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Detection range of two acoustic transmitters in four reservoir habitat types using passive receivers

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Abstract

Background: Recently, South Dakota Department of Game, Fish, and Parks (SDGFP), has undertaken a suite of rigorous acoustic telemetry studies. The goals and scope of the individual research projects vary but all use the same receiver array throughout Lake Sharpe in central South Dakota. Prior to initiating the telemetry studies, we sought to describe the detection probability of receivers from a representation of habitats within Lake Sharpe, South Dakota. We used both a V9-2H transmitter and a V13-1L transmitter in combination with VR2W 69 kHz passive receivers [all from Innovasea (Vemco)] to determine detection probability in four novel habitats of Lake Sharpe. Both transmitter and receiver were moored at fixed distances (200 m 400, and 600 m) for multiple consecutive days and detection probability compared between transmitter type, distance, site, and diel period using ANOVA following arcsine square-root transformation.

Results: We found significant differences in detection probability between the four habitat types for both the V9 and V13 transmitters. Sites protected from wind and wave action, and with little boat traffic, had larger detection ranges compared to areas that were wind exposed and host more boat traffic. The site immediately downstream from a hydroelectric dam that is exposed to both high wind fetch and is popular for boating, exhibited the poorest detection probability at all distances for both transmitter types. V13 transmitters consistently exhibited greater detection probability relative to V9 transmitters and this difference was greater at further distances. In general, detection probability was higher at nighttime compared to daytime and these differences were significant dependent on transmitter, site, and distance.

Conclusions: Using the information presented, SDGFP has modified their receiver array to maximize the ability to detect acoustic transmitters in the novel habitats of Lake Sharpe. Specifically, receiver spacing was reduced and/or expanded dependent on the distance, where 50% detection probability was attained. More work is needed to identify those factors that influence detection probability of acoustic telemetry systems.

Keywords: Acoustic telemetry, Detection probability, Freshwater fish telemetry, Passive array, Range testing

Background

Acoustic telemetry systems have been used to monitor the presence, movement, behavior, and/or survival of aquatic organisms [1]. As technological advances reduce transmitter size, increase transmitter life, increase power output, and reduce costs, the use of these technologies is expected to increase [1]. Of the acoustic telemetry systems currently used, the

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submerged passive acoustic telemetry system is becoming particularly commonplace [2]. Passive acoustic telemetry systems offer several benefits compared to active-tracking [3] including (1) less labor intensive compared to active tracking, (2) data is collected constantly throughout the duration of the battery life of the transmitter, (3) multiple individuals and species can be tracked simultaneously using a single receiver array and (4) multiple receiver arrays can be communally accessed through data sharing further reducing individual research agency time and resource investment for discrete research projects.

One drawback to passive acoustic telemetry systems is the lack of site and time specific information regarding detection probability for acoustic transmitters. Detection probability is the likelihood that a receiver registers a transmitter at a given distance from the receiver [2]. Acoustic transmitter detection probability is dictated by a suite of factors that include distance between transmitter and receiver, transmission power, signal absorption, line of sight, reflection/refraction, multipath, and both natural and man-made environmental noise (i.e., wind and wave action or boat sonar interference [4, 5]. Although the maximum distance that transmitters can be detected exceeds 11 km, reliable detection ranges are usually much shorter [6]. In addition, in the literature, detection ranges can vary from a few meters to greater than 1,000 m dependent upon aforementioned abiotic and biotic conditions. Most manufacturers of telemetry equipment provide general guidelines for detection ranges but also recommend site and tag specific range testing to suite the research to be conducted.

As the use of acoustic telemetry systems popularized, so too has the study of specific detection probabilities. Detection probability testing has varied methodologies and analyses. Static range testing involves placing transmitters at specific distance from receivers and registering detections over long periods of time [2, 6] either before the study begins, or throughout the study using sentinel tags [7]. Conversely, mobile range testing is achieved by moving a transmitter past a receiver to evaluate detection probability along a distance gradient [25]. Both methods have been widely used and there is general agreement that temporal and spatial differences occur even in similar system types.

