Mounting Vemco Receivers to the Tail of a SUB Buoy

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Introduction

FORCE deploys C-POD instruments on SUB floats tethered to the seafloor near their tidal turbine test site. For this project, WR2W and HR2 receivers were also mounted to each SUB float. This economized on the cost of mooring instruments. Initially the WR2W and HR2 receivers were attached directly to the tail fin of the SUB float using a nylon bracket. Unfortunately, tethered SUB floats are unstable [1] so tail fins were sometimes broken and several instruments were lost.

Here we describe the installation of a mounts to accommodate a HR2 receiver and a VR2W receiver at a position just forward of the tail fins on a SUB buoy. The idea is to create a mount system that is more hydrodynamically stable and also less likely to break.

The prototype system consists of four 4”×2” (102 mm × 51 mm) box-section Aluminum mounts that fasten to the spin of the SUB buoy. Each box-section is 6” (152 mm) long and has wall thickness 3/16” (4.76 mm). Density of Al is 2700 kg/m^3 so discounting displaced water the weight of each box-section is 0.38 kg.

The four Al box sections are fastened to the spine by four 2” long 1/4” stainless steel bolts. Density of stainless steel is 7700 kg/m^3 so discounting displaced water the weight of each bolt is 0.011 kg.

The HR2 receiver is attached to two box-sections using stainless steel U-bolts (approx 400 mm long by 1/4” diameter, discounted weight $\approx$ 0.1 kg). The VR2W receiver is attached to the box-sections on the other side of the spine using a stainless steel U-bracket and a 3” long 1/4” stainless steel bolt.

Figure 1: Picture of the SUB buoy with: (1) C-POD mounted in the middle, HR2 receiver mounted infront of the right side of the tail, and VR2W receiver mounted infront of the left side of the tail.

Discounted weight of the 3” bolt is 0.016 kg. The stainless steel U-bracket is made from 5.5” long flat bar that is 1” wide and 1/8” thick. Discounted weight of the U-bracket is 0.075 kg.

Total submerged weight of the mounting assembly is approximately 1.85 kg.

Assembly

Tools

- Two 11 mm sockets (one deep, one normal)
- One extension drive (at least 4” long)
- One 11 mm ring spanner
- Two crafted wooden wedge systems

- One 3/4 inch socket
- One 3/4 inch open jaw spanner

Proceedure

Box-section Aluminum and U-bolts are used to fasten the HR2 receiver to the spine of the SUB float (Figure 2). On the other side of the spine, we attach the VR2W receiver using box-section aluminum and a stainless steel U-bracket which locks onto the nylon collar with a retaining bolt (Figure 3).

- Tightly fit the HR2 receiver with the U-bolt fastened to the lower box-section
- Loosely fit HR2 receiver with the U-bolt fastened to the upper box-section
- Loosely fit the custom, stainless U-brackets to the other box sections (which will hold the VR2W receivers).
- Place 4 bolts (with washer) through the HR2 box-sections and use the crafted wooden wedge system to hold them in place. Make sure that a longer bolt is used on the forward hole of the lower box-section.
- Place HR2 box-sections in place so that the 4 bolts go through the spine of the SUB buoy.
- Fit top box-section on the other side (will be used to mount the VR2W). Place washers (one flat, one lock) on the bolts. Use an extension bar and 11 mm socket to fit the 11 mm nuts. Remove the wooden wedge system so a small socket can be used to hold the head of the bolt. Use a 11 mm socket and extension bar to tighten the nuts via access holes in the VR2W box-section.
- Fit and fasten the lower box section for the VR2W. This will be a little more difficult than for the top box-section but the same proceedure will work for bottom as it did for top.
- Fit the VR2W with retaining bolt and mark the position of the U-brackets.

- Remove the retaining bolt and VR2W.
- Tighten U-brackets in marked position.
- Fit the VR2W's and tighten their retaining bolt.
- Fit anodes to the VR2W retaining bolts (Figure 4).

Further Thoughts

The prototype mount system has now been used through several deployment cycles. It has proved to be robust, with instruments remaining attached. Corrosion of the Al had been expected, but is not evident. Nevertheless, corrosion can be difficult to accurately assess and I recommend substituting a marine grade stainless steel for the Al.

Al box section was used for the prototype because it was inexpensive, strong, and easy to work. It was never intended as a long term solution. Indeed, box section makes mount assembley difficult.

Presently, I suggest:

1. The aluminum box-sections be replaced with stainless steel U-sections. This would make assembly more easy and would minimize possible corrosion issues for multiple/long deployments.
2. A nylon retaining clamp be made for the HR2 receivers, similar to that which we have for the VR2W receivers.

One SUB buoy was deployed with only a C-POD and HOBO G-Logger mounted to it. Instability is evident, as has been found for other seafloor-tethered SUB float installations in Minas Passage [1]. Adding small wings to the SUB float (lift) and modifying the tail are the most obvious ways in which stability might be improved. Experiments are required, because the instability of tethered SUB floats has impeded environmental monitoring in Minas Passage for more than 10 years.

Figure 2: HR2 receiver mount

Figure 3: VR2W receiver mount

Figure 4: Anode attachment points on the protruding end of the retaining bolt for mounting the VR2W receiver.

Station	Sub/C-POD	HR2	VR2W	Latitude	Longitude	# wgts
	2790	461203	110156			2-lead
	2931	461204	119153			1-lead
	2792	461196	113594			1-iron
	2793	461201	110530			2-lead
	XXXX*	—	—			0

Table 1: Mooring information for September 2018 deployments by FORCE. * Has HOBO G-Logger.

References

[1] Sanderson B.G., Buhariwalla, C., Adams, M., Broome, J., Stokesbury, M. J. W., and Redden, A. R., 2017. Quantifying Detection Range of Acoustic Tags for Probability of Fish Encountering MHK Devices. Proceedings of the 12th European Wave and Tidal Energy Conference, 27 Aug-1 Sept 2017, Cork, Ireland.

Detection Range Testing in Minas Passage
June 2018

Brian Sanderson, Mike Adams, and Mike Stokesbury

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Contents

1 Introduction

There has been, and continues to be, a substantial effort to implant acoustic tags in fish that either migrate through Minas Passage or otherwise inhabit Minas Passage and neighbouring waters. Acoustic receivers continue to be deployed at the tidal turbine test site and at the Ocean Tracking Network line in Minas Passage as well as many sites in and around Minas Basin. Such receivers detect acoustic tags which establishes the presence of individual tagged fish “somewhere near” the receiver.

There are two ways in which the location of a tagged fish can be better defined than “somewhere near”. First, if the same signal from a tagged fish is received by an appropriate array of synchronized receivers then we might calculate the position of the fish. Although this method is conceptually obvious, it is expensive and technologically demanding. A second method is to measure the probability that a signal would be detected if it was transmitted from some range. Such measurements are commonly referred to as “detection range” experiments. As things turn out, probability of detection might also depend upon environmental variables. In Minas Passage it depends strongly upon current speed, Sanderson et al. (2017) [1]. Thus, by evaluating this probability of detection for many ranges at many current speeds we might define the effective area of detection at some time when a tagged fish is detected by a receiver, as has been carefully explained by Sanderson and Redden (2016) [2].

Having achieved a useful model for the probability of detection, and thus the effective area that a receiver monitors, one is in a position to estimate the likely performance of an array of receivers for determining the position and tracks of tagged fish Sanderson et al. (2019a) [3].

Probability of detection is also the key to convert detections of tagged fish into an estimate the probability that a fish will encounter a tidal turbine. Sanderson and Redden (2016) [2] considered the local population of striped bass and calculated the probability of encounter with a tidal turbine. Sanderson, Redden and Stokesbury have extended the method to also obtain probability of encounter for the population of Atlantic sturgeon which regularly returns each summer to Minas Basin/Passage. Much of this work is unpublished, although results have been presented at two international meetings: European Wave and Tidal Energy Conference (EWTEC) 2017, and Environmental Interactions of Marine Renewables (EIMR) 2018. Results have also been presented to local audiances: a May 2017 workshop on Fish Population Level Effects of In-Stream Tidal Turbines at the Acadia University KC Irving Centre, and a Acadia University Biology seminar 2019.

Several matters limit the utility of range of detection and therefore limit what we can hope to say about fish-turbine encounters and fish behaviour (eg avoidance) near instream tidal turbines. Some substantial matters are:

1. Instability of tethered SUB floats in fast currents has been implicated as a major factor that

degrades performance of instruments that detect harbour porpoise vocalizations (Adams et al., 2019 [5]) and acoustic tags that have been implanted within fish (Sanderson et al., 2017 [1]). Informally, this has been a matter of concern for more than 10 years. This matter is outside the scope of the present project but we will be able to propose some ways to work around the problem.

2. Previously, most range detection measurements in Minas Passage have attached receivers and tags to tethered SUB floats [1]. It is unclear whether or not a tethered tag will accurately represent a tag carried by a fish swimming in the water column. The present project will address this question by using a drifter to suspend tags within the water column in order to measure how well they are detected by tethered receivers.

3. Previously, a few range detection measurements have used two drifters; one to suspend the tags within the water column and the other to suspend the receiver within the water column. Such measurements are few but it seemed that detection range was less corrupted by fast currents [1]. This method is made more attractive by the recent demonstration of a quasi-stable drifter trajectory in Minas Passage, Sanderson et al., (2019b) [6]. The present project will do more drifter-to-drifter range testing.

4. Most range testing in Minas Passage has focused on VEMCO 69 kHz PPM technology with a little testing of the VEMCO 180 kHz PPM technology [1]. VEMCO 170 kHz HR (high resolution) technology is a recent innovation that was designed specifically for obtaining positions and tracks of tagged animals. The present project will undertake the first detection range measurements of 170 kHz HR signals in Minas Passage.

In June 2018 we made a set of range-testing measurements. HR2 receivers and 69 kHz VR2W receivers were attached to the tail fins of SUB buoys[1] which were deployed on four moorings (W1, W2, D1, S2) within and nearby the FORCE Test site (Table 1). Unfortunately the HR2 receiver at the S2 mooring was lost because the tail fin smashed. All SUB buoys were weighted with 16 kg of ballast[2] but this may have compromised buoyancy and thus the capacity for the moored instruments to be kept clear of the bottom when current speed was high.

The range testing was done using acoustic tags that were suspended from drifters. In this way we attempted to mimic detection of tagged fish. Three types of drifter were used:

- A long-term drifter (LTD) which swept back and forth through Minas Passage, four times a day for 13 days. This quasi-stable drifter trajectory is reported more fully by Sanderson

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[1] Subsequent to the present work, Sanderson designed and built a better mount system, [4].

[2] This was done to ensure that a radio transmitting locator would have its antenna clear of the water when it was released to the surface. Subsequent to the present work, ballast weight was reduced.

Site	Time Deployed (UTC)	Latitude deg North	Longitute deg West	Depth (m)	HR2 Receiver Serial #
W1	2018-05-04 12:42:00	45.36555	-64.43530	45	461196
W2	2018-05-04 12:35:00	45.36595	-64.44342	44	461201
D1	2018-05-04 14:10:00	45.36280	-64.42325	30	461200
S2	2018-05-04 12:55:00	45.35050	-64.43002	69	461195

Table 1: Mooring positions have been corrected for ships heading and the distance from the release point to GPS receiver. Serial number is indicated for the HR2 receiver at each site. Depth is that of instrument near low tide.

et al., [6, 8]. Presently we are concerned with the many passes that the LTD made over the OTN line. The LTD suspended a 69 kHz PPM tag (ID 32335, transmitting every 30-90 s) and a HR tag (ID 61956) that transmitted both 180 kHz PPM (25-35 s) and 170 kHz HR (1-2 s). Tags were tied to a thin line with a small weight[3] which detached at some unknown time during the drift. Nevertheless, the tags remained in the water but tangled with the drogue at about 5-6 m depth.

- A range-test drifter (RTD) suspended a 69 kHz PPM tag (ID 32337) at 19 m as well as an HR tag (ID 61957) at 20 m that transmitted both 180 kHz PPM (25-35 s) and 170 kHz HR (1-2 s). The range test drifter also suspended a HR2 receiver 461250 (TAG ID 170-1802-62250) at 17 m below sea surface.
- A line was suspended from the drifting boat (boat line, BL) which held:
  - HR2 receiver 461205 (Tag ID 170-1802-62205) at 17 m below sea surface
  - 69 kHz VR2W receiver 113694 at 16 m below sea surface
  - 69 kHz VR2W receiver 105999 at 15 m below sea surface
  - 1239 icListen at 18.5 m below sea surface
  - 180/170 kHz tag ID 61986, 1249587 at 20 m below sea surface

Using these various transmitters and receivers, we were able to investigate tag detection (69 kHz PPM, 180 kHz PPM, 170 kHz HR) along paths that went from drifter to mooring as well as between drifters.

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[3] In order to undertake these measurements we had to comply with FORCE. Our original plan was to use a robust rope and also deploy a Vemco receiver with the tags. Shifting to a thin line amounted to abandoning a reliable technology for untested technology which resulted in poor performance.

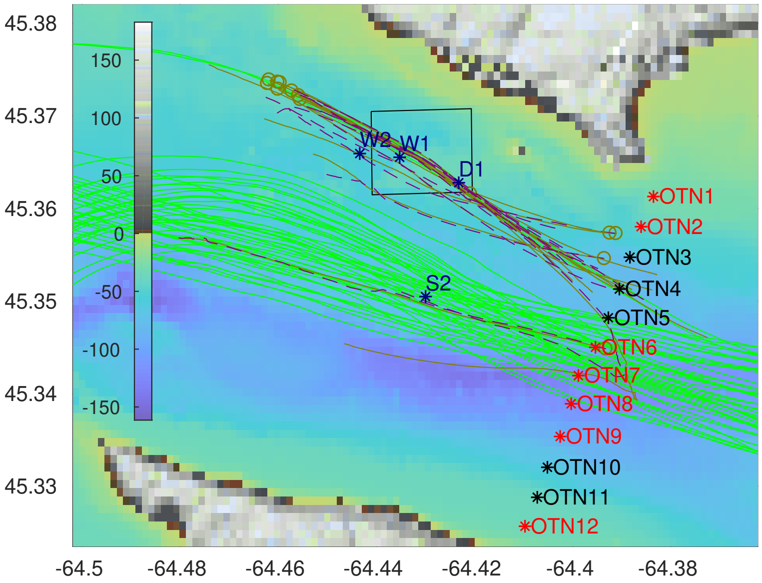

Figure 1: Layout of receivers and nearby tracks of drifters: LTD (green), RTD (brown), boat-line (dashed magenta). Data were not recovered from the VR2W180 kHz receivers at the OTN moorings which are colored red.

Given that the moored HR2 receivers also transmit, we also have the option of measuring mooring to drifter paths. Those measurements are not presently analyzed.

The Ocean Tracking Network (OTN) has a line of VR2W-180 kHz PPM receivers deployed across Minas Passage, to the east of the FORCE test site. Detection of 180 kHz PPM signals by OTN receivers will also be examined. Figure 1 presents an overview of the experiment. Unfortunately, many of the OTN receivers failed to provide data.

The icListenHF hydrophone enables detailed analysis of individual signals. This has not been been presently done but the data are available. Such analysis would be desirable for better nailing down the various mechanisms that influence signal reception.

2 Results from the long Term Drifter (LTD)

2.1 LTD and W1,W2,D1,S2 moorings

Figure 2 shows that the LTD passed nearby the S2 mooring many times and swept close to the W2, W1, D1 moorings during two flood tides. Unfortunately the HR2 receiver was not recovered from S2 so we cannot say whether or not the 180/170 tag signals might have been detected at that site.

Amazingly, the 69 kHz PPM signals were **not detected** at the S2 site. Indeed, there was only one detection by moored receivers of the 69 kHz PPM tag on the LTD, and that was at D1 on 12-Jun-2018 13:30:57 (Figure 3). Perhaps significant, the D1 mooring is the most shallow site

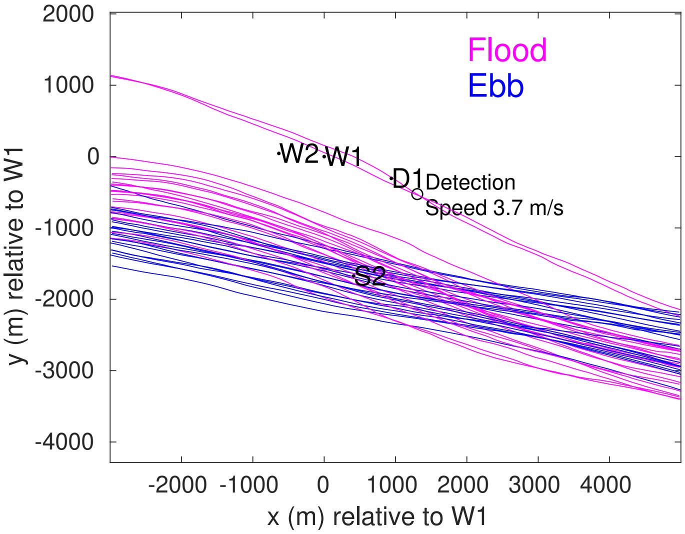

Figure 2: Paths of the long term drifter (LTD) relative to the locations at which receivers were moored.

with instrument depth at 30 m at low tide (Table 1). It should be noted that the 69 kHz PPM tag on the range test drifter (RTD) was also not detected at S2. Yet the S2 mooring did detect other 69 kHz PPM tags (Figure 2) that were present when current speed was low, most often at high tide.

