16	108	108		
17	22	22		
18	87	87		
20	189	189		
21	245	245		
22	262	262		
23	130	130		
24	259	259		
25	271	271		

Results

Accuracy Experiment

The mean location error across all benchmarks and flights was 178 m ($N = 42$, SE = 17.9) (Table 1). The mean location error based on the 9 benchmarks located underwater in the canal across all three flights was 189 m ($N = 26$, SE = 25.2). The mean location error based on the 14 benchmarks located out of the water on the banks of the canal across all three flight was 161 m ($N = 16$, SE = 23.5). There was no statistical difference in location errors between benchmarks in the canal versus those on the banks of the canal (*t*-test, $P = 0.424$). The accuracy of locations at specific benchmarks ranged from 22 to 426 m. The distribution of benchmarks and corresponding aerially determined telemetry locations along the Covey Canal are shown in Figure 1.

Literature Review

In our review of the terrestrial literature from 2000 to 2003, we found 651 terrestrial studies that

TABLE 2.—Results from a literature search of terrestrial (2000–2003) and aquatic (1994–2003) peer-reviewed publications that utilized radio telemetry to locate organisms.

Type of study	Years	Total number of telemetry studies	Number of telemetry studies that used aerial telemetry	Number of aerial telemetry studies reporting accuracy	Percentage of aerial studies reporting accuracy
Terrestrial	2000–2003	650	34	15	44.1
Aquatic	1994–2003	415	17	4	23.5

used telemetry and 34 of these involved aerial telemetry (Table 2). Of the 34 terrestrial studies that used aerial telemetry, 15 (44.1%) reported the accuracy of their aerial locations; their mean location error was 159 m (Figure 2). The review of aquatic studies from 1994 to 2003 found 415 studies that utilized telemetry. Seventeen of these aquatic studies reported using aerial telemetry, but only 4 (23.5%) provided an accuracy assessment; their mean location error was 153 m (Figure 2). When we combined aquatic and terrestrial studies that assessed the accuracy of aerial telemetry, the mean location error was 158 m (SE = 31).

Discussion

Aerial telemetry is a valuable tool for studying long-distance fish movements, for documenting habitat use at riverscape scales, or for quickly locating fish for follow-up ground telemetry studies. In our work on how irrigation canals impact trout populations, we found aerial telemetry crucial for locating transmitter-implanted fish because the canals extended over 50 km and many were without adjacent roads. These circumstances made it logistically difficult to walk the entire length in a timely manner and prevented roadside tracking from a vehicle. Without aerial telemetry, locating our fish would have been much more difficult and time-consuming.

Several factors could contribute to the measurement errors associated with our aerially determined transmitter locations. First, the GPS unit on board the aircraft that was used to determine the location of the plane, and therefore, the location of transmitters had an accuracy of 15 m. However, because our mean error was 178 m, other factors must also have contributed to the location errors. One likely source is the ability of the pilot to mark the location of the transmitter signal when it appears to be directly under the airplane. The accuracy of that recorded location depends on the ability of a pilot to mark the location where the transmitter signal is loudest (i.e., the loudest signal occurs when the transmitter is directly below the plane, and if that point is incorrectly marked, then error occurs). The magnitude of this error could be assessed by having the pilot record the location of the same transmitter during multiple passes on a single flight. This was not done during our study, and we are unaware of other studies where this source of location error has been measured. Weather conditions that influence location errors are mainly associated with wind, which can make it difficult to fly directly over the transmitter and pinpoint its location.

Relocating transmitter-implanted fish using aerial methods has potential limitations. A mean location error of 178 m, which is what we found in our accuracy assessment, can limit the conclusions made from a radiotelemetry study. For studies involving habitat use at the scale of channel units (pools, runs, and riffles), such levels of error are not acceptable. Channel units in most small to midsize streams are less than 200 m long; thus, fish locations determined by aerial telemetry may not be accurate enough to locate fish within channel units. In our study of cutthroat trout, we were trying to determine the movement and fate of fish entrapped in irrigation canals. In some cases the canals ran parallel to and were located within 20 m of the main stem of the Smiths Fork (the river of interest). Because of limitations in the accuracy of fish locations determined by aerial telemetry, we needed to verify all such aerial fish locations on the ground to determine if fish were in the canal or the river.

In studies using aerial telemetry to determine long-range movements of fish or large-scale habitat use, location errors on the order of 200 m might be acceptable. For example, Colorado pikeminnow *Ptychocheilus lucius* undergo spawning migrations of about 200 km, so an error of about 200 m in aerial telemetry locations would be relatively inconsequential (Tyus and McAda 1984). Location errors of this magnitude might also be unimportant when assessing habitat use at large spatial scales, such as the use of stream reaches with suitable thermal conditions by Chinook salmon *Oncorhynchus tshawytscha* (Torgersen et al. 1999). These thermal patches usually encompassed stream seg-