Despite the increased use of passive acoustic telemetry in freshwater systems, most published range testing studies have occurred in marine environments [4]. Recently, South Dakota Department of Game, Fish, and Parks (SDGFP), has begun a suite of rigorous acoustic telemetry studies involving five different fish species of varying size using varying tag sizes, tag delays, and output power. The goals and scope of the individual research projects vary but all use the same receiver array throughout Lake Sharpe in central South Dakota.

Prior to implementing the telemetry studies, we sought to describe the detection probability of receivers from a representation of habitats within Lake Sharpe, South Dakota. The reservoir follows typical zonation patterns and includes a riverine zone, transition zone, and lacustrine zone; each with unique habitat attributes that likely impact detection probability of acoustic tags. In addition, Lake Sharpe is a popular pleasure-boating and angling destination with many boats frequently on the water near receivers. Hence, the potential for reduced detection probability caused by human interference through boat motor and/or recreational fish sonar is high. Thus, our objectives for this study were to (1) describe the detection probability of passive receivers in four unique reservoir habitat types, (2) make comparisons between day (high human use) and night (low human use) detection probability, and (3) make recommendations for future acoustic telemetry studies on Lake Sharpe, South Dakota.

Results

We found significant differences in detection probability for both V9 and V13 transmitters between all the sites and at all three distances from the receiver (Table 1). For the V9 transmitters, the Crappie Hole consistently exhibited greater detection probability compared to the other locations (Fig. 1). Interestingly, the Crappie hole receiver showed substantially greater detection probability for the V9 tags at the 600 m distance (83%) compared to the other three sites (all less than 13%; Fig. 1). Conversely, Echo Point consistently exhibited the lowest detection probability with the V9 tags and, at the shortest distance (200 m), only recorded a 51% detection probability, while all other sites recorded a detection probability of greater

Table 1 ANOVA test results comparing the detection probability of V9 and V13 transmitters at four locations within Lake Sharpe, South Dakota, USA

Transmitter	Distance	*F*-Statistic	*P* value
V9	200 m	$F_{3,1266} = 176.485$	< 0.001
V9	400 m	$F_{3,1311} = 189.031$	< 0.001
V9	600 m	$F_{3,1193} = 931.761$	< 0.001
V13	200 m	$F_{3,1264} = 95.865$	< 0.001
V13	400 m	$F_{3,1673} = 186.184$	< 0.001
V13	600 m	$F_{3,1193} = 564.937$	< 0.001

The percentage of detections registered relative the transmissions sent within a 15 min analysis bin were arcsine square root transformed and then compared within each location, for a given distance, and for a give transmitter type using ANOVA. Data presented in the table include transmitter type (Transmitter), distance from transmitter to receiver (Distance). *F*-Statistic, and *P* value