The current speed was always greater than 3 m/s when the LTD passed over S2 and so this was, undoubtably, a significant factor for poor performance — although the mechanism has not been unambigously determined. Another factor was the loss of a small weight which was supposed to hold the tags well below the level of the drifters drogue. Without the weight, the tag line tangled with the drogue and the tag was much nearer the sea surface. Signal reflection from the sea surface (and perhaps the drogue) may have degraded performance. It should be noted that S2 was the deepest mooring (69 m) and so this increased range from tag to receiver.

2.2 LTD and OTN moorings

The LTD made many passes over the OTN line (green lines in Figure 1) but most passes were over stations OTN6-8 from which detection data were not recovered. Nevertheless, there were a few trajectories that passed close by OTN4 and OTN5 where the VR2W180 kHz receivers were recovered. The LTD was within 100 m of OTN4 for a total of 112 s (during which average LTD speed was 3.2 m/s) and there was 1 detection of the 180 kHz PPM tag. The LTD was within 100 m of OTN5 for a total of 200 s but there were no detections of the 180 kHz PPM tag. LTD speed was a little higher (3.7 m/s) when passing near the OTN5 mooring. Also, the OTN5 mooring was found to be "lost" at during the recovery effort (20 Nov 2018), with the receiver being recovered from the beach at Kingsport and last available detection listed as being on 9 Oct 2018. It is

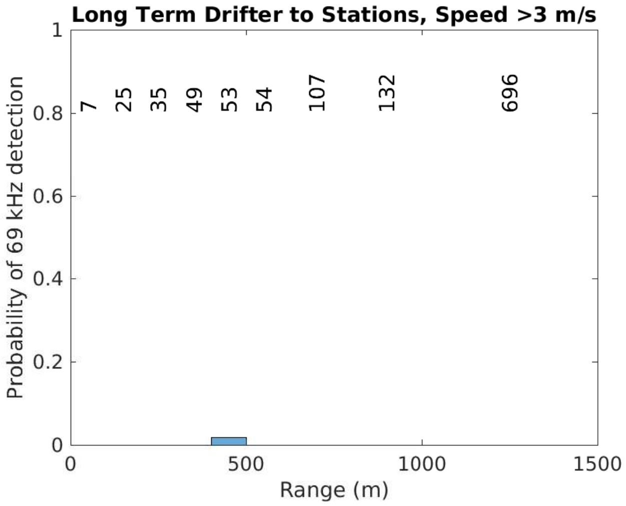

Figure 3: Probability of moored receivers detecting 69 kHz PPM signals from the LTD when current speed is greater than 3 m/s. There was only 1 detection, at D1 (depth 30 m). Here the range is only the horizontal component of the distance from drifter to mooring. Numbers on the plot indicate the expected number of detections given perfect signal transmission.

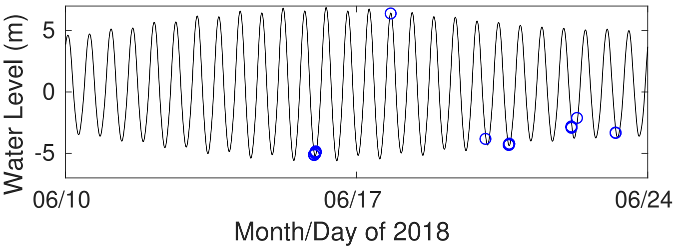

Figure 4: Detections of 69 kHz PPM tags at S2 during the period of time that the LTD was operating. Note, most of these detections are of tagged fish that probably spend most of the tidal cycle in Minas Basin but are displaced by the ebb tide so that they are at S2 at low tide. In one instance, a tagged fish that would be mostly in Minas Channel is displaced to S2 at high tide.

possible (although probably unlikely) that the OTN5 mooring had failed before our June drifter experiments. The LTD 180 kHz PPM tag transmitted every 25-35 s so it seems that detection efficiency is very poor at current speeds greater than 3 m/s.

3 Range Test Drifter (RTD): PPM Signals at 69 kHz

The 69 kHz PPM signals from the RTD were detected by moored receivers (Figure 5) as well as by receivers suspended on the boat line BL (Figure 6).

When current speeds are low, moored receivers are capable of efficiently detecting 69 kHz PPM tags out to ranges of 500 m with efficiency declining but detections still obtained out to more than 1000 m (Figure 5 LEFT). At increased current speed, detection efficiency drops dramatically (Figure 5 RIGHT), although some detections are obtained at ranges of 500 m or more. These results explain, to some extent, the fish detections by moored receivers being mostly near slack water when fish are fitted with 69 kHz PPM tags (Figure 4).

In part, the poor performance of 69 kHz PPM tags in fast currents might be explained by high levels of ambient sound. But this may not be the entire story. The right panel of Figure 5 shows low detection efficiency even when the range is small, and tag signals should not be overwhelmed by ambient noise.

There is another mechanism that may cause poor PPM detection performance in fast currents. The idea of PPM tags is to code identifying information in the delay of the arrival of one pulse and arrival of the next. If the receiver is moored but the tag moves with the current, then the delay will be modified by current speed. Consider a simple example, where distances between receiver and tag are in the horizontal and the current velocity V moves the tag towards the receiver. If the delay between pulse transmissions is τ, and then the second pulse will be transmitted when the tag is a distance $V\tau$ closer to the receiver. Thus, the time lag measured by the receiver will be $\tau(1 - V/c)$ where c is the speed of sound. This can be considered to be a Doppler shift on the pulse modulation interval. A typical time interval between pulses is $\tau = 0.3$ s for PPM ecoding. At a current speed of 5 m/s, the error would be 1 ms when $\tau = 0.3$ s.

In Minas Passage it has become a common practice to attach VR2W and/or HR2 receivers to a tethered SUB buoy. Tilt measurements demonstrate that such mooring arrangements are unstable in the fast currents of Minas Passage as reported by Sanderson et al (2017) [1] and as has been measured by many others who work in Minas Passage. Indeed, SUB floats have often been observed top be physically damaged in a fashion that is consistent with instabilities causing them to crash violently into the seafloor. Such unstable moorings suggest rapid movement of the VR2W (or HR2) receiver will cause additional error in the time interval measured between pulses — indeed, HR2 receivers were sometimes broken off the SUB floats and lost, although this has not been a problem since the mount system was revised (Sanderson 2018) [4].

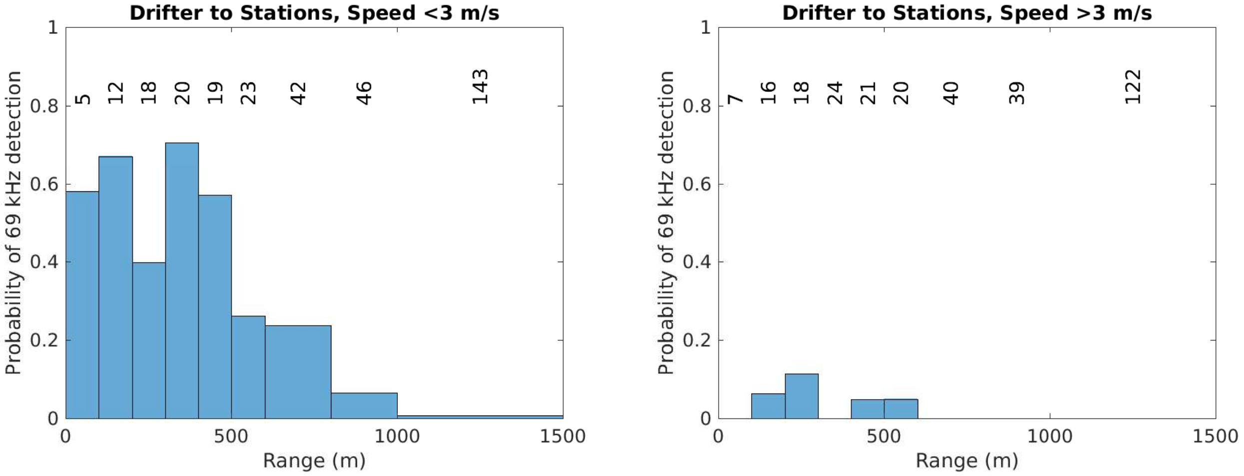

Figure 5: Probability of moored receivers detecting 69 kHz PPM signals from the range test drifter (RTD). LEFT: when current speed is less than 3 m/s. RIGHT: when current speed is more than 3 m/s. Here the range is only the horizontal component of the distance from drifter to mooring. Numbers on the plot indicate the expected number of detections given perfect signal transmission.

It is unclear what accuracy of inter-pulse interval is required for reliable signal identification/detection, but previous experience suggests that 1/1000'th of a second matters. When working in fast currents, it may be a good idea to allow a little more slop in the inter-pulse timing. Providing the inter-pulse intervals are recorded along with their detection time, one can then apply a correction for tidal velocity after the receivers are recovered. Tidal currents are very predictable. In principle it may be possible to program a correction for the Doppler effect into the receiver so that the matter can be resolved in real time.

When a drifting tag is detected by a drifting receiver (Figure 6) the detection efficiency is noticably better at low current speeds. Although we have few measurements at higher current speeds, it seems that detection efficiency is not so poorly degraded when the tag and receiver are both drifting. Doppler shift on the pulse modulation is largely avoided when both tag and receiver are moving more or less together.

There is another advantage to using receivers on drifters when measuring in fast tidal currents. The drifters largely move with the fish. Thus, a single fish is essentally tracked for a period of time, giving more detailed information about detected animals. Additionally, if there are zones of convergence and stable trajectories, then these may well be areas with more fish, and will also be areas where drifters will be swept into. On the other hand, in a given time period, more animals will be swept by a moored instrument. A fuller understanding might be achieved using both

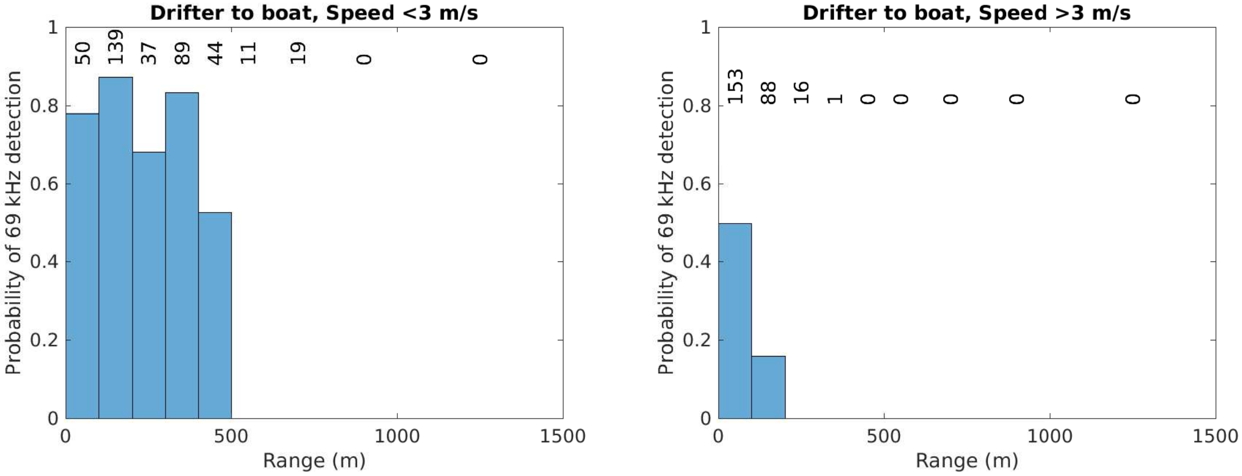

Figure 6: Probability of boat-line (BL) receivers detecting 69 kHz PPM signals from the range test drifter (RTD). LEFT: when current speed is less than 3 m/s. RIGHT: when current speed is more than 3 m/s. Here the range is only the horizontal component of the distance from drifter to mooring. Numbers on the plot indicate the expected number of detections given perfect signal transmission.

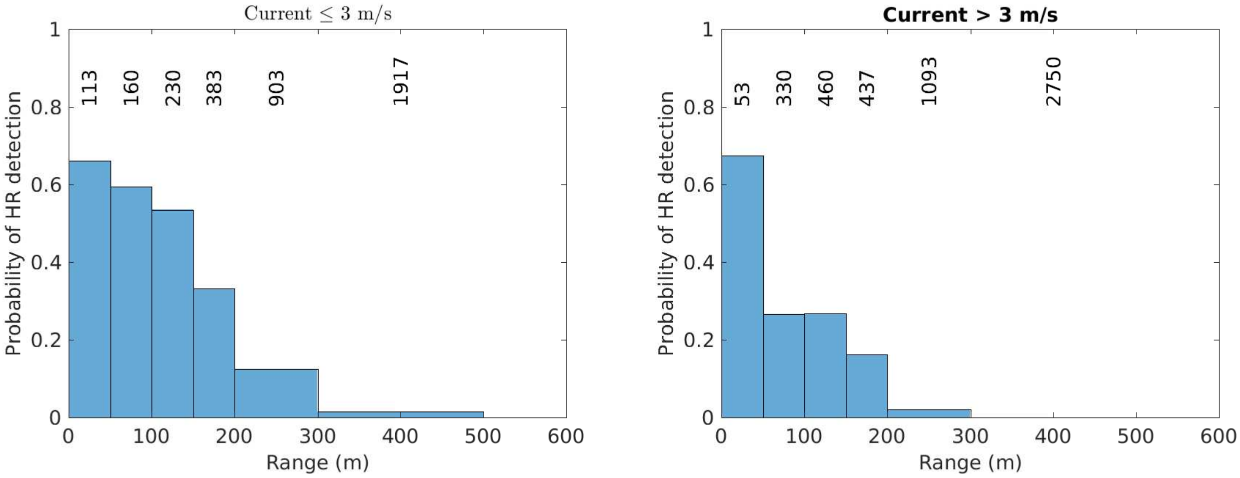

Figure 7: Probability of a 170 kHz HR signal from the RTD being detected by a moored HR2 receiver. LEFT: when current speed is less than 3 m/s. RIGHT: when current speed is more than 3 m/s. Note, range is the horizontal component of distance from RTD to the mooring.

drifters and moorings.

4 Detection of 170 kHz HR signals by Moored Receivers

The 170 kHz HR signals from the RTD and BL were detected by moored receivers. At low current speeds and short range < 200 m, the 170 kHz HR tag seems to be similarly well detected as the 69 kHz PPM tag (left panels of Figures 5 and 7). At greater ranges, when current speed is low, the 69 kHz PPM tag is better detected; probably because the 60 kHz PPM tag transmits a more powerful signal than the 170 kHz HR tag and sound absorption is greater at the higher frequency.

Probability of detection of the 170 kHz HR tag was reduced when current was fast (Figure 7) but the effect of current is not so great on 170 kHz HR signals as it is on the 69 kHz PPM signals.

The HR signals do not use period encoding, so they should be immune to the previously discussed Doppler shift on the pulse modulation. Figure 7 confirms this expectation, although our measurements are more exploratory than definitive, so additional experiments are required for confirmation.

The above results indicate that the 170 kHz HR tags/receivers stand a good chance of being able to measure tracks of tagged animals in the immediate vicinity of a tidal turbine. The HR2 receivers would have to be well clear of reflecting/obstructing infrastructure [9, 10] and the mount must be streamlined and stable [10]. Present results are only relevant to obtaining paths upstream

Site	HR #	Distance (m)	Speed (m/s)	PPM #	Distance (m)	Speed (m/s)	Ratio HR/PPM
W1	41	182	3.78	1	150	3.81	41
D1	73	97	3.91	2	60	3.79	37

Table 2: Moored receiver detections of the 170/HR and 180/PPM tag on the long term drifter LTD.

of the turbine. Our measurements say nothing about the potential for signal disruption in the turbulent downstream flow. Previous experience indicates that hydrophone performance (and therefore tracking) might be severely degraded if active acoustic devices (ADCPs and sonar) are installed on the instream turbine [11].

5 Detection of 170 kHz HR signals vs 180 kHz PPM signals

Given that tags transmit a 170 kHz HR signal every 1.5 s (on average) and the a 180 kHz PPM signal every 30 s (on average) we expect that the ratio of the number of HR to 180-PPM detections would be 20. In practice many signals are not detected because transmission is imperfect.

Receivers that detect the 170-HR signal are very much more expensive than those that detect the 180-PPM signal. This raises the practical question:

> Will a tagged fish be more likely to be detected by its 170-HR signal than by its 180-PMM signal?

Our measurements enable this question to be addressed.

First we consider tags suspended by the long term drifter (LTM) which passed by the receivers W1, W2, D1 on two occassions (Figure 2). It was not detected at W2 but it was detected at W1 and D1. Table 2 indicates that the receiver at W1 detected the 170-HR signal 41 times but only detected the 180-PPM signal once. Average drifter-receiver range and drifter speed at the times of detection are also indicated in the table. Similar results were obtained at D1. In both of these instances, either HR or PPM signals would have served to determine that “a tagged fish had passed by”. Obviously, however, the result for the PPM tag is less robust.