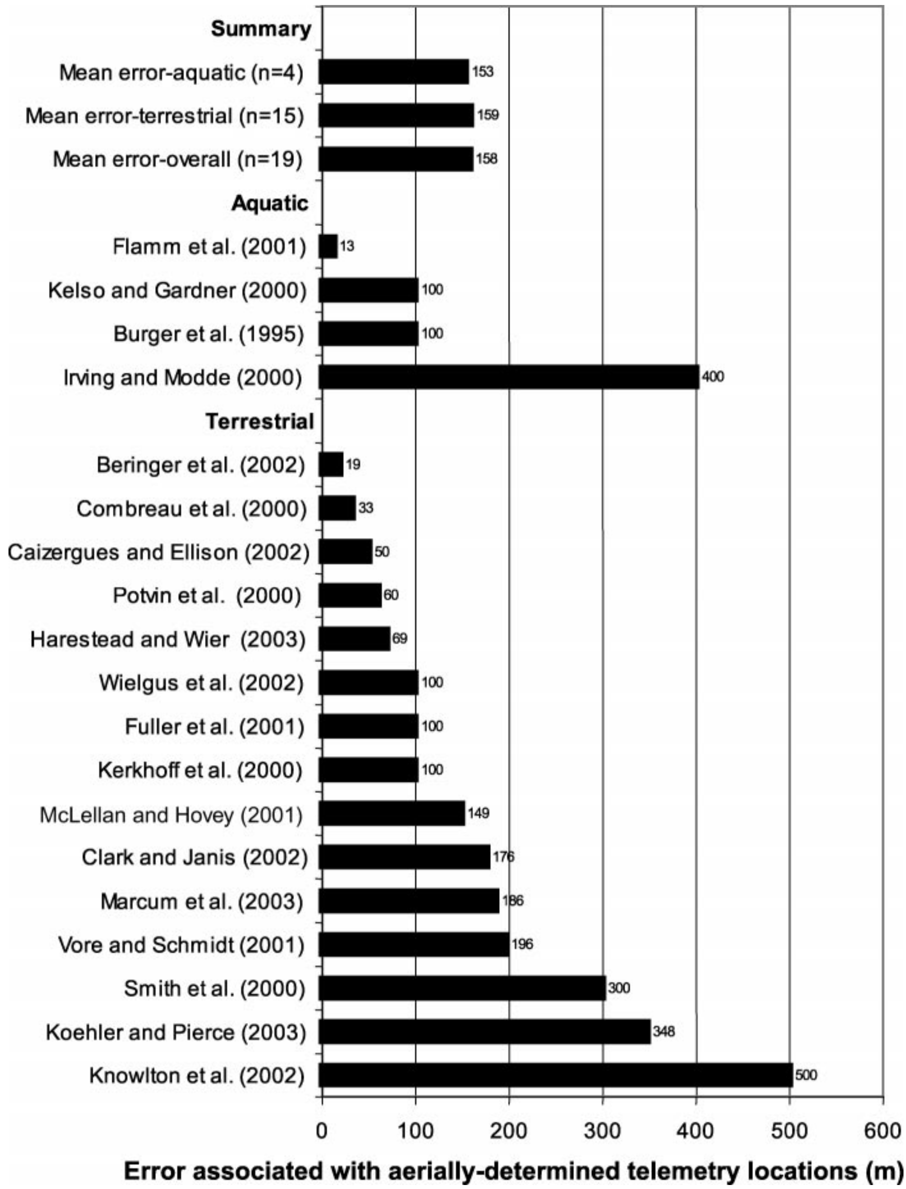

FIGURE 2.—The accuracy as indicated by error associated with aerial telemetry locations from terrestrial (2000–2003) and aquatic studies (1994–2003) published in peer-reviewed journals; numbers to the right of the bars are the mean errors depicted by the bars, as reported for a given study.

ments on the order of kilometers, so an aerial telemetry error of about 200 m in locations of fish would probably have little effect on the determination of habitat use.

Two approaches have been used to estimate location errors associated with aerial radiotelemetry. One approach involves placing transmitters at locations unknown to the pilot, and then having the pilot locate them just as they would locate transmitters implanted in an organism (White and Garrott 1990). Of the 19 terrestrial and aquatic studies reporting the error of aerially acquired telemetry data, only 6 used this method and of these, only 3 used the GPS technique we suggest for providing accurate assessments of location error (Burger et al. 1995; Beringer et al. 2002; Marcum et al. 2003). In the other three studies, the locations of test transmitter locations were plotted on a map, based on reference landmarks, before the flight was undertaken. During the flight, the locations of transmitters were plotted on similar maps, again using reference landmarks on the ground (Vore and Schmidt 2001; Wielgus et al. 2002; Koehler and Pierce 2003). The difference between ground-acquired and aerially acquired locations was used as a measure of location error. Because neither location is known with certainty, this technique tests the orienteering skills of the observer rather than the accuracy of aerial telemetry. In the remaining 13 studies, the approach used to determine location errors was simply to determine the maximum detection distance of transmitters while in flight (Irving and Modde 2000). This distance was then assumed to represent the maximum location error. However, this approach provides little insight as to the average error in locating organisms implanted with radio transmitters.

Aerial accuracy estimates involve increased project time and added expense. For our study the average price of a transmitter was US$178 and average price of a flight was $722. Because the accuracy of radio telemetry locations can vary with pilot experience, the equipment used to detect transmitter signals, weather, and the local environmental conditions, studies involving aerial telemetry should budget for determining the accuracy of the locations found through aerial telemetry.

Aerial telemetry provides valuable information at large spatial scales and can be useful in locating fish for follow-up searches on the ground where reach scale habitat conditions can be assessed. As fisheries managers seek to understand how landscape factors influence fish abundance and movement patterns, the use of aerial telemetry will increase (Fausch et al. 2002). The method we used, as described by White and Garrott (1990), is an effective way to assess aerial accuracy in aquatic studies. We encourage researchers to consider measurement error when employing aerial radiotelemetry so that fish habitat associations and movement patterns are interpreted at the appropriate spatial scale.

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