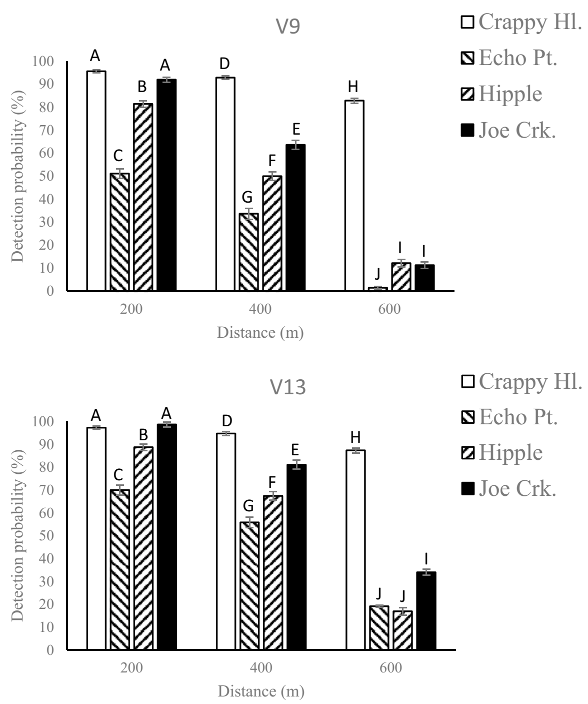

Fig. 1 Average detection probability of V9 and V13 transmitters at four locations within Lake Sharpe, South Dakota, USA. Both panels represent the percentage of detections registered relative the transmissions sent within a 15 min analysis bin for the V9 transmitter (top panel) or V13 transmitter (bottom panel). Raw detection percentages were arcsine square root transformed and compared using ANOVA. Letter groupings within a test distance that contain different letters represent significantly different average detection range ($P<0.05$). Locations include Crappie Hole (Crappie Hl.), Echo Point (Echo Pt.), Hipple Flats (Hipple), and Joe Creek (Joe Crk.). Error bars reflect standard error. Test statistics can be found in Table 1

than 81% (Fig. 1). Like the other receivers, detection probability at Echo Point declined with distance and this site registered the lowest detection probability at 600 m at 1.5% (Fig. 1). Detection probability at both the Hipple Flats and Joe Creek sites were in-between those recorded for the Crappie Hole and Echo Point (Fig. 1). At 200 m and 400 m, detection probability for Joe Creek was significantly greater than the Hipple Flats site. However, there was no significant difference between these sites at 600 m.

Interestingly, the V13 transmitters exhibited almost identical trends in detection probability as the V9 transmitters (Fig. 1). The Crappie Hole receiver once again showed substantially greater detection probability for the V13 tags at the 600 m distance (87%) compared to the other three sites (all less than 34%; Fig. 1). However, detection probability for V13 transmitters was consistently greater than that of the V9 transmitters (Fig. 1). These differences between the tag types were most

Table 2 ANOVA test results comparing the detection probability of V9 and V13 transmitters at four locations within Lake Sharpe, South Dakota, USA during daylight and nighttime hours

Location	Distance	*F*-Statistic	*P* value
Crappie Hole	200	$F_{3,733}=3.908$	<0.01
	400	$F_{3,723}=1.564$	$=0.197$
	600	$F_{3,958}=10.321$	<0.001
Echo Point	200	$F_{3,604}=14.023$	<0.001
	400	$F_{3,394}=23.216$	<0.001
	600	$F_{3,352}=28.882$	<0.001
Hipple Flats	200	$F_{3,814}=50.405$	<0.001
	400	$F_{3,1332}=32.965$	<0.001
	600	$F_{3,700}=17.904$	<0.001
Joe Creek	200	$F_{3,370}=25.067$	<0.001
	400	$F_{3,584}=20.642$	<0.001
	600	$F_{3,368}=24.788$	<0.001

The percentage of detections registered relative the transmissions sent within a 15 min analysis bin were arcsine square root transformed and then compared within each location, for a given distance, for a give transmitter type, between the 2 time periods (day/night) using ANOVA. Data presented in the table include site location (Location), distance from transmitter to receiver (Distance). F-Statistic, and *P* value

apparent at the greater distances of 400 m and 600 m. For instance, at the Echo Point site at 600 m, the V13 tags recorded a detection probability of 19%, while the V9 tags only recorded a detection probability of 1.5%. The Crappie Hole again had significantly greater detection probabilities and Echo Point had significantly lower detection probabilities for all the distances examined (Fig. 1). Like the V9 transmitters, V13 transmitters at Hipple Flats and Joe Creek registered detection probabilities less than that seen at the Crappie Hole but greater than at Echo Point (Fig. 1).