Second we consider tags suspended by the range-test drifter (RTD) which had trajectories that passed by the receivers W1, W2, D1 on many occassions. These trajectories passed at variable distances from the three moorings. Each row in Table 3 indicates detections at a mooring site for a single trajectory. (We do not tabulate occassions when a site did not detect either a HR or a PPM

Site	HR #	Distance (m)	Speed (m/s)	PPM #	Distance (m)	Speed (m/s)	Ratio HR/PPM
W1	20	151	3.92	0	—	—	∞
D1	28	74	4.01	1	41	4.01	28
W1	51	161	2.93	2	130	2.93	26
D1	67	122	3.06	1	76	3.14	67
D1	5	272	2.33	0	—	—	∞
W1	44	73	2.82	1	28	2.85	44
D1	46	119	3.16	2	68	3.13	23
W2	14	149	3.25	0	—	—	∞
W1	3	170	3.25	0	—	—	∞
W1	14	144	4.56	0	—	—	∞
D1	9	39	4.65	1	11	4.70	9
W1	6	113	4.63	0	—	—	∞
D1	6	77	4.93	0	—	—	∞
W1	15	134	4.48	0	—	—	∞
W1	20	150	3.85	1	141	3.86	20
D1	17	70	4.31	1	66	4.34	17
W1	107	221	2.40	2	208	2.41	54
D1	89	92	2.13	2	100	2.08	45

Table 3: Moored receiver detections of the 170/HR and 180/PPM tag on the range test drifter RTD.

signal from a drifter trajecotry.) Now it is clear that the 170-HR signal serves better than the 180-PPM signal for determining that “a tagged fish had passed by”. In part this is expected because the drifter might have moved ≈ 100 m in the ≈ 30 s between PPM transmissions. Similarly, the passage of a tag on the boatline (BL) is more likely to be registered by its 170-HR signal whereas it would be frequently missed if we were to rely only upon its 180-PPM signal (Table 4).

On the other hand, when we consider a signal path between the boat-line and the range-test drifter we obtain a quite different result. This experiment corresponds to placing a receiver on a drifter, so that it moves in the same coordinate system as a tagged fish. Now we find that for every trajectory that is detected by the 170-HR signal (ie all of them) we can be assured that the trajectory will also be detected by the 180-PPM signal. Furthermore, the ratio of HR to PPM detections is usually not greatly more than 20. Thus, the efficacy of 170-HR signals is mostly that they can be more frequently transmitted (they have less power demand) whereas a given 170-HR signal is only a little more likely to be detected than a given 180-PPM signal.

Previously we used an icListenHF mounted on a drifter to make many 180-PPM detections of a

Site	HR \#	Distance (m)	Speed (m/s)	PPM \#	Distance (m)	Speed (m/s)	Ratio HR/PPM
W2	18	185	3.26	0	—	—	∞
W1	7	109	3.24	0	—	—	∞
W1	5	102	4.39	0	—	—	∞
W1	5	139	4.74	0	—	—	∞
D1	10	90	5.04	0	—	—	∞
W1	23	157	3.98	1	153	3.98	23
D1	25	54	4.04	1	24	4.06	25
W2	6	279	2.65	0	—	—	∞
W1	130	181	2.55	4	142	2.53	33
D1	110	106	2.34	3	62	2.30	37

Table 4: Moored receiver detections of the 170-HR and 180-PPM tag on the boat line BL.

nearby tagged fish [7]. Given the existence of stable drifter trajectories through the Minas Passage [8], it is clear that mounting VR2W receivers to a drifter would be one cost-effective method to measure the movement of tagged fish within and through Minas Passage.

6 RTD 180 kHz PPM detections by the OTN VR2W180 Receivers

Figure 1 shows that sometimes the range test drifter (RTD) passed close by an OTN site from which detections might be obtained. Table 6 documents results when the RTD passed within 300 m (in the horizontal) of an OTN station. Instrument depths at OTN4 and OTN5 were nominally[4] at 86 m and 90 m, respectively. The RTD had a 170/180 kHz tag that was 20 m below the sea surface. The only time when detections were obtained was when current speed is low.

Note, the detections by OTN5 are an indication that that receiver was also likely to have been in place when the LTD passed nearby (see earlier results).

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[4] Without making adjustment for tidal elevation.

Signal Path	HR #	Distance (m)	Speed (m/s)	PPM #	Distance (m)	Speed (m/s)	Ratio HR/PPM
BL-RTD	378	52	3.87	14	60	3.90	27
BL-RTD	441	107	2.94	18	120	2.95	25
BL-RTD	1000	84	1.63	50	85	1.62	20
BL-RTD	199	136	-2.77	7	133	-2.74	28
BL-RTD	466	66	3.22	16	62	3.22	29
BL-RTD	369	29	4.54	10	29	4.51	37
BL-RTD	564	27	4.72	17	23	4.71	33
BL-RTD	168	41	4.56	3	39	4.50	56
BL-RTD	796	54	4.04	25	52	4.10	32
BL-RTD	703	165	2.30	28	156	2.37	25

Table 5: Detections of the 170-HR and 180-PPM tag on the boat-line BL (or range-test drifter RTD by a receiver on the range-test drifter RTD (or boat-line BL).

Date 2018	Drift #	Site #	Min Range (m)	Speed (m/s)	# Detections
12 June	1	OTN4	123	2.9	0
..	3	OTN5	79	1.2	6
15 June	1	OTN4	96	2.9	0
..	2	OTN3	123	3.9	0
..	2	OTN4	285	3.8	0
..	3	OTN4	27	3.5	0
..	4	OTN4	68	3.3	0
..	5	OTN4	9	3.5	0

Table 6: Detections of the 180-PPM tag on the range-test drifter RTD by a receiver on the OTN line.

Date 2018	Drift #	Site #	Min Range (m)	Speed (m/s)	# Detections
12 June	3	OTN5	47	0.9	0
15 June	1	OTN4	192	3.2	0
..	5	OTN4	49	2.9	1

Table 7: Detections of the 180-PPM tag on the boat-line by a receiver on the OTN line.

7 Boatline 180 kHz PPM detections by the OTN VR2W180 Receivers

Figure 1 shows that sometimes the boat-line BL passed close by an OTN site from which detections might be obtained. Table 7 documents results when the BL passed within 300 m (in the horizontal) of an OTN station. The BL had a 170/180 kHz tag that was 20 m below the sea surface. Only one detection was obtained, for a trajectory with minimum horizontal range of 49 m when current speed was 2.9 m/s.

8 icListenHF measurements of 69 kHz PPM tag

The experiment had a 69 kHz PPM tag on the drifter a 19 m below seasurface and the boat line had the 1239 icListenHF receiver at 18.5 m. Drifter speed and distance from the boat line were plotted and a few minutes of icListenHF measurements were selected to examine any tag signals in the time series.

In order to visualize the time series, we used a band-pass filter with linear ramps above and below 69 kHz. Note, such filtering leaves many signals other than the pulses emitted by the tag. Thus, unless ambient levels are very low, additional steps are required to find signals from the tag.

Detecting tags in a time series is difficult. One method is to examine spectrograms. Examining spectrograms is laborious. Here we will use a matched filter to find PPM signals. The 69 kHz PPM tag emitted 8 pulses, each pulse with duration 10 ms. Thus a 69 kHz sine function with pulse duration 10 ms was used as the response function for the matched filter.

Time series of the filtered signal and the matched filter are shown in Figure 8. Signal amplitude falls inversely with separation, as expected. The bottom-left plot (121 m range, 1.2 m/s) shows a signal that can be considered as the summation along two paths, with the signal arriving first by the short path, then combining signals from both short and longer paths, and finally only the signal that took the longer path. The matched filter gives an ambiguous time of arrival in this instance.

Given that the hydrophone and tag are both at about 20 m below the surface, then for a range

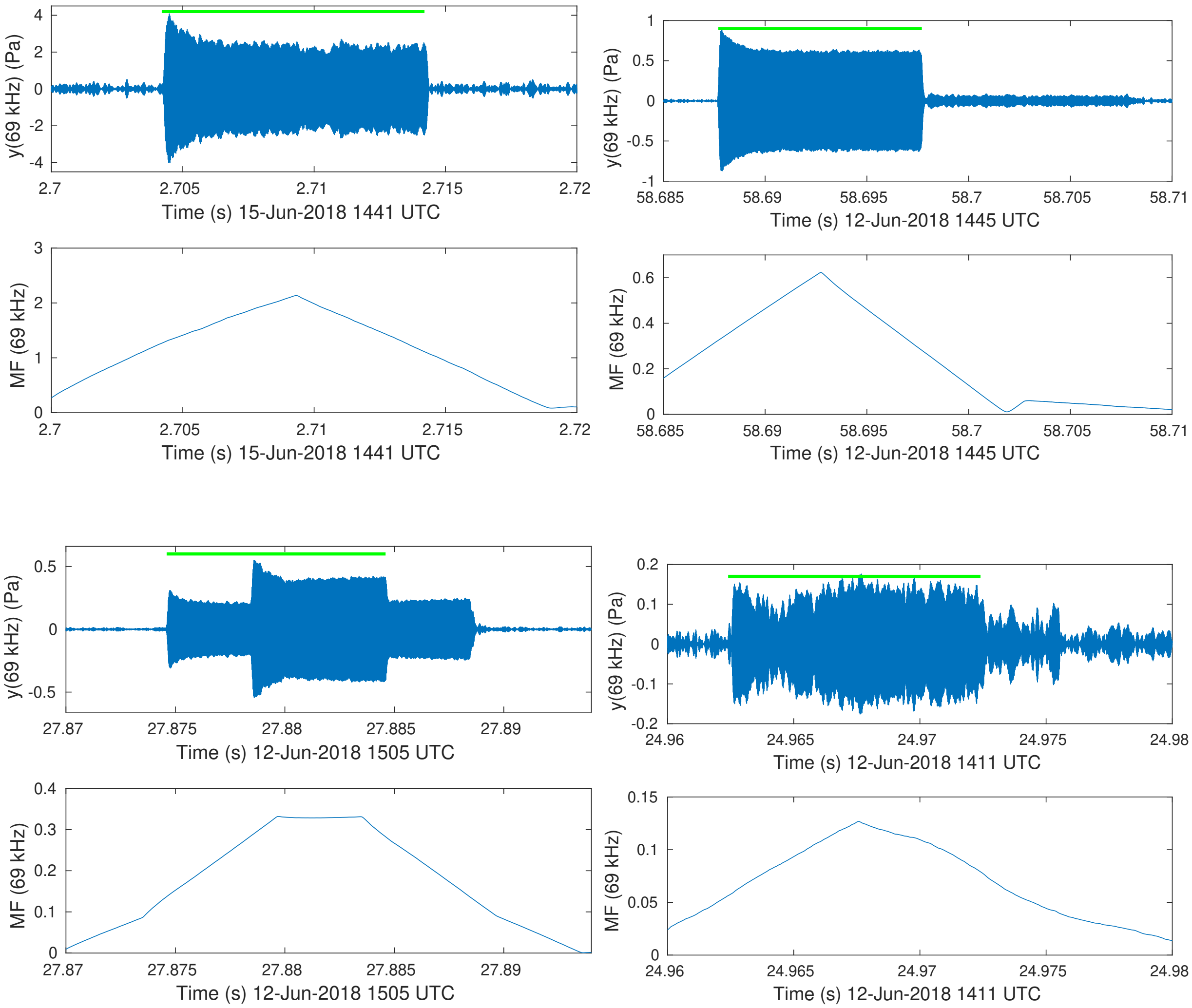

Figure 8: Four plots, each with an upper sub-plot showing the band-pass filtered signal and a lower sub-plot showing the Matched Filter (MF). The green line indicates 10 ms. TOP LEFT: 6 m separation of boat-line from drifter and current speed 4.6 m/s. TOP RIGHT: 35 m separation of boat-line from drifter and current speed 2 m/s. BOTTOM LEFT: 121 m separation of boat-line from drifter and current speed 1.2 m/s. BOTTOM RIGHT: 190 m separation of boat-line from drifter and current speed 2.9 m/s.

$r = 121$ m we can calculate the time delay $\Delta\tau$ between a direct path and reflection from the surface.

$$\Delta\tau = \frac{2\sqrt{(r/2)^2 + 20^2} - r}{c}$$

which is about 4 ms when $r = 121$ m. This time delay is less than the duration of the pulse, which introduces a few ms ambiguity in the time of signal detection. The matter is particularly concerning, because a reflected signal can be just as strong[5] as that taking the direct path. A shorter pulse would prevent the ambiguity.

A slightly longer path (190 m) in faster current (2.9 m/s) still gave a signal that was clearly detected by the matched filter (lower right of Figure 8). Now, however, we see small scintillation effects caused by small amounts of sound energy propagating by many paths.

Our range test results (Figure 5) showed poor detection performance beyond 100 m range when current was greater than 3 m/s. Clearly, multiple signal paths are a significant issue. To a good extent, multiple paths can be ameliorated by making the pulse shorter. The other major issue is the great increase of ambient sound as current speed increases. Figure 9 shows that at 59 m range the matched filter clearly demarks the 10 ms pulse but when we look to the band-passed signal we see that the noise levels are rising relative to the signal. At twice the range, the signal will be half as strong, and difficult to see. The matched filter will still finds the signal well, although the "writing is on the wall".

To improve matters, two methods are immediately brought to mind.

- Move to a higher tag frequency, where ambient sound may be less dependent upon current.
- Make the pulse duration shorter and the amplitude larger.

Opting for the former seems like a good strategy but perhaps not quite so good at the FORCE test site in Minas Passage. Sanderson et at (2017) [1] showed that the FORCE test site was unusual. At the FORCE test site, current increases ambient sound levels even as high as 180 kHz! There is no physical explanation, but that is what the (albeit limited) measurements show.

Opting for a shorter pulse with higher amplitude would seem to be a winner providing there are no intrinsic technological barriers. This is the strategy that echolocating animals have evolved. Harbour porpoises, for example, have a pulse duration of about 0.1 ms and maximum sound level 205 dB — albeit over a narrow beam.

9 icListenHF measurements of 180 kHz PPM tag

The experiment had a 180 kHz PPM tag on the drifter a 20 m below seasurface and the boat line had the 1239 icListenHF receiver at 18.5 m. Drifter speed and distance from the boat line were

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[5] Indeed, sometimes the reflected signal is stronger.

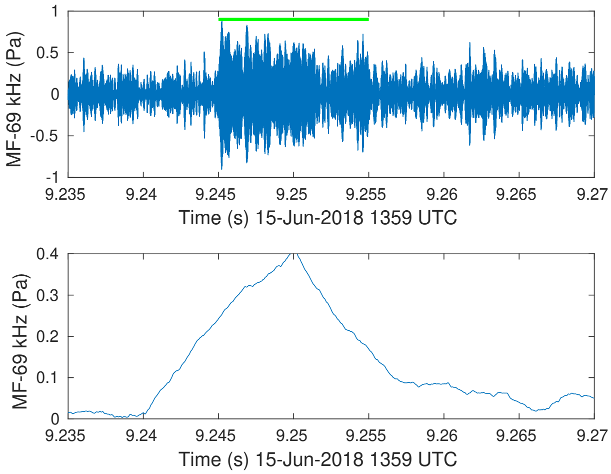

Figure 9: Upper sub-plot showing the band-pass filtered signal and lower sub-plot showing the Matched Filter (MF). A 59 m separation of boat-line from drifter and current speed 4.7 m/s.

plotted and a few minutes of icListenHF measurements were selected to examine any tag signals in the time series.

In order to visualize the time series, we used a band-pass filter with linear ramps above and below 180 kHz. Unless ambient levels are very low, additional steps are required to find signals from the tag.

Here we will use a matched filter to find PPM signals. The 180 kHz PPM tag emitted 8 pulses, each pulse with duration 4 ms. Thus a 180 kHz sine function with pulse duration 4 ms was used as the response function for the matched filter.

At short range at low current (top left of Figure 10) a relatively clean signal is detected and the matched filter appears to have a relatively unambiguous peak, so time of arrival might be accurately obtained. We see a weaker signal reflected from the surface which is well separated from the direct path, so it causes no ambiguity.

A quite different outcome is obtained when current speed is even lower but the range is greater (lower left plot of Figure 10). Now the reflected signal arrives immediately following the signal taking a direct path and, to make matters worse, the reflected signal has the greater amplitude. This causes the matched filter to have two peaks, with the larger peak being the wrong peak!

The top right plot in Figure 10) causes us to contemplate the possible effects of strong currents. Now the range is 59 m which is not so different from the 35 m range of the top left plot. Indeed, the surface reflection can be seen to be well separated from the direct path. What is notable is the fluctuations of signal amplitude which are quite evident in the signal taking a direct path

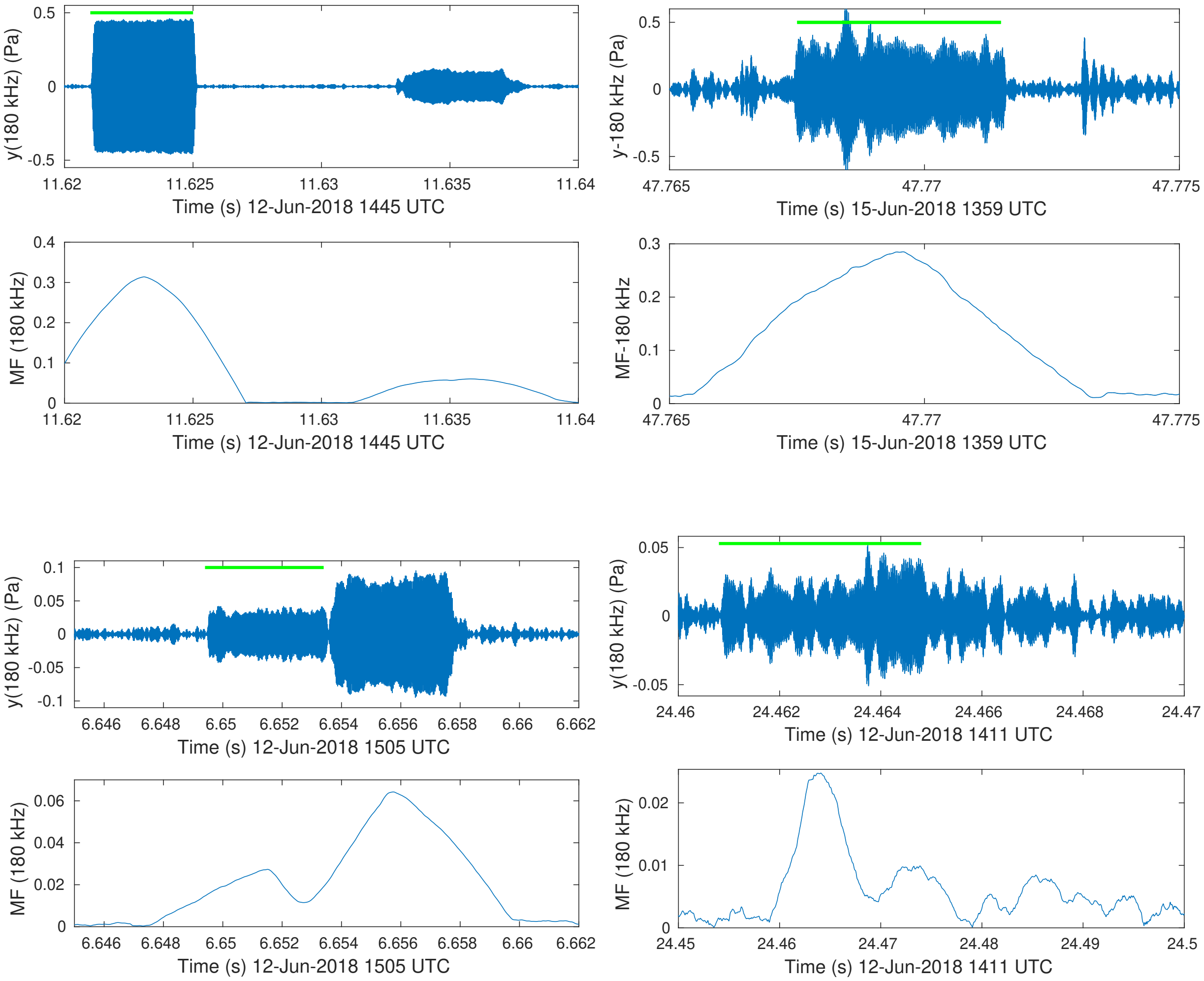

Figure 10: Four plots, each with an upper sub-plot showing the band-pass filtered signal and a lower sub-plot showing the Matched Filter (MF). The green line indicates 4 ms. TOP LEFT: 35 m separation of boat-line from drifter and current speed 2 m/s. TOP RIGHT: 59 m separation of boat-line from drifter and current speed 4.7 m/s. BOTTOM LEFT: 121 m separation of boat-line from drifter and current speed 1.2 m/s. BOTTOM RIGHT: 190 m separation of boat-line from drifter and current speed 2.9 m/s.

and extreme in the signal taking a reflected path. Two physcial mechanisms can cause these fluctuations.

1. Ambient noise associated with the stronger current.
2. Small fluctuations in travel time of nearby rays. In the present circumstances, these differences might be associated with turbulent currents. Thus, almost parallel rays arriving by the direct path will have slight phase differences. The effect will be an apparently random variation of signal amplitude. This 'twinkling effect' is also known as scintillation.

With the present measurements, it is not clear that we can definitively distinguish the above mechanisms because both ambient noise and scintillation increase with increased turbulent current. The best method to distinguish the effects would be to have a tag that transmitted with a variety of amplitudes. The effect of ambient noise becomes less evident when the tag has large amplitude whereas scintillation would be still be evident.

If ambient noise is a significant confounding mechanism, then better performance can be expected by increasing the amplitude of the signal transmitted by the tag. Given our previous reasoning for reduced pulse duration, signal amplitude could be increased without much changing the energy requirements of a tag.

10 Hydrodynamics and Receiver Sites

We have obtained multiple range test drifter tracks from well upstream of the CLA to downstream locations near the OTN (Figure 1). Averaging over flood tide drifter trajectories, we obtain an average trajectory shown by the black line in the lower panel of Figure 11. This averaged trajectory crosses the raised bathymetry of the volcanic platform in the CLA. Moving with the drifter, current speed increases across the raised platform (top panel of Figure 11). Further downstream, where the drifter approaches the OTN line, water depth increases and current speed is reduced.

Currents in the top panel of Figure 11 are obtained by differencing the averaged drifter trajectory so spatial variation of the current is illuminated but not time variation. The temporal variation during 15 July 2018 is obtained for two sites by extrapolating from tidal harmonics fitted to simulations made using a hydrodynamic model. The magenta line in Figure 12 shows current in the middle of the volcanic platform and the black line shows current at the eastern end of the averaged drifter track (not far from the OTN 4 station). Both hydrodynamic model simulations and drifter measurements confirm that flood current speeds are about 1 m/s greater on the volcanic platform than in the deeper water to the east.

Sanderson et al., (2017) [1] found that high-frequency (> 100 kHz) ambient sound levels increased more with current speed in the CLA than at other locations that we have measured

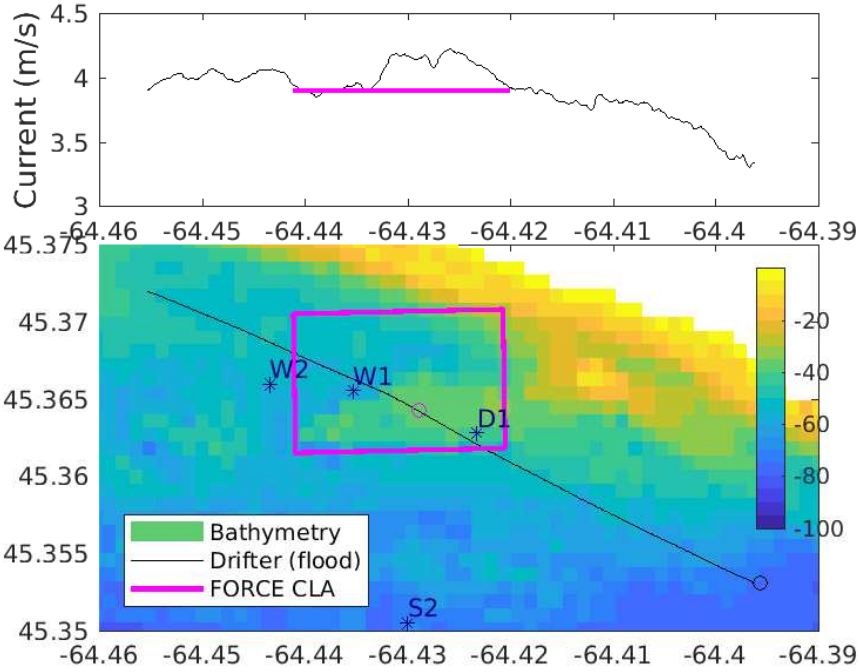

Figure 11: Averaging over 7 flood tide trajectories (12 and 15 June 2018). TOP: Current speed is obtained from the average drifter motion and plotted as a function of the latitude of along the average drifter track. BOTTOM: Average drifter track with the middle of the volcanic plateau marked with a magenta circle and the eastward end of the average drifter track marked with a black circle.

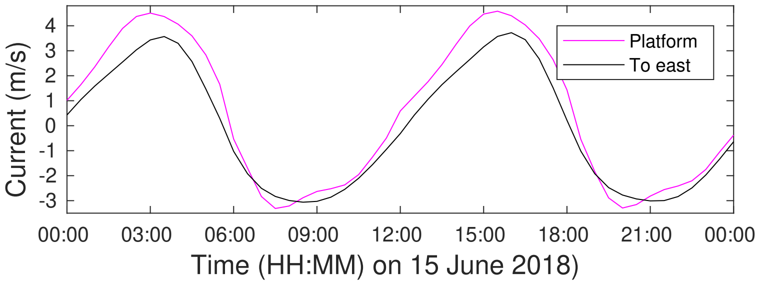

Figure 12: Currents obtained by using tidal a fit to tidal harmonics to extrapolate hydrodynamic model simulations to 15 June 2018. Magenta line shows current at the middle of the volcanic plateau. Black line shows current at the eastward end of the average drifter track.

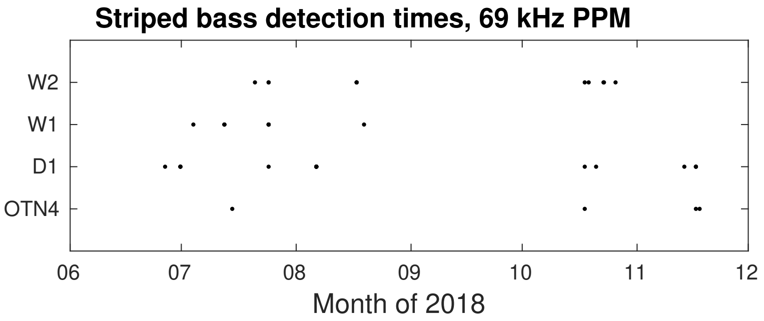

Figure 13: Times at which tagged stripped bass were detected by VR2W-69kHz PPM receivers.

in Minas Passage. Acceleration of water flow crossing the volcanic platform is likely a factor that makes it difficult to detect acoustic fish tags. Such flow acceleration is likely associated with increased turbulence, more instability of tethered SUB floats, and ambient sound levels that degrade reception of acoustic tags.

10.1 Detections at the OTN line vs CLA sites

Previously it has been found that detection of acoustic tags generally declines with increasing current speed [1]. Declining current speed as water deepens to the east of the CLA (Figure 11) might, therefore, suggest that the OTN line is better positioned to detect tagged fish that crossed the FORCE test site on the flood tide. Let us test the hypothesis that receivers at the OTN line will more efficiently detect acoustically tagged fish on the flood tide than will receivers in the CLA.

The sites W2, W1, D1, and OTN4 are along the water mass trajectory for a flood tide. Sturgeon are detected less frequently than stripped bass so detections of striped bass at those sites might test our hypothesis. Two types of tags have been implanted into fish. The 69 kHz PPM tag is the older technology and is detected using a VR2W-69kHz receiver. More recently, Vemco has created a new type of tag which can produce both 180 kHz PPM signals and 170 kHz HR signal. The OTN line has VR2W-180kHz receivers which can detect the 180 kHz PPM signal whereas the sites W2, W1, D1 have HR2 receviers which can detect both 180 kHz PPM and 170 kHz HR signals. Vemco claims that the HR2 receivers are more effective than VR2W-180kHz receivers for detecting 180 kHz PPM signals. It follows that our hypothesis can only be tested by comparing detections of 69 kHz PPM tags by the VR2W-69kHz receivers.

Figure 13 indicates times at which VR2W-69kHz receivers detected striped bass at the sites of interest when there was a strong flood tide. A flood tide is defined as being strong when the current speed was greater than 2 m/s at the middle of the volcanic platform. An animal might sometimes be detected as it passed consecutive instruments in the array but often not.

Viewing the VR2W-69kHz detections in Table 8 indicates that the OTN4 site detects fewer tagged striped bass during a strong flood tide. This directly contradicts our hypothesis. The site

Site	#69kHzPPM	#180kHzPPM	#170kHzHR
W2	11	2	38
W1	9	2	26
D1	21	14	82
OTN4	4	1	

Table 8: Striped bass detections, strong flood tide $s > 2$ m/s. From 15-Jun-2018 to 19-Nov-2018. No instruments were deployed at FORCE sites 23 August to 6 Sept 2018.

Site	#69kHzPPM	#180kHzPPM	#170kHzHR
W2	197	86	1186
W1	95	23	350
D1	112	19	167
OTN4	129	29	
OTN3	80	13	

Table 9: All striped bass detections from 15-Jun-2018 to 19-Nov-2018.

with the weakest current has fewer detections, not more. Although detection efficiency is commonly observed to decline with current speed, that decline might not be entirely due to current speed itself. Turbulence levels and entrained bubbles might be high at OTN4 which is downstream of the raised volcanic platform.

Table 9 shows all the striped bass detections, regardless of tide. There is a good deal of site-to-site variability. Site W2 obtains substantially more detections than any of the other sites and this result applies for all types of tag signal.

It is also of particular interest to compare the effectiveness of the HR2 and VR2W-180kHz receivers for detecting 180 kHz PPM signals. Here we are detecting types of receivers, so we leave W2 out of the comparison because it appears to be a site that is different from the rest. The 180 kHz PPM detections at the OTN sites are quite similar to those at W1 and D1 (Table 9) which indicates that the HR2 receiver has detection efficiency similar to the VR2W-180kHz receiver. This is not to say that the HR2 isn't a better instrument. The HR2 could well have lower self noise and be more sensitive. But when ambient levels are high, it could be the ratio of signal to ambient sound that is the determining factor for signal reception. In that case, the instrument Q-factor would be most important. Above all, we caution that the present comparisons are based upon only a small number of measurements and without instrument replication on each mooring.

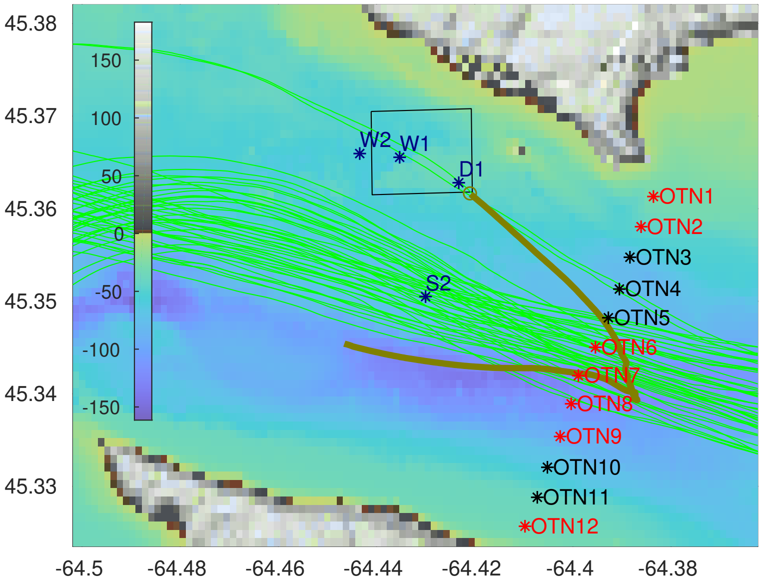

Figure 14: Thick brown line shows a trajectory of the range test drifter near the turn of the high tide (1440-1646 12-Jun-2018). Receiver locations are shown along with the LTD drifter track (green).

10.2 Cape Sharp Jet

Cape Sharp acts as a headland on the flood tide so that its associated embayment is sheltered from strong currents and has increased water level. Approaching the turn of the tide (from flood to ebb) a pressure gradient results, so that a jet of water exits the embayment near Cape Sharp and pushes southwards across Minas Passage. The effects of this jet very evident in the trajectory of the drifter shown in Figure 14 and are even more evident when observing from a small boat which is drifting within this jet. Such jet-like flow is highly turbulent and may degrade tag detection on the northern end of the OTN line near high tide.

11 Summary Points

- Bottom-tethered SUB floats are unstable in fast currents. This remains a long standing problem for many monitoring measurements. See §1, §3.
- Bottom-tethered SUB float methods for deploying instruments have undergone a variety of modifications through the years. Some changes were probably counter productive for some of the presently reported range tests. Subsequent to the range testing, improvements were made. See §1.
- A drifting 69 kHz PPM tag was well detected when current speed was low but poorly detected at current speeds above 3 m/s. This result is qualitatively consistent with previous range

detection measurements that used a moored 69 kHz PPM tag. See §3, and [1]. Support is therefore provided for the encounter probabilities obtained by Sanderson and Redden [2].

- Calculations show that fast currents might disrupt period encoding by changing the received interval between PPM pulses from that transmitted. This is a type of Doppler effect. Corrective methods are suggested. See §3.
- 170 kHz HR technology shows promise for obtaining tracks of tagged animals that are upstream and nearby to an instream tidal turbine. In particular, the range tests indicate that such tracks might be obtained even in fast currents. See §4
- IcListenHF hydrophone measurements show that reflections from the sea surface and high ambient sound levels can degrade detection of both 69 kHz PPM signals and 180 kHz PPM signals. See §8 and §9.
- A moored HR2 receiver seems to detect drifting 170 kHz HR tags a little better than drifting 180 kHz PPM tags. See §5.
- A drifting HR2 receiver detects drifting 180 kHz PPM tags with close to the same efficiency as drifting 170 kHz HR tags. See §5.
- An argument is made that in fast flowing waters it might be beneficial to reduce pulse duration of PPM tags. See §5.
- Consideration of the hydrodynamics and trajectories thrrough the FORCE test site leads us to suggest that the monitoring equipment is deployed at the most practicable sites. See §10.