The detection probability at night was generally greater than during the day (Table 2; Fig. 2). The Crappie Hole is the only sight that showed no significant difference between detection probability between day and night except for V13 transmitters at 600 m, where there was a significant decline in detection probability between day (91%) and night (82%; Fig. 2). However, detection probabilities for both time periods at 600 m were greater than 85%. Conversely, Hipple Flats transmitters (both V9 and V13) exhibited significantly greater detection probability at night across all study distances (Fig. 2). At Joe Creek, nighttime detection probability was generally greater than daytime detection probability and this was a significant difference at 200 m and 400 m for the V9 transmitters, but no significant diel improvement in detection probability was seen with the V13 transmitters at Joe Creek (Fig. 2). Echo Point detection probability was also improved at night and was significantly greater at 400 m for both the V9

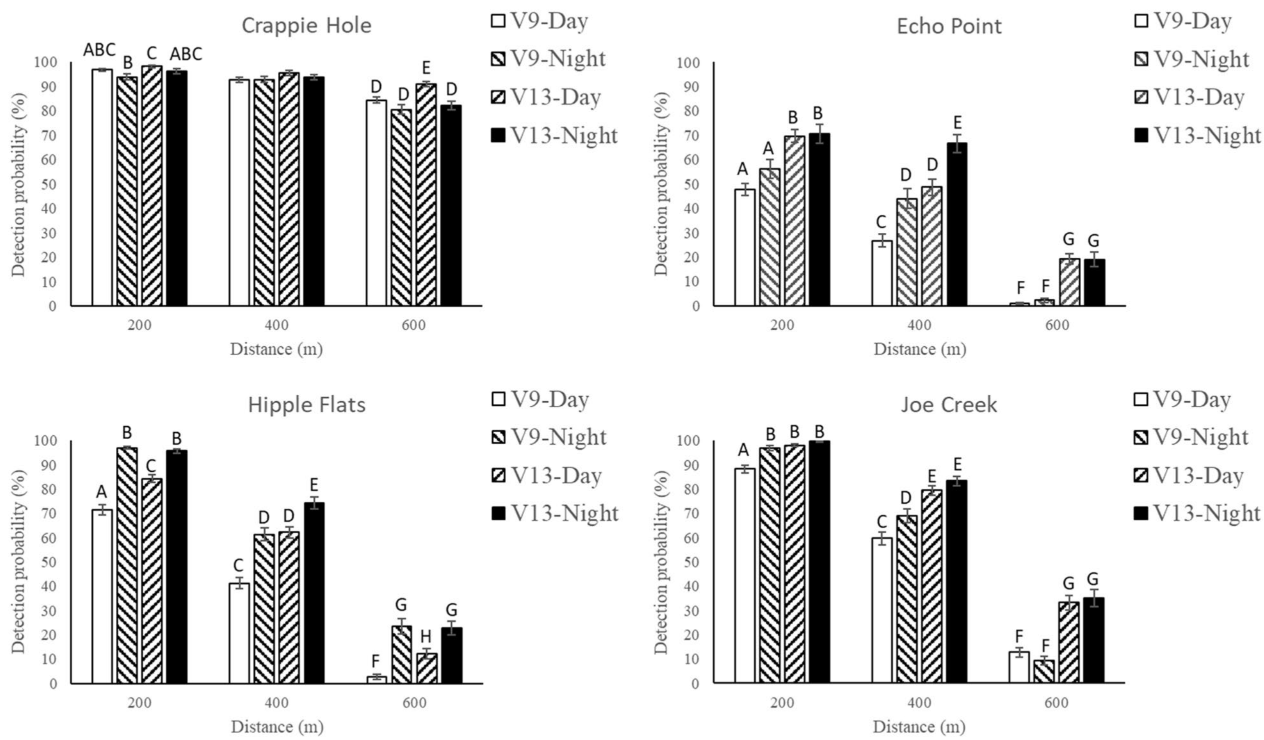

Fig. 2 Average detection probability of V9 and V13 transmitters at four locations within Lake Sharpe, South Dakota, USA. All panels represent detection probability, or the percentage of detections registered relative the transmissions sent within a 15 min analysis bin. Comparisons between tag type and time period were made within each of four locations including Crappie Hole (top left panel), Echo Point (top right panel), Hipple Flats (bottom left panel), and Joe Creek (bottom right panel). Open bars represent the V9 transmitter detections for the daytime period, forward slash bars represent the V9 transmitter detections for nighttime period, backward slash bars represent the V13 transmitter detections for the daytime period, and the filled bars represent the V13 transmitter detections for nighttime period. Raw detection percentages were arcsine square root transformed and compared using ANOVA. Letter groupings within a test distance that contain different letters represent significantly different average detection range ($P < 0.05$). Test statistics can be found in Table 2

and V13 transmitters (Fig. 2). Interestingly, within the day or nighttime periods, detection probability was relative stable at fixed differences as evidenced by the low measures of variation (standard error) reported during these sampling windows (Fig. 2).