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Testing HR Tags at Whiterock

Brian Sanderson, Mike Stokesbury, Mike Adams, Jessie Lilly

November 13, 2019

Contents

1 Introduction

The VEMCO HR2 receiver is a relatively new technology that can detect two types of acoustic fish tags; a 180 kHz pulse position modulation (PPM) signal and 170 kHz high resolution (HR) signals. Sanderson et al (2019) [1] presents broadband hydrophone measurements of both of these signals. The 180 kHz PPM signal consists of 8-10 pulses with pulse duration $5 - 10$ ms and uses intervals between pulses to encode tag identification and other information. The 170 kHz HR signal has pulse duration of $\approx$ 6 ms and uses about 30 abrupt phase changes within the one pulse in order to encode tag identification and other information. Nominally, a HR signal encodes the identity of a tag using an order of magnitude less energy than a PPM signal. Compared to a PPM signal, a HR signal transmits tag identity more often before the battery is depleted. VEMCO use the Fang (1990) [2] algorithm to obtain position of a transmitting tag from signal times of arrival at three HR2 receivers. The reader is referred to Smith (2013) [3] for futher details, such as synchronizing receivers.

Our previous experience with the new HR2 technology was limited. Sanderson et at (2017) [4] present probability of the 180 kHz PPM signal as a function of range and current speed in Minas Passage. No analysis of the 170 kHz HR signal was undertaken, although physical considerations suggest that one might expect similar results to those obtained for the 180 kHz PPM signal. Those measurements were made with both the receiver and the tag drifting within the water column, far from either surface or bottom boundaries. Those very preliminary results indicated some hope of obtaining paths of tag bearing fish near a tidal turbine.

For the Gaspereau River study, it was hoped that the HR2 technology might provide detailed paths for tagged fish immediately downstream of the Gaspereau dam. Such information was deemed useful for understanding how the dam and fish bypass might influence animal behaviour. A section of a river that is immediately downstream of a hydroelectric dam represents a quite different situation from that measured by Sanderson et al (2017) [4]. Before deploying an array of HR2 receivers, it was judged prudent to make a few quick measurements that might illuminate HR2 performance downstream of the dam.

On 19 March 2018 our field team[1] tested the reception of an acoustic tag by the HR receiver. Conditions were cold to the point that it was difficult to operate. Each test will be described below, along with results. Times were recorded in both UTC (HR2 receiver), and local time (icListenHF and field notes). Reporting is done in UTC. We also describe the array of HR2 receivers that was subsequently deployed downstream of the dam on 14 April 2018 and recovered late May 2018.

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[1] Mike Stokesbury, Mike Adams, Brian Sanderson, and Jessie Lilly

Figure 1: Tag positions (magenta) and an HR2 receiver position (red) at the tail race of the dam. The HR2 receiver was suspended from a long pole, about 1.5-2 m out from the wooden casing. Subsequently an icListenHF was suspended in the same way.

2 HR2 Reception in the Tail Race

The HR2 receiver was deployed off the wooden casing at the tail race. The HR2 receiver was suspended from a beam that extended about 1.5 m out from the casing. A lead weight held the HR2 receiver below the surface.

There is some randomness in the delay interval between signals. A fish tag was suspended beneath a float that was attached to a fishing line/pole. The tag (serial number 61986) emitted a PPM signal every 30 seconds (on average) and a HR signal every 1.5 seconds (on average). Reception was tested with the tag at three positions within the tail race (Figure 1):

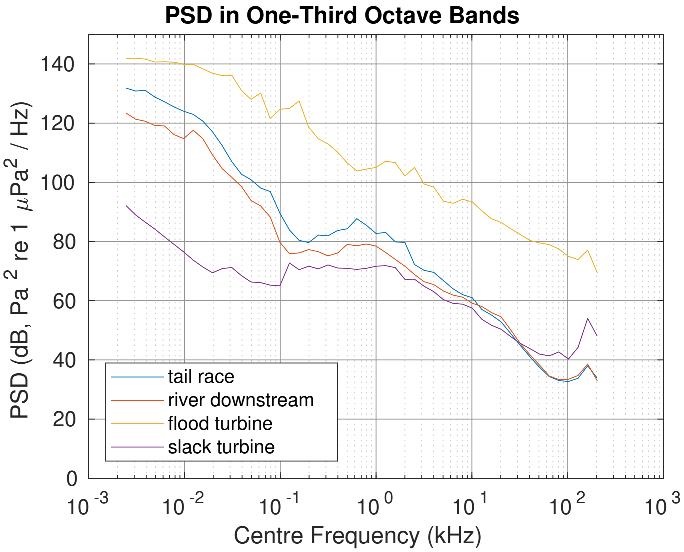

Figure 2: Power spectral density (PSD) obtained from icListenHF measurements. Blue line shows PSD in the tail race of the Gaspereau dam. Red line shows PSD further downstream of the dam. Yellow shows PSD for a flood tide (0048 UTC, 28 March 2017, icListenHF SN 1404). Magenta shows PSD near slack water at the OpenHydro turbine (0433 UTC, 28 March 2017, icListenHF SN 1404).

- From 1415-1420 UTC the tag was on the far side of the channel in extremely strong currents.
- From 1421-1425 UTC the tag was directly behind the tail race.
- From 1426-1431 UTC the tage was in the central gyre of the.

There were no detections at any of these positions. Ranges from receiver to tag were variable — from 9 m to 15 m — as estimated using the GoogleEarth ruler relative to features in the image. Neither PPM nor HR signals from the tag were recorded by the receiver.

An icListen was deployed [1450-1508 UTC] at the same location as the HR receiver. Unfortunately, we did not deploy the tag when the icListenHF was in the water. Thus it is not possible to look for the signal from the tag in the icListenHF measurements. Nevertheless, the icListenHF does give us information about ambient sound levels which may be relevant to the detection of the tag. Power Spectral Density (PSD) is shown with a blue line in Figure 2. At lower frequencies the ambient sound levels are very large in the tail race but not so at the high frequencies (170 and 180 kHz) that are used by the tag. Ambient sound levels are sufficiently high to expect some degradation of signal reception but ambient sound is not so high that it should totally prevent signal detection.

Beyond the ambient sound levels, a variety of other factors might cause the HR2 receiver to fail to detect a tag at the tail race:

- Reflective walls cause reflected signal to interfer with the signal taking a direct path.
- Bubbles in the tail race. In particular, the two fish bypass pipes generate large plumes of bubbles where they enter the tail race (Figure 1).
- Entrainment of air by the line that was used to hold the HR2 receiver and weight.

Measurements made for this quick pilot study are insufficient to rigorously evaluate all of the above factors.

River flow is stopped and levels lowered when the HR2 array is deployed. That enables receivers to be mounted on rebar driven into the bottom substrate. So there was some hope that the HR2 array would perform better than for this preliminary test where the receiver was suspended from above. It was also hoped that bubbles and ambient sound levels would be more congenial further downstream from the tail race.

3 Testing HR2 Reception Downstream in the River

Given the failure to detect signals in the tail race, there was a pressing need to measure signal detection further downstream. The HR2 receiver was deployed downstream of the tail race and latitude and longitude are marked at an adjacent point on the river bank (Figure 3). The acoustic fish tag was deployed at two distances upstream from the HR2 receiver: 22 m at first and

Figure 3: Tag and receiver positions downstream of the dam. Mike Adams waded into the water with a long pole from which was suspended the HR2 receiver and a weight. The receiver was about 3 m out from the waters edge. Subsequently the icListenHF was suspended in the same way.

Tag Distance (m)	Nominal Time HHMM	PPM detect/expect	HR detect/expect	Minutes
22	1537-1544	6/10	25/200	5
35	1545-1551	0/8	0/160	4

Table 1: Detections of the tag by the HR2 receiver downstream of the dam as shown in Figure 3. Note, times (UTC) are nominal — so measurements were only analyzed over the mid-range of the nominal interval of deployment.

later at about 35 m upstream. Distance from tag to receiver was estimated by walking a long measuring tape along the bank.

The tag was suspended beneath a float that was attached to a fishing line/pole. Using the fishing pole, Mike Stokesbury was able to keep the tag about 3+ m off the bank. The HR2 receiver was suspended by a rope from a pole and held beneath the surface by a weight. Mike Adams waded about 2 m out from the bank and so the receiver would have been about 3 m offshore.

The river bank is not natural. Rather the bank is steep and has been heavily reinforced by lining it with rock. Rock walls are considered to be reflective for signals from acoustic tags. Pulse length of the acoustic signals is about 5 ms and in that time span sound propagates about 7 m. Thus, the HR2 receivers should be deployed at least 3 m clear of the bank to minimize the reflected signals interfering with signals taking a direct path. Of course, reflection off the water surface is also an issue in shallow water.

Table 1 shows that only about 10% of the HR signals were detected at a range of 22 m and none at a range of 35 m. It might be hoped that signal detection would be better at smaller ranges. Unfortunately, downloading and review of the received signals is not something that could be achieved in the cold and difficult field conditions. With hindsight, it would have been useful to make measurements with the tag at a range of about 10 m. However, we had not anticipated such poor instrument performance. Even if we had, cold and the generally difficult working conditions had already stretched the field crew to the limits of endurance.

After the HR2 receiver measurements were completed, it was switched out with an icListenHF hydrophone. The icListenHF was deployed at the same downstream position as the HR2 receiver from 1601-1611 UTC. At lower frequencies the tail race was noticably more loud than at the downstream location. At the high frequencies used by fish tags, the sound levels at the downstream position were, surprisingly, not that much different from near the tail race (Figure 2).

3.1 Comparison with Sound at the CLA

Sound levels measured at the OpenHydro turbine that was deployed in the Crown Lease Area (CLA), Minas Passage have also been included on Figure 2. Near slack tide the high frequency sound levels in Minas Passage are comparable to the river — although the CLA is not so noisey for lower frequencies). During moderately strong flood tide the sound levels become very much higher at the OpenHydro turbine that was deployed in the CLA.

3.2 Sound and Detections in Minas Passage

The reader is directed to Sanderson et al (2017) [4]. That presents some 180 kHz PPM tag detection tests in which both the tag and receiver were suspended at about 20 m below the surface using drifters in Minas Passage (near the OTN line). Reception range for 180 kHz PPM signals was far better in Minas Passage than in the river even though the ambient sound levels were not much different.

Clearly, the Minas Passage measurements had clear transmission paths whereas this was probably not the case in the river. Also, tethering to a drifter that moves with the water circumvents any problems that might be caused by either mooring motion or so called "flow noise". Results of Sanderson et al [4] indicate that fast currents cause tethered SUB floats to become unstable and that this degrades detection of 69 kHz PPM acoustic tags.

4 The HR2 Array

It is possible (likely) that the integrity of signal transmission in the river is degraded by rough boundaries (both surface and bottom). The amount of bubbles in the tail race may have caused signal degradation along the transmission path.

The detection range measurements in the river were with both receiver and tag relatively close to shore. Better performance might be expected nearer the middle of the river where the water might be deeper. Also, the present range test measurements did not preclude the possibility that HR2 detection performance would be much better at shorter ranges.

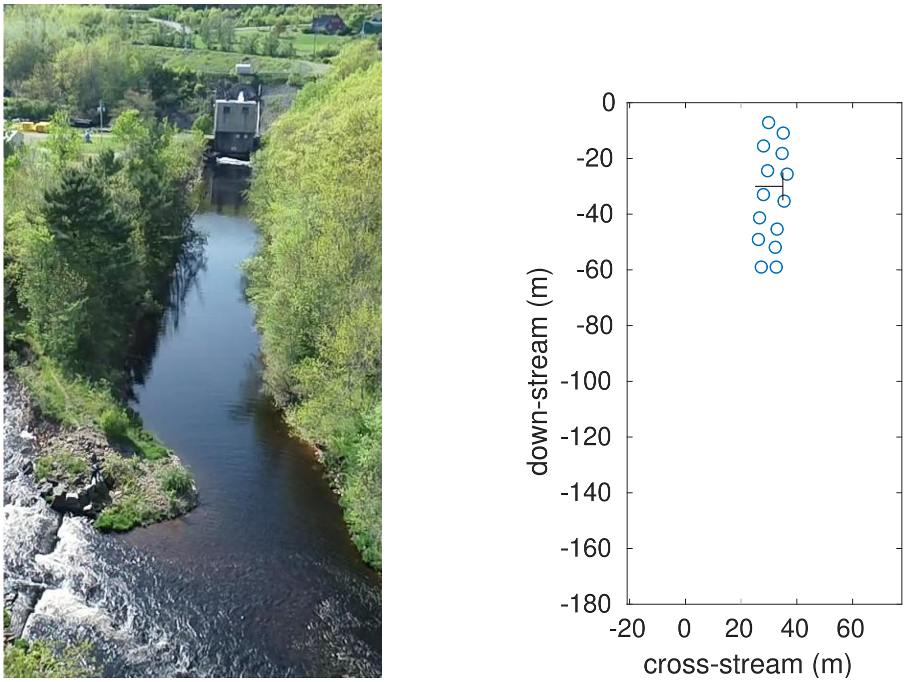

Figure 4: LEFT: Photograph looking upstream from the confluence of the bypass river to the dam. Distance from the tail race to the confluence is about 180 m. RIGHT: Positions of an array of HR2 receivers to measure position of tagged fish within 60 m downstream of the tail race. Black lines indicate a 10 m scale in both dimensions.

Our scientific objective was to measure paths taken by tagged fish after they had passed through the dam or the two bypass pipes and cleared the tail race. Ideally, we would have measured paths from the tail race to the confluence with the bypass river (left panel of Figure 4). Given the results of the above range test, it was deemed necessary to keep the spacing between HR2 receivers less than 10 m. At greater spacing (say 20 m) the probability becomes negligible that the same signal might be detected by multiple receivers. Positions used for the HR2 receiver array are indicated with blue circles in the right panel of Figure 4. The array covers the area most immediately downstream from the tail race, where it was thought most likely that fish behaviour might have been influenced by passage past dam. Receivers are close to the thalweg in order to avoid reflections from the reinforced river banks.

4.1 Limitations for determining tag position

The VEMCO Positioning System (VPS) is described by Smith (2013) [3]. It uses times of arrival of a signal at three receivers, following the method of Fang (1990) [2]. This method assumes that the vertical coordinate can be obtained from some other means. One of us (Sanderson) has carefully reviewed the algebra used by Fang, considered generalizations, and coded Fang's solution so that is can be checked in user-selected configurations. Solutions often become ambiguous for tag positions outside the triangle of receivers.

There is no need to restrict position finding to times of arrival at only three receivers. Sanderson has coded many much less restrictive algorithms for obtaining positional information from various array configurations, including that used by Sanderson et al (2019a) [5]. Algorithms by Sanderson are coded to accomodate technologies where clocks on the receivers and transmitters are synchronized as well as technologies where only the receivers are synchronized. It was hoped that detections by many receivers in the array (Figure 4) might be obtained in order to demonstrate these better methods.

4.2 Performance of the array

Only a few tagged fish were detected by receivers within the array. Unfortunately, there were no instances when the same tag signal was detected by

3 or more receivers. Thus, VPS position finding was not possible and using trajectories to study fish behaviour was not possible.

The poor performance of the array in Gaspereau River should not be extrapolated to indicate that HR2 technology will not be useful for measuring positions of tagged fish near turbines. Sanderson et al (2019a) [5] demonstrate that acoustic position finding has utility in general and Adams (in progress) has achieved even more convincing results.

In addition, we can point to two more sets of measurements which support the possibility that HR2 technology will be useful at tidal turbine installations in Grand Passage and at the Minas Passage test site.

4.2.1 Grand Passage measurements

A HR2 receiver and 180/170 kHz fish tag were deployed on the PLAT-I in Grand Passage, Sanderson et al. (2019b) [6]. This was collaboration of the present project with the Sensor Testing Research for Environmental Effects Monitoring (STREEM) project [6]. Care was taken to deploy the HR2 receiver on a streamlined, stable mount system. This mount system held the HR2 receiver so that it aligned into the flow at about 3 m depth in order to minimize problems with signal reflections. The tag was drifted at a depth of about 5 m from upstream towards the receiver.

A high proportion of both 170 kHz HR signals and 180 kHz PPM signals were received. Unfortunately, the project was terminated before further tests could be achieved using an array of HR2 receivers. We also note that our measurements were made before the turbines were installed and operating on PLAT-I.

4.2.2 Minas Passage test site

ISEM (2019) [7] deployed icListenHF hydrophones on the OpenHydro turbines installed at the Minas Passage test site. Ocean Sonics reported (ISEM 2019) [7] detection of VEMCO 69 kHz PPM tags by those hydrophones. Recently Brian Sanderson and Jillian Duggan (Ocean Sonics) revisited some of those hydrophone measurements and found that 170 kHz HR signals and 180 kHz PPM signals were also detected.

The Stokesbury team has begun an effort to further examine these hydrophone measurements and their implications for tracking tagged fish by using combinations of VEMCO technologies with Acadia University and Ocean

Sonics technologies. This work is being undertaken under a MITACS grant...

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Drifter with a VR2W-180kHz PPM Receiver,
A Pilot Study,
Sep-Oct 2019

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Jessie Lilly, Perry Comolli

November 17, 2019

Contents

Introduction

Environmental monitoring for the FORCE test site began by establishing that species of interest are found in the vicinity where instream tidal turbines might be installed. Such monitoring was achieved by mooring C-POD event detection hydrophones at the test site in order to register vocalization of marine mammals (particularly Atlantic harbour porpoise) should they be in the general vicinity [1]. A similar method was used for fish (American eel, striped bass, Atlabntic sturgeon, and Atlantic salmon) by implanting an acoustic tag in the body cavity and detecting tag signals with VEMCO receivers [2, 3, 4].

The major problem with the above methods was that it is very difficult to reliably detect such acoustic events in the fast tidal currents at the FORCE test site. Nevertheless, detections were achieved, particularly near slack water, and presence of some animals was demonstrated to an extent that warranted more quantitative assessment of how they might encounter an instream tidal turbine and perhaps avoid or otherwise interact with the turbine. To date, Acadia University researchers have got as far as measuring detection range for fish tags [5] and calculating probability that fish encounter an instream tidal turbine [6]. There have also been failed attempts to measure animal-turbine interactions by working with tidal power developers in order to mount hydrophone arrays and sonar on instream turbine platforms [7, 8].

All of the abovementioned work has deployed instruments at a fixed geographical positions in order to briefly measure any animal that tides sweep along paths that extend back and forth for 30-40 km. Furthermore, tidal power sites challenge performance of scientific instruments more than most other positions along the trajectories taken in each tidal excursion.

Acadia University researchers have recently undertaken a different approach. Using drifters as an instrument platform [9, 10], scientific instruments move with the tide so that any animal is observed over longer periods with infrastructure at a fixed geographic being briefly seen. Performance of instruments on a drifter has outstripped performance of instruments that were tethered at fixed points near sites where instream turbines have been deployed [11]. Improved instrument performance has enabled more advanced analytical methods to be developed and employed: first to obtain positional information of porpoises [12], and more recently to obtain tracks and abundance (Adams, in progress). These are key developments along the path towards measuring probability of encounter and avoidance behaviour. Obviously, the experimental and analytic methods which have been developed should also be implimented with instruments at fixed geographic positions if a complete understanding of animal-turbine behaviour is ever to be achieved.

Quasi-stable drifter trajectories in Minas Passage [9, 10, 13], and encouraging results obtained using drifters to study harbour porpoises [11, 12], have motivated the present pilot study in which a drifter is used as a platform for a VEMCO VR2W receiver in order to detect fish that carry a 180 kHz PPM acoustic tag.

Drifter Design

A drifter was constructed by mounting a power supply (stacks of D-cells) and electronic components to an ABS backing which then fits snuggly inside 1.5 inch sch 40 ABS tube. The lower end of the ABS tube is sealed with a standard end cap and the above-water end was fitted with a screw cap for access. Internal electronics consisted of an automobile 12V to 5V USB power adapter and a Tractive dog-tracker (GPS with 3G communication to shore/smart phone APP) that was used to obtain drifter position. A GlobalStar GPS/satellite tracker (ESN 1368875) was enclosed in a Maximum box and mounted externally (above the float) and set to report position every hour, as a backup system

A buoyancy unit was made by gluing together insulation styrofoam (2 inch thick). Drag was achieved using a cross vane drogue (0.6 m^2 X-section) at 6.4 m below the sea surface. The VR2W-180kHz PPM receiver was attached at 15 m depth. Three weights were distributed along the line below the VR2W, with the bottom weight at about 17.5 m below the sea surface.

Deployment and Recovery

For deployment, we launched a small research vessel from the Kingsport boat ramp at about 1.5 hours before high tide. The drifter was released near (-64.23669, 45.32488) on the 10:49 am 10 Sept 2019 high tide (13.96 m).

The drifter track could be monitored in real time using a webpage link to drifter positions reported by the Tractive. Tractive data were downloaded to a linux workstation once a day by Brian Sanderson. Positions from the GlobalStar GPS/satellite tracker were downloaded to a NOAA website at approximately 3 hour intervals and Brian Sanderson downloaded them onto the workstation after the drifter was recovered.

After drifting for 1 month, the drifter came close to shore near Halls Harbour (NS, Bay of Fundy). The drifter grounded offshore, where water was about 17 m deep at high tide.

For recovery, a small research vessel was launched at the Halls Harbour boat ramp about 2 hours before high tide. Recovery was a simple operation, with the drifter still being grounded at the same position as had been recorded since the previous low tide. The drifter was recovered before high tide on Tuesday 15 October. Although the drifter was caught on the rocky seafloor, it only required a slight tug to release from the bottom. The bottom weight was polished by contact with the seafloor. Rope attaching the weight was slightly scuffed.

Drifter Performance

The Tractive was still reading a full battery upon recovery. It has been left outside on a lawn to see how long it takes to deplete the power supply. The Tractive continues to operate at full power as this report is written.

Having a weight at depth did restrict the depth of water to which the drifter could approach shore. Thus, this seems to be a viable method for controlling drifters in complex bathymetric channels like Minas Basin. Setting the depth of the weight to somewhere near the middle of the tidal range would enable the drifter to become grounded at a point where it could be recovered without a boat at low tide — or left to float off on a new track during the next high tide. Thus drifter deployment/recovery in Minas Basin (or other macrotidal areas) could often be achieved by walking from shore.

The instruments and instrument housing system performed perfectly. Ropes were only slightly worn. A good deal of macroalgae had grown on the drifter float and the ABS tube was slippery with slime. In future, we should take samples of such growth because it may be informative about the ecology of the system and such information may also be useful for the operation of tidal power infrastructure and associated monitoring equipment.

The drogue did not have macroalgae growing on it (perhaps because light conditions were not sufficient at its depth) but it was slimy and seemed “dirty”. There may have been microalgae on the drogue. Again, in future we should take samples for identification.

Drifter Track

The drifter goes through the middle of Minas Passage most of the time, missing the FORCE CLA. Mostly mid-passage trajectories are expected from elementary considerations: conservation of mass, water being incompressible, and vertical stretching associated with flow through the deeper water in the center of Minas Passage.

Previously Sanderson *et al.* [9] had observed two quasi-steady drifter trajectories in spring/early summer. One was a more or less rectilinear back and forth motion that paralleled the coastline to the south of Halls Harbour. The other had trajectories extending from off Cape Spencer (Minas Channel), through Minas Passage and into the northwest corner of Minas Basin. This latter quasi-stable trajectory is associated with the convergence zone that was first reported almost 80 years ago [13].

The present drifter track includes quasi-stable trajectories through Minas Passage (QS1 in Figure 1) — although the small drogue on the present drifter and strong wind conditions probably account for that trajectory being less stable than when previously measured. Another set of quasi-stable trajectories (QS2) are observed in Minas Channel, extending from a little west of Cape D’Or,

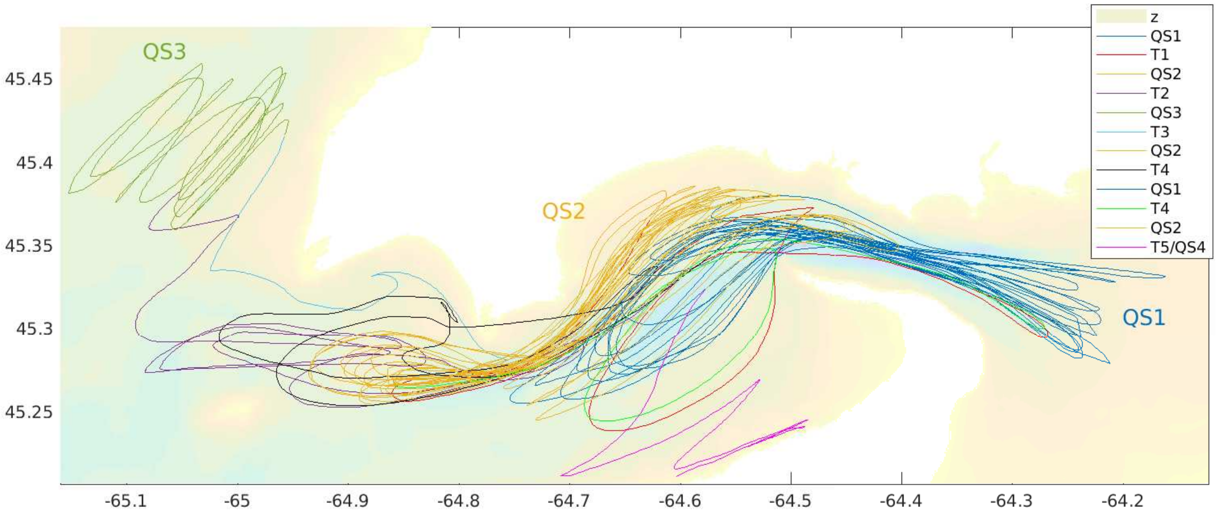

Figure 1: Drifter track, 10 Sept to 10 Oct 2019, showing transitions (T1, T2, T3, T4, T5) between quasi-stable trajectories (QS1, QS2, QS3, QS4).

into the coastal bight to a little west of Minas Passage (eg Port Greville). A quasi-stable trajectory (QS3) was observed in Chignecto Bay.

Areas with hyperbolic flows are observed between these quasi-stable zones, so abrupt transitions (T1, T2, T3, T4, T5) from one quasi-stable trajectory to another were observed. Further discussion of drifter tracks will be deferred until Professor Karsten (Acadia University) has had an opportunity to undertake model simulations.

Detection of 180kHz PPM Signals from Moored HR2

The QS1 quasi-stable trajectories through Minas Passage sometimes pass closely over the S2 site (depth 69 m) that is used by FORCE for environmental monitoring. Table 1 documents close approaches to the S2 mooring. Only two of those passes resulted in the VR2W receiver detecting 180 kHz PPM transmissions (ID number 62204) from the HR2 receiver moored to a SUB float on a 2 m riser at the S2 site. Both detections happened when current speed was low (-0.65 m/s, -1.46 m/s) on the ebb tide. Horizontal range from drifter to S2 was (284 m, -128 m) when these PPM signals were detected. There were many occasions when the drifter passes closer to S2 but the PPM signal from the HR2 was not detected. All of the passes without detection had speeds

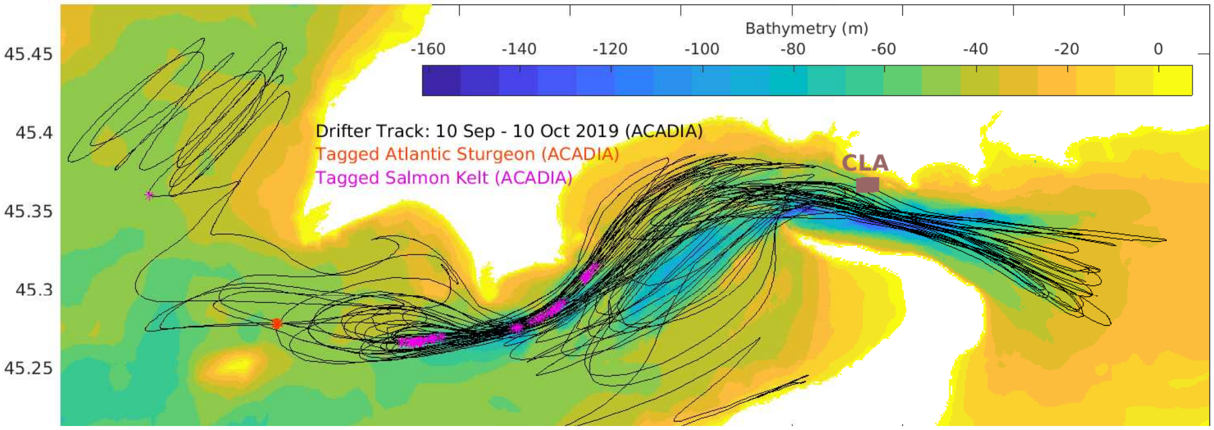

Figure 2: Drifter track, 10 Sept to 10 Oct 2019. Positions are indicated where the VR2W receiver detected fish with 180 kHz PPM tags.

with magnitude in the range 2.86 m/s to 4.1 m/s, and commonly above 3.5 m/s.

Current speed is therefore indicated as a significant factor that determines whether or not a 180 kHz PPM signal is detected when the transmitter is moored to the bottom and the receiver is drifting in a fast current. There are four mechanisms that can cause poor performance at high current speed.

- Ambient sound levels increase with increasing current speed. Thus the signal to noise ratio is degraded in fast currents.
- The HR2 receiver had a nominal delay of 20 s between 180kHz PPM transmissions. At 1 m/s, that corresponds to a transit distance of 20 m between transmissions whereas at 4 m/s it's 80 m. Thus at low current speeds there will be more transmissions within a detectable range and it is more likely that a transmission will coincide with the closest approach of the drifter.
- As current speed increases, so does the Doppler shift of the pulse modulation intervals. Thus, intervals between the pulse modulations may shift sufficiently to corrupt the coding for tag identification.
- It is a well-known fact that SUB floats become unstable in fast currents [5]. This instability adds movement to the attached instruments, causes pseudo-sound, and results in vibrations (huge vibrations when the unstable float crashes into the seafloor). Such instability exacerbates mechanisms above.

Date	HH:MM:SS	distance (m)	speed (m/s)	Detection Time
11-Sep-2019	00:07:54	252	3.4	—
12-Sep-2019	13:13:19	435	3.87	—
13-Sep-2019	02:04:03	-448	3.27	—
01-Oct-2019	16:37:50	-19.2	4.1	—
02-Oct-2019	17:06:29	69	3.78	—
03-Oct-2019	05:46:02	-487	3.72	—
03-Oct-2019	18:13:16	-545	3.58	—
04-Oct-2019	06:36:02	786	3.51	—
04-Oct-2019	19:14:47	-440	3.24	—
10-Sep-2019	17:36:21	35.8	-2.86	—
11-Sep-2019	06:10:34	-332	-3.11	—
11-Sep-2019	19:20:34	-171	-2.52	—
12-Sep-2019	07:25:27	144	-3.28	—
01-Oct-2019	08:55:55	176	-3.95	—
01-Oct-2019	21:42:01	-341	-3.58	—
02-Oct-2019	10:14:51	246	-3.71	—
02-Oct-2019	22:32:05	-264	-3.71	—
03-Oct-2019	11:15:10	-527	-3.43	—
03-Oct-2019	23:32:57	-191	-3.51	—
04-Oct-2019	11:37:58	-11.1	-3.54	—
07-Oct-2019	12:08:45	284	-0.652	12:06:53
08-Oct-2019	01:10:23	-128	-1.46	01:09:04

Table 1: When the drifter passed close to the S2 mooring. Closes approach distance is positive for a trajectory to the north and negative for a trajectory to the south. Current speed (drifter speed) is positive for flood tide and negative for ebb tide. Detection time is indicated when the VR2W-180kHz receiver picks up the PPM signal that is transmitted by the HR2 receiver at site S2.

We note that even at low current speeds, only one transmission was detected when the drifter passed the S2 mooring. In part this may be bacause the mooring is in deep water and so the slant range is long. Or it may just be that detection efficiency is generally low for the 180 kHz PPM signals. In this regard, another mechanism comes to mind:

- When the signal path has a large vertical part (generally the case for S2) we might expect that signals reflected from the seafloor could interfere with those following a direct path. Each PPM pulse has duration 4 ms (or more) and sound travels about 6 m in that time. Thus, when the HR2 is only 2 m above the seafloor, the signal reflected from the seafloor can be expected to interfere with that taking a direct path. The resulting reverberations make it difficult to accurately detect the signal taking a direct path.

Detection of a Tagged Salmon Kelt

In 2017, Acadia University researchers detected the acoustic tag of a salmon smolt in Minas Passage within the record of an icListenHF hydrophone suspended beneath a drifter [10]. Presently, our drifting VR2W receiver detected a tag 180 kHz PPM tag (50039) that had been implanted into a salmon kelt by ACADIA University in Spring 2019. The salmon kelt was released at Gasperau. This tag transmitted a PPM signal with nominal delay 12-18 s (average 15 s) and a 170 kHz HR signal with nominal delay 1.9-2.1 s. Positions at which our drifter/VR2W detected the salmon kelt are indicated with magenta asterisks in Figure 2. Four sequences of detection times were obtained.

The first sequence of detections extended from 1319:35 to 1406:34 during the flood tide on 14 Sep 2019, as documented in Table 2. There were 28 detections over a period of 47 minutes. Given an average duration of 2 s for a PPM signal and an average of 15 s between signals, that means that there would have been about 166 tag transmissions in 47 minutes. This gives a detection efficiency of about 1 out of every 6 transmissions. Current speeds are in the range 2.1-3 m/s, so the tagged kelt would drift an average distance of about 300 m between detected transmissions. The fact that the drifter moves with the water enables it to more thoroughly detect any nearby tagged fish. Obviously, this salmon kelt cannot have had a very large swimming velocity if it is detected over such a long interval of time. Movement of both drifter and kelt are largely with the water.

The above is an example of an important aspect of animal behaviour that simply could not be achieved with a geographically fixed VR2W receiver near the FORCE test site. Even if animal trajectories could be reliably measured near a turbine, they would give an incomplete understanding of avoidance behaviour if we did not know such things.

A second sequence of detections was obtained approximately 8 hours later (Table 3) when the same salmon kelt was detected 30 times during a period of 3338 seconds, from 21:52:06 to 22:47:44.

Date	HH:MM:SS	speed (m/s)
14-Sep-2019	13:19:35	2.8
14-Sep-2019	13:21:35	2.8
14-Sep-2019	13:22:06	2.8
14-Sep-2019	13:22:45	2.9
14-Sep-2019	13:27:32	2.9
14-Sep-2019	13:29:47	2.9
14-Sep-2019	13:31:04	3
14-Sep-2019	13:32:29	3
14-Sep-2019	13:33:04	3
14-Sep-2019	13:35:19	3
14-Sep-2019	13:36:29	3
14-Sep-2019	13:37:19	3
14-Sep-2019	13:37:42	3
14-Sep-2019	13:38:41	3
14-Sep-2019	13:39:07	3
14-Sep-2019	13:40:03	3
14-Sep-2019	13:40:34	3
14-Sep-2019	13:41:14	2.9
14-Sep-2019	13:43:03	2.9
14-Sep-2019	13:57:01	2.4
14-Sep-2019	13:57:27	2.4
14-Sep-2019	13:57:59	2.3
14-Sep-2019	13:58:34	2.3
14-Sep-2019	13:59:29	2.3
14-Sep-2019	14:00:34	2.3
14-Sep-2019	14:03:38	2.2
14-Sep-2019	14:04:43	2.2
14-Sep-2019	14:06:34	2.1

Table 2: First sequence of 28 detections of a salmon kelt with acoustic tag (50039).