Discussion

We found significant differences in detection probability in different habitat types throughout Lake Sharpe, South Dakota. In short, embayments protected from wind and wave action, and with low boating use, had higher detection ranges compared to areas that were wind exposed and exhibit higher boating use. Of particular significance was the poor detection range at a location immediately downstream of a large hydropower facility (Oahe Dam). The SDGFP has identified several instances of escapement of freshwater fishes through large Missouri River mainstem hydroelectric dams [8, 9]. Future fish escapement work using acoustic–telemetry systems with passive receivers should consider the reduced detection probability when determining receiver site selection below this hydroelectric facility. Our results suggest that receivers should be placed at a maximum of 200 m apart to secure a 50% detection probability of transmitters in this location.

Wind and wave action is known to mix air bubbles into the water which can attenuate sounds by scattering and absorption which can impede sound waves [10]. In the Bure River, wind speed was a significant factor impacting detection probability of fixed acoustic tags [11]. Approximately 27 km offshore of the Belgian coast, wind speed negatively influenced detection probability at further distances between receiver and fixed transmitter, but this influence was less apparent at closer distances [12]. In the Jarvis Bay Marine Park off the coast of New South Wales, up to a 15% reduction in detection efficiency was associated with increasing wind speeds [13]. Similarly, we found the greatest detection probability in the most wind protected habitat types. The Crappie Hole exhibited the greatest detection probability at all distances and is the most protected from wind and wave action and was located in an area closed to motorboats (both recreational and angling).

We found substantially greater detection probability at night compared to during the day. These differences were most pronounced in areas of higher boat traffic and less protection from wind and wave action. Conversely, the Crappie Hole is closed to recreational boating use and this site showed no diel differences in detection probabilities. This is like detection probability estimates in Lake Skrukkebukta in Norway that observed a 4–15% increase in detection probability at night compared to during the day [14]. In some marine systems, detection probability can be higher at night or during the day but depends on the specific location being assessed [13, 15]. In South Australia, detection probability was higher for acoustic transmitters during the day compared to night as nocturnally active crustaceans increase biological noise during the nighttime hours subsequently causing interference with acoustic transmitters [16]. Thus, factors that influence detection probability can be very site specific and needs to be addressed using range testing, since many fish exhibit differing diel activity patterns that may be mis-interpreted as detection probability often exhibits differences diurnally [17].

All four of the South Dakota Missouri River impoundments freeze (surface ice) in the winter and routinely hit 27 ℃ (surface temperature) in the late summer. We performed all range tests in May and June as water temperatures in the reservoir are warming but still well below their temperature maximum [18]. Detection probability has shown to decrease with increasing water temperatures [11] thus, care must be taken when applying the current detection probabilities to time periods when the lake is warmer as the detection probability is likely reduced during these times. We also conducted these experiments prior to establishment of a thermocline in the water column which has also been shown to impede sound waves [4, 14]. Though Lake Sharpe rarely experiences a thermocline [18], other systems should evaluate specific receiver locations before and after development of a thermocline. Our range tests took place prior to growth of dense aquatic vegetation. In general, Lake Sharpe only witnesses dense macrophyte growth in the backwater habitats of Lake Sharpe. However, these areas correspond to two of the sites in which we documented the high range detection distances (Crappie Hole, Hipple Flats). This is important as dense macrophytes can decrease acoustic telemetry detection probability and ranges [19, 20]; thus, future work should describe detection probability in late summer and early fall when aquatic macrophytes have become established in these habitats.

Conclusions

There is still much to learn about detection probability of acoustic telemetry systems. Various methods have been used to define detection range and the most supported definition derived from Kessel et al. [2] states "The relationship between detection probability and the distance between the receiver and tag". Using the current results, SDGFP defined an adequate detection range of the distance at which 50% detection probability was achieved. Thus, SDGFP has modified receiver arrays to maximize the ability to detect fish in the novel habitats of Lake Sharpe. Specifically, receivers in habitats such as Echo Point (riverine habitats) were placed closer together (approximately 400 m apart to capture 50% detection probability), while receivers placed in backwater protected bays could be spaced over 600 m apart (such as Hipple Flats). More work is needed to further identify specific mechanisms that dictate differences in detection probability so that researchers can better account for detection probability in future acoustic telemetry studies.

Methods

We selected four locations within Lake Sharpe, in central South Dakota to examine acoustic passive receiver detection probability. Sites were selected based on spatial relevance to future fisheries telemetry studies and included Echo Point, Crappie Hole, Hipple Flats, and Joe Creek (Fig. 3). The Echo Point site can be characterized as a riverine site roughly 4 km downstream from Oahe Dam. It exhibits swift current, changing bottom morphology, is shallow at less than 3 m, and has moderate to high boating use. Water depth and velocity at Echo Point change frequently and are dictated by hydropower demand from Oahe Dam. It is not uncommon for discharge from Oahe Dam to change by as much as 30% within a matter of hours as energy demand dictates. The Crappie Hole is a site within a reservoir embayment called Hipple Lake and this site is furthest from the mouth of the bay. It exhibits no flow, is protected from wind and wave action on 3 sides, and is moderately deep at 3 to 5 m. The Crappie Hole is unique as it sits within an area closed to the recreational use of motorized vessels. Thus, acoustic interference from boat motors or depth sounders is assumed to be limited. The Hipple Flats site is located within the same embayment as the Crappie Hole location; however, it is close to the mouth of the embayment. The site can be characterized by minimal flow, moderate protection from wind, shallow water at less than 2 m, moderate submergent vegetation, but has high boater use (both recreational and angling). Joe Creek is located further downstream on Lake Sharpe and is considered a main reservoir site. Joe Creek is a deep bay (approximately