Over that time span we might expect 196 transmissions. This corresponds to a detection efficiency of about 1 out of every 6.5 transmissions. During this second sequence, the tide was ebbing and currents were weak (less than 1 m/s).

Table 4 documents two additional days when the drifter VR2W detected the tagged salmon kelt. Presumably the drifter did not come so close to the kelt as it did previously, because there are relatively few detections. Nevertheless, it is not a huge jump of logic to suspect that the drifter and salmon kelt essentially moved with the tidal current over a 5 day period. In that time span, the drifter moved from a quasi-stable trajectory in Minas Channel to a quasi-stable trajectory in Chignecto Bay (Figure 2). So did the salmon kelt.

The fact that the salmon kelt broadly moved with the water mass, from one stable trajectory to another is of substantial importance with regards to animal-turbine interactions. If animals do avoid a turbine then this amounts to a systematic change of trajectory. In some instances such changes might remove animals to a different quasi-stable trajectory, in others not. This is an indication of how hydrodynamic modelling might be employed to examine the influence that local turbine-animal interaction have on the larger scale distribution of a population.

Detection of an Atlantic Sturgeon

An Atlantic sturgeon was detected off Advocate over a 277 s period on 19 Sep 2019 during the ebb tide (Figure 2). About 16 transmissions are expected in 277 s and 10 were detected. Thus, detection efficiency is relatively high. On the other hand, the tag was only detected for a short period of time. It may be that the drifter was moving relative to the sturgeon. This would certainly be the case if the sturgeon was just sitting on the bottom. If so, given the current speed, the relative displacement would have been 330 m in the period for which the tag was detected.

The Way Forward

This pilot study only used one VR2W receiver and was undertaken after Atlantic sturgeon had already begun their migration from Minas Basin. Weather conditions had also turned more windy. Proof of concept was demonstrated so more elaborate instrumentation might be deployed in future.

This drifter uses inexpensive consumer technology, inexpensive building materials, and is easy to construct. More substantive measurements might be achieved in future by adapting this drifter design.

An obvious application would be to parallel some of the work done with Atlantic harbour porpoises [10]. By suspending an array of HR2 receivers beneath a drifter, one obtains positions of fish carrying acoustic tags. Knowing the position relative to the drifter amounts to detections

Date	HH:MM:SS	speed (m/s)
14-Sep-2019	21:52:06	-1.1
14-Sep-2019	22:00:18	-1
14-Sep-2019	22:00:45	-1
14-Sep-2019	22:01:21	-1
14-Sep-2019	22:03:00	-1
14-Sep-2019	22:04:08	-1
14-Sep-2019	22:04:32	-1
14-Sep-2019	22:09:09	-0.99
14-Sep-2019	22:09:42	-0.98
14-Sep-2019	22:12:25	-0.94
14-Sep-2019	22:17:03	-0.89
14-Sep-2019	22:17:44	-0.89
14-Sep-2019	22:18:17	-0.89
14-Sep-2019	22:18:47	-0.89
14-Sep-2019	22:19:15	-0.88
14-Sep-2019	22:19:45	-0.88
14-Sep-2019	22:21:47	-0.88
14-Sep-2019	22:25:42	-0.85
14-Sep-2019	22:26:44	-0.84
14-Sep-2019	22:27:10	-0.83
14-Sep-2019	22:27:44	-0.82
14-Sep-2019	22:28:17	-0.82
14-Sep-2019	22:34:32	-0.73
14-Sep-2019	22:35:07	-0.72
14-Sep-2019	22:39:32	-0.67
14-Sep-2019	22:46:17	-0.61
14-Sep-2019	22:47:44	-0.6

Table 3: Second sequence of 30 detections of a salmon kelt with acoustic tag (50039).

Date	HH:MM:SS	speed (m/s)
15-Sep-2019	10:12:51	-1.1
15-Sep-2019	10:14:05	-1.1
20-Sep-2019	13:06:55	0.16
20-Sep-2019	13:07:56	0.16
20-Sep-2019	13:09:41	0.16

Table 4: Two additional days when there were detections of the salmon kelt with acoustic tag (50039).

Date	HH:MM:SS	speed (m/s)
19-Sep-2019	10:14:42	-1.2
19-Sep-2019	10:15:43	-1.2
19-Sep-2019	10:16:15	-1.2
19-Sep-2019	10:16:35	-1.2
19-Sep-2019	10:16:52	-1.2
19-Sep-2019	10:17:09	-1.2
19-Sep-2019	10:17:25	-1.2
19-Sep-2019	10:17:40	-1.2
19-Sep-2019	10:17:58	-1.2
19-Sep-2019	10:19:19	-1.2

Table 5: Detections of the Atlantic Sturgeon with acoustic tag (50115).

of tagged fish also becoming a range test experiment. It also directly enables detections of tagged animals to be interpreted as abundance of tagged animals — the primary biological quantity pertaining to fish-turbine encounters and any avoidance behaviour.

Most importantly, a drifter is a convenient platform for testing an array of receivers at a variety of locations. Instrument performance can be tested under a range of ambient conditions without potentially confounding effects, such as platform vibration and pseudo sound. Scientific experiments can be undertaken in a controlled fashion, without "fighting the current". In short, the optimal performance of instruments can be tested in the ambient sound environment of interest. Such testing should be a good starting point for advancing to placing receiver arrays on instream turbine platforms. In particular, we observe that few instream turbine platforms have been installed and *it has proved impossible to use those few platforms for successful scientific experimentation* [7, 8]. The drifter represents a convenient and inexpensive platform for the necessary testing of the scientific methods that needs to be achieved *before* arrays of HR2 receivers (and icListenHF hydrophones) are mounted to instream tidal turbine platforms for environmental monitoring.

Summary Points

- Three sets of quasi-stable trajectories are evident in the present measurements and a fourth is known from previous work.
- Areas with hyperbolic flow are indicated and the drifter was observed to switch between quasi-stable modes when it entered such areas at an appropriate stage of the tide.
- The drifter drogue was too small to enable highly accurate current tracking when wind speed is high. This likely contributed to passage out of stable trajectories. For detection of fish tags, it may be an advantage if the drifter deviates somewhat from exactly following the tidal displacement. Such deviation increases the sample volume over the long time scale.
- A drifter that approximately follows a fast-moving water mass seems to be a better platform than a mooring for detecting an acoustically tagged fish in some circumstances.
- A drifter that approximately follows a fast-moving water mass can illuminate aspects of animal behaviour that would be difficult to determine using geographically fixed instruments.
- The motion of the salmon kelt was dominated by the tidal current.
- How close the drifter approaches the high tide level can be controlled by placing the weight at an appropriate level below the sea surface. This raises the prospect of deployment and

recovery sometimes being possible without a boat. This would be very convenient when working in Minas Basin.

- The drifter provides substrate to study growth of macrophytes and microphytes.
- The Tractive dog tracker worked well and the basic drifter design seems sound, and workable.

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Windsor Causeway,
Equipment Test,
1-20 Nov 2019

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Jessie Lilly, Perry Comolli, Mike Adams

December 3, 2019

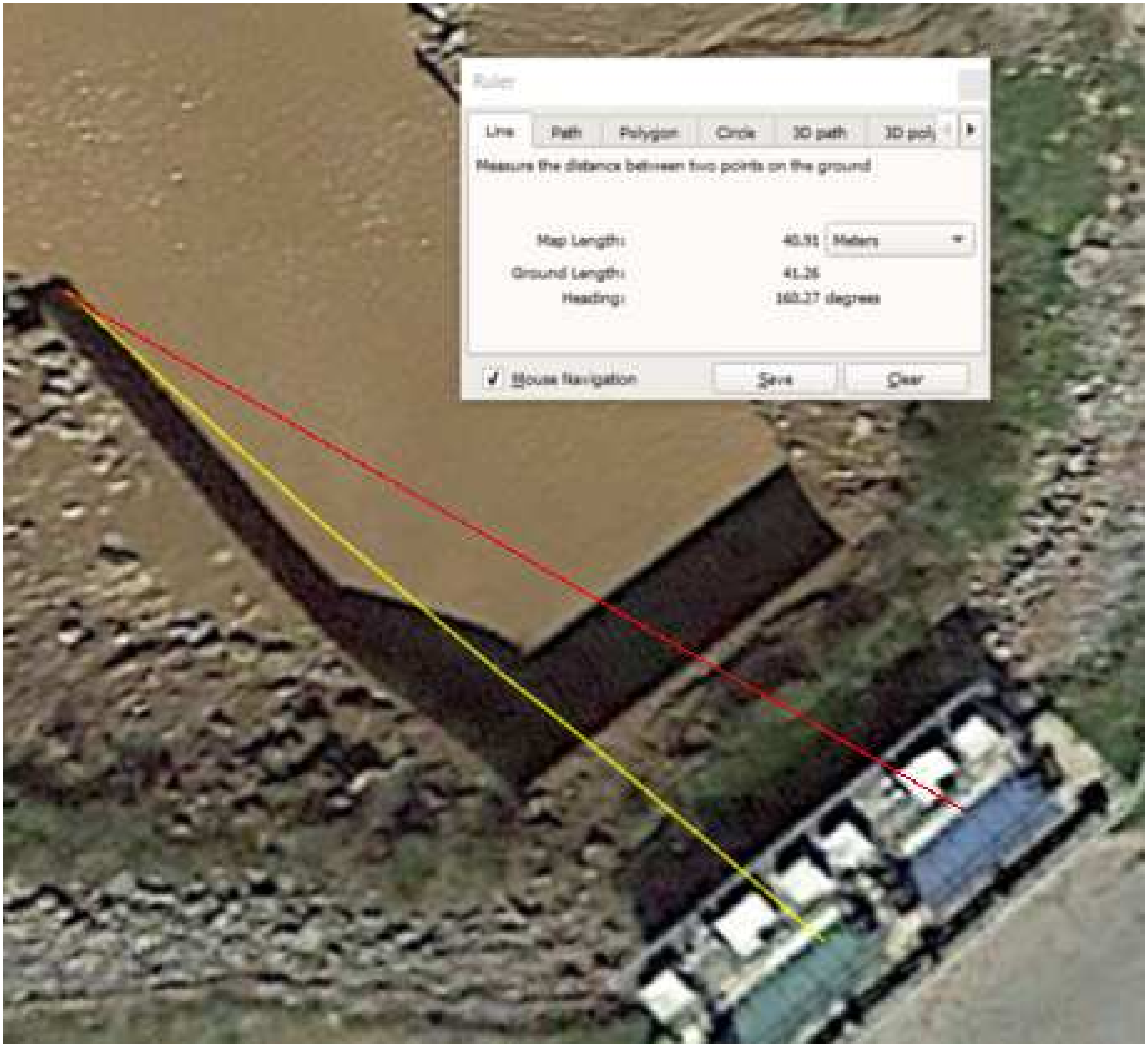
1 Introduction

Vemco 170/180 kHz acoustic tags have been implanted within the body cavities of Tomcod on the ocean side of the Windsor Causeway. The idea is to see if Tomcod frequent the area near the causway gates and whether or not they sometimes make it past the gates and into the Windsor impoundment. Thus HR2 receivers are deployed on each side of the gates. Figure 1 shows the ocean side of the gates. In particular, an objective was to measure locations of tomcod on the ocean side, immediately adjacent the gates.

Here we report detections by two HR2 receivers that were placed on ledges of the gates (Figures 2, 1). The receivers were mounted to the ocean side of the gates on or about 31 October 2019 and recovered on the morning of 20 Nov 2019. A range test tag (ID 51408) was placed on the ocean side of the gates (Figure 1) at the same time that the receivers were deployed. It was expected (hoped) that the receivers would also detect any tagged fish that approached the gates. There were also HR2 receivers deployed on the impoundment side of the gates (Table 1). The HR2 receivers transmit 170/180 kHz signals. It was hoped that receivers mounted to the ocean side of the gates would not detect signals transmitted from receivers in the impoundment.

2 Results

Tables 2 and 3 show that the test tag (ID 51408) was detected by both of the HR2 receivers that were mounted on the ocean side of the west (461247) and east (461245) gates. The tag was on the



Measure the distance between two points on the ground

Map Length: 40.91 Meters

Ground Length: 41.26

Heading: 160.27 degrees

☑ Mouse Navigation

Figure 1: View of the ocean side of the gates at the Windsor Causeway. Yellow line shows 41 m path from a range test tag (ID 51408) to the west HR2 receiver (ID 62247) The red line shows a 43 m path from the range test tag (ID 51408) to the east HR2 receiver (ID 62249).

Figure 2: Looking from the ocean at the gates to the Windsor impoundment. Near low tide, an HR2 receiver was mounted a ledge of each gate. At high tide, water rises well above the top level seen in the photograph.

HR2 Receiver: SN, ID	Latitude	Longitude
461244, 62244	44.99504	-64.14661
461245, 62245	44.99482	-64.14677
461246, 62246	44.99458	-64.14682

Table 1: HR2 receivers deployed on the impoundment side of the gates. Deployment date was 24 Oct 2019, 0950 AST.

west side of the channel so the receiver on the west gate had a more direct line to the test tag and was also slightly closer (41 m from test tag to west receiver, 43 m from test tag to east receiver). NOTE: I'M ASSUMING THIS, DOES ANYONE HAVE A RECORD OF WHICH RECEIVER WAS ON WHICH GATE?

The range test tag (ID 51408) transmited 180 kHz PPM signals from 60-120 s and 170 kHz HR signals from 2-4 s. On average, PPM signals were transmitted every 90 s and HR signals every 3 s. Thus the transmission ratio of HR signals to PPM signals is 30:1. The results in Table 2 give a received HR:PPM ratio of 6.55:1. Similarly Table 3 indicates a received HR:PPM ratio of 4.36:1. It follows that a given PPM signal is about 5.5 times more likely to be detected than a HR signal.

Our work in Minas Passage suggested that an HR signal is just as likely to be detected as a PPM signal [1]. But the Minas Passage work did not involve receivers that were closely adjacent steel gates. At the Windsor Causeway, the HR2 receivers were only a foot or so from the steel gate. In 1 ms sound travels 1.5 m in water so the reflected signals are time shifted from the direct signal by about 1/3 ms. PPM encoding utilizes the envelope of pulses with duration 6 ms, or so. For PPM encoding, the reflected signal and the direct signal have essentially the same pulse envelope, so detection is not expected to be a major issue. On the other hand, the HR2 signal uses phase shifting of 1/5 ms segments of signal and so reflections from such a nearby wall are expected to degrade reception. It seems that the test measurements bear out that expectation.

Overall, the measurement period spanned 18 days, in which time the test tag is expected to have transmitted 518400 HR signals and 17280 PPM signals. Detection efficiency is about 6-7% for 170 kHz HR and about 33-40% for 180 kHz PPM signals. Of course, for some of the time the water level below the level of the receivers so detections of the test tag (Figure 3) should be understood within that limitation. We did not measure water level, otherwise it may have been possible to measure detection efficiency as a function of water level. It is recommended that water level recorders be placed with receivers on the next servicing cycle. We can back calculate water level (to a high degree of accuracy) if such measurements are made — and thence obtain detection efficiency as a function of water level.

Although we did not measure water level, it is still possible to estimate the times when water level was sufficiently high for the test tag to be detectable. 'Detectable minutes' were defined as minutes in which a test tag signal had been detected by either of the HR2 receivers within

ID	HR	PPM	Observation
4567	2	0	unknown
7621	1	0	unknown
32218	2	0	unknown
36401	1	0	unknown
37125	1	0	unknown
37765	2	0	unknown
44717	2	0	unknown
47278	1	0	unknown
47405	1	0	unknown
48186	2	0	unknown
50037	22	3	salmon kelt
50095	9116	3419	eel
51408	39538	6033	Test Tag
51457	2704	350	tomcod
51459	102	2	tomcod
51465	9254	573	tomcod
51466	3045	176	tomcod
51474	4	0	tomcod
51478	579	34	tomcod
51479	71	3	tomcod
51482	336	11	tomcod
51582	318	78	tomcod
56979	1	0	tomcod
62245	0	159	HR2 receiver on impoundment side
62247	3	0	detected self as though it was external
62249	3	236	HR2 receiver on east gate, ocean side

Table 2: Detection by HR2-180_461247 receiver mounted on the ocean side of the west gate. Measurement period, 2019,11,1 00:00 UTC to 2019,11,20 00:00 UTC.

ID	HR	PPM	Observation
HR+PPM HR PPM 3304	1	0	unknown
13726	1	0	unknown
17759	2	0	unknown
19922	1	0	unknown
31702	1	0	unknown
33329	1	0	unknown
50037	10	5	salmon kelt
50095	8016	3571	eel
50459	1	0	unknown
51402	4	0	unknown
51408	30668	7040	Test Tag
51457	2136	460	tomcod
51459	62	4	tomcod
51465	6358	548	tomcod
51466	2259	187	tomcod
51478	353	22	tomcod
51479	58	4	tomcod
51482	166	14	tomcod
51582	480	74	tomcod
51833	0	2	tomcod
62245	0	115	HR2 receiver on impoundment side
62246	0	73	HR2 receiver on impoundment side
62247	1	265	HR2 receiver on west gate, ocean side
62249	3	0	detected self as though it was external

Table 3: Detection by HR2-180_461249 receiver mounted on the ocean side of the east gate. Measurement period, 2019,11,1 00:00 UTC to 2019,11,20 00:00 UTC.