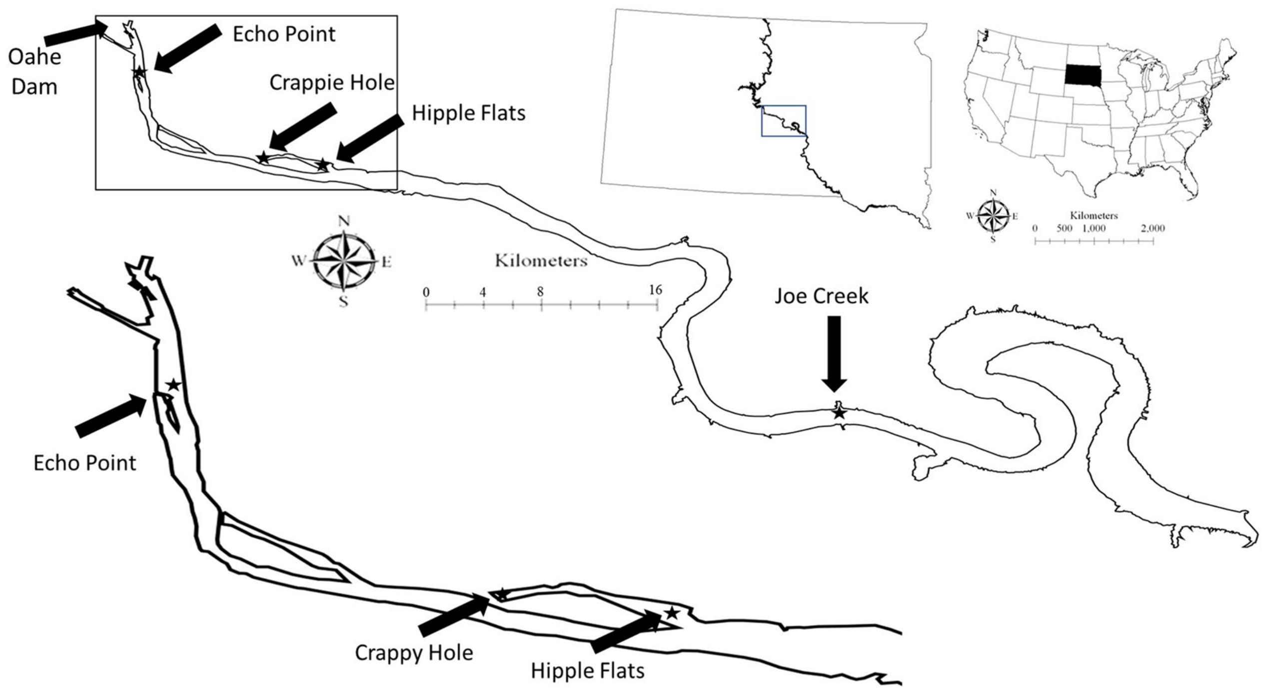

Fig. 3 Depiction of Lake Sharpe in central South Dakota, USA. The four sites selected for detection range determination included Echo Point, Crappie Hole, Hipple Flats, and Joe Creek and are denoted with a star

10 m) with no water velocity and moderate boating activity.

In May and June, Innovasea (Vemco) range test transmitters were used to assess detection probabilities at each site in Lake Sharpe. The size and power output of range test transmitters were selected based on use in future fish movement studies. Specifically, we examined detection range of V9-2H transmitters with a power output of 151 dB and V13-1L transmitters with a power output of 147 dB. All transmitters were set for a fixed 60 s delay. We used Innovasea (Vemco) VR2W 69 kHz passive receivers to register the transmitter signals. Receivers were placed on a metal stand on the bottom of the reservoir set approximately 1 m above the sediment (Fig. 4). Both transmitters were hung simultaneously from a weighted and buoyed line with the transmitters suspended approximately 1 m below the water surface. We used the "single tag placement at varying distances from a fixed receiver" method as this approach provides a robust technique to evaluate detection probability [2]. The transmitters were placed 200, 400, or 600 m from the receivers for approximately 2–3 days at a random orientation from the receiver. However, in some cases, distances from the transmitter to the receiver was greater than the distance from receiver to shore. In those instances, transmitters were placed non-randomly, in an unimpeded direction (i.e., open line of sight), within the deepest part of the reservoir. Daylight hours were fixed at 7 am to 9 pm and night hours were fixed from 9 pm to 7 am. The first and last hour of detections when transmitters were deployed or retrieved was omitted to avoid interference caused by the research vessel.

Fig. 4 Depiction of three acoustic receivers attached to their constructed bases used for telemetry studies on Lake Sharpe in central South Dakota, USA

Detection probability provides a detailed account of the likelihood of a receiver registering a defined number of detections within a course of time and has been used by many researchers to assess detection range within acoustic systems [21, 22]. We defined detection probability as the percent of detections registered within a specified time bin (15 min). Detection probability is of particular interest to SDGFP as future fish telemetry studies on Lake Sharpe will use a suite of arrays to track movements in and out of defined habitats. Thus, we were interested in the likelihood of a fish being registered during its movement past the array. To compare detection probability between tags, sites, daylight vs. nighttime period, and distance from transmitters, we first arcsine square root transformed the detection histories, since our data formed a binomial, rather than a normal distribution [23, 24]. We then used one-way ANOVA with a Tukey's honest significance test (TSD) to compare detection probabilities. First, we used a one-way ANOVA to compare detection probability between the four habitat types for a given tag (V9 vs. V13) at a set distance (200, 400, 600 m). We then used one-way ANOVA to compare detection probability at a single habitat type temporally (day vs. night) and for a given tag type (V9 vs. V13) and these comparisons were made for each of the study distances. Group comparisons were deemed significant at an alpha level of 0.05.

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Author contributions
All authors participated in the field, analysis, and writing of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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