±5 minutes (Figure 4). Calculated this way, 48% of the measurement period (18 days) was estimated to be 'detectable time'. Redefining a detectable minute as minutes with detections within ±1 minute resulted in 43% of the measurement period being 'detectable time'. Prorating for 'detectable time', the detection efficiency is about 69-83% for PPM signals.

It had been hoped that the HR2 receiver on the west gate would not detect the HR2 receiver on the east gate. To a very good approximation this turned out to be so for HR signals, with three such HR detections in Table 2 and only one in Table 3). A larger number of PPM signals were received from the adjacent receiver. The HR2 receivers transmit self PPM signals about every 5 minutes, so about 5184 would be transmitted over the measurement period. Again, water level is needed to fully interpret the results. Nevertheless, only about 5% of such PPM signals are received (265 PPM signals from receiver 461247 were detected by receiver 461249). All of these 265 detections happened at times that had been denoted above as detectable minutes (based on detections of the test tag). Thus, prorating for 'detectable minutes', the efficiency of detection was 10.7% for PPM signals transmitted by 461247 and received by 461249.

Of more concern are the receptions of HR2 receivers on the impoundment side (62245, 62246 in Figure 5) by the receivers on the ocean side of the gates. No HR signals were received in this fashion, but PPM signals were (159, 155, 73 receptions). This amounts to detection efficiencies of about 3%, again with no allowance for tide. To meet project objectives, some care will be required to judge the relative number of detections of each type of signal on each side of the gate. For example, of the 159 PPM signals (ID 62245, recevier 461245) that were detected by the receiver 461247 on the ocean side of the gate, 138 were detected during 'detectable minutes' whereas 21 were detected during minutes that were not deemed 'detectable' according to the test tag measurements. This may be physically plausible, if we consider transmission via the vibrating gate — further investigation is required.

3 Discussion

It might seem strange that PPM signals (and a few HR) seem to propagate across the thick concrete barrier that ostensibly separates the HR2 receivers ont he west and east gates. In fact, sound propagates very well from water to steel because steel has relatively high acoustic impedance. (Similarly sound propagates well from air to water.) Once in the steel, sound will swiftly travel wherever the steel may lead. If both steel gates are connected by a steel guide post, it seems likely that there is a conduit for sound. Sound does not propagate will from steel to water, but even marginal propagation will do the trick when the receiver is sufficiently close to the steel gate.

A simple physical model can be considered to explain the fact that a sound wave propagating in a steel plate will have an associated sound wave propagating in the water within which the steel is immersed. Density of steel is about $\rho_s = 7700$ kg/m^3 and that of water is about $\rho = 1000$ kg/m^3.

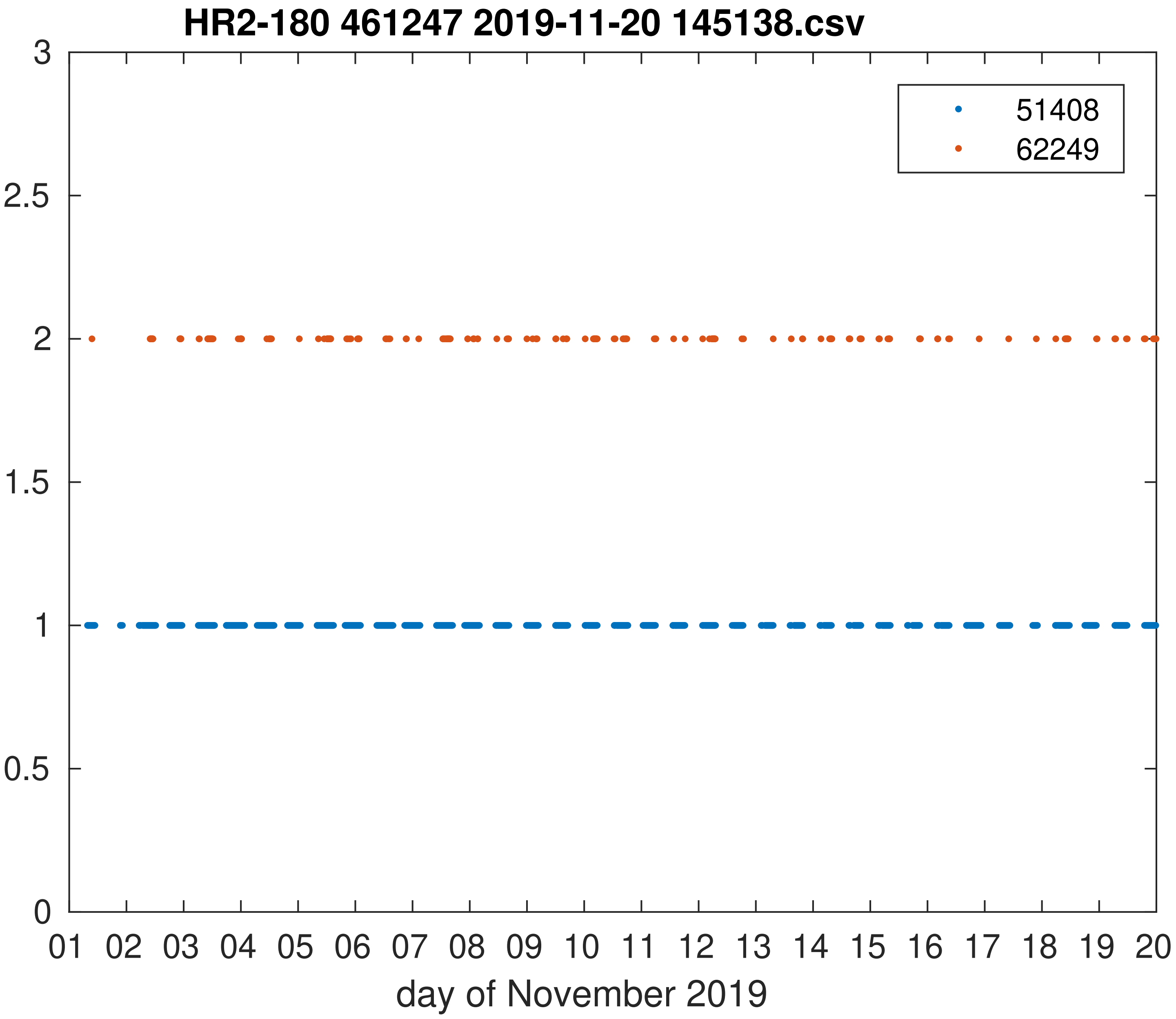


Figure 3: Time series of test tag detection by receiver 461247 at the west gate.

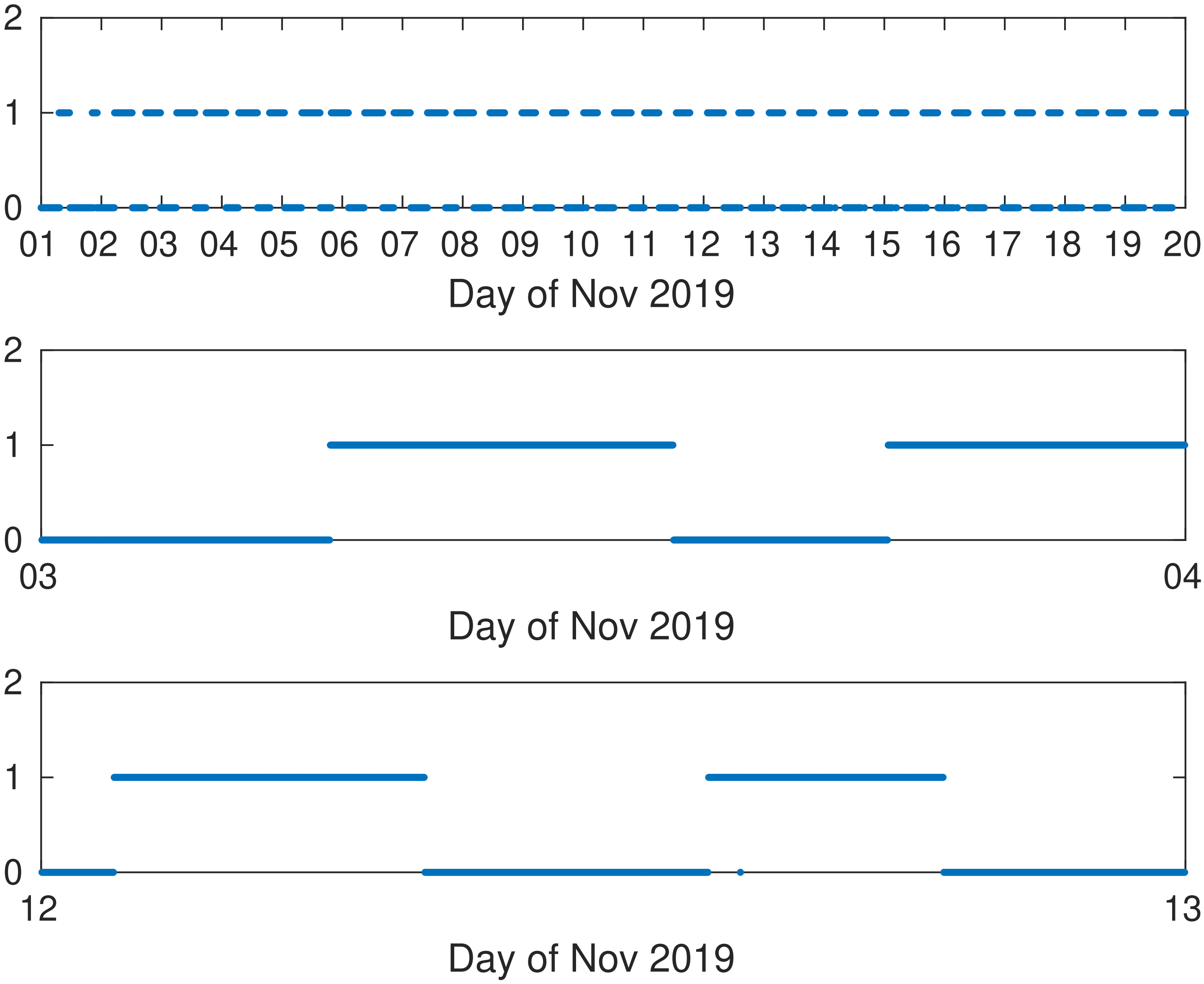


Figure 4: Detectable minutes for HR2 receivers placed on the ledge of the gates, ocean side. Value of 1 denotes a detectable minute whereas a value of 0 is not a detectable minute. Defines a minute to be detectable if a signal had been received within ±5 minutes.

Figure 5: Equipment deployed, showing the test tag on the ocean side and the HR2 receivers on the impoundment side of the causeway. Straight line distance from the impoundment receivers to the gate receivers is about 230 m.

The speed of sound is $c_s = 5900$ m/s in steel and $c = 1480$ m/s in water.

If we consider an plane wave that is travelling through water and is perpendicularly incident upon a steel. The ratio of the pressure signal transmitted into the steel to the pressure signal of the incident wave is

$$\frac{p_{\text{transmitted}}}{p_{\text{incident}}} = \frac{2\rho_s c_s}{\rho_s c_s + \rho c} \approx 1.94$$

The transmission also depends upon the angle of incidence, but the above is sufficient to demonstrate that sound can propagate very well from water to steel. Let us assume that a transmitter has created a plane wave that propagates along a plate of steel. The surface of the steel will have areas of high-low pressure that propagate with the speed of sound in steel. Newtonian mechanics requires that there be matching pressures on the water side of the steel-water interface. Those matching pressures can be achieved by a sound wave in the water that propagates at some angle α to the steel. The most straightforward way to obtain α is by aligning wave fronts in the water so that they match the wave fronts in the steel at the steel-water interface. Thus the angle that the water wavefront makes to the air-steel surface is

$$\alpha = \sin^{-1}\frac{c}{c_s}$$

which is about 14^{o}. Thus, the wave transmitting along the steel plate has an associated wave that propagates out into the water at an angle of 14^{o} from the perpendicular to the steel plate.

The above is an incomplete calculation, but it does give the general idea of how a steel plate can transmit from one HR2 to a second HR2 which, at first glance, appears to be isolated by a thick concrete wall! We must also observe that this mode of transmission is much faster than transmission through water. It follows, therefore, that position finding algorithms will not be much use because those algorithms are based upon signals only moving through water!

PPM signals from tags in the impoundment might be detected by the receivers on the ocean side of the gates but HR signals appear not to be. One must qualify this observation, because we did not test the detection of a tag that is both in the impoundment and near the gate. Presently HR signals are our best bet for determining whether or not a tagged animal might be on the impoundment side. But further testing is required in order to unambigously meet project objectives.

HR signals messed up by reflections from very nearby surfaces. Thus, to work well on a tidal turbine installation one must take care to position the receiver so that it will not suffer from reflected signals and so that it is also optimally oriented relative to the current [2].

PPM signals are not much influenced by reflections from very nearby surfaces. If PPM signals have shorter pulses (say < 1 ms instead of > 6 ms) then they may serve very well for localization under some circumstances. Additionally, the shorter pulses would enable larger pulse amplitude (and more pulses) to be achieved with the same energy (battery).

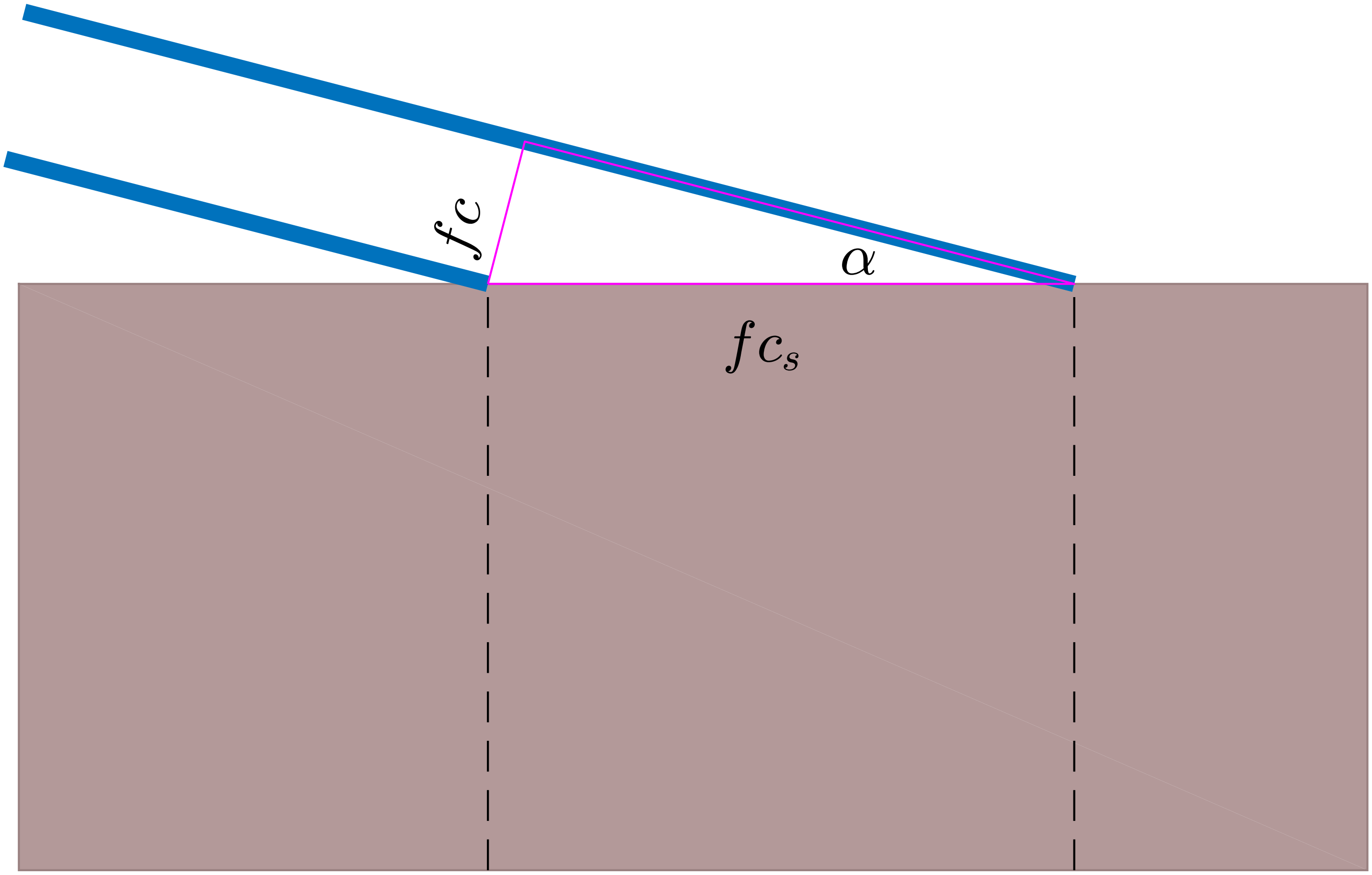


Figure 6: Dashed lines show wavefronts propagating through steel. Blue lines show matching wavefronts in water. Wavelength is fc in water and fc_s in steel.

All of the above have (obvious) implications for detecting tags from hydrophones mounted to instream tidal turbines and related infrastructure.

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