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Evaluation of PIT tag detection for a SNA 1 tagging programme

New Zealand Fisheries Assessment Report 2017/64

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EXECUTIVE SUMMARY

Middleton, D.A.J.; Middleton, S.A.; Wilson, O.L. (2017). Evaluation of PIT tag detection for a SNA 1 tagging programme.

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The detection range of passive integrated transponder (PIT) tags potentially suitable for use in a tagging programme for estimating the abundance of snapper (*Pagrus auratus*) was systematically evaluated. For the tags typically used in fish tagging applications, detection ranges are inherently short – of the order of tens of centimetres. A range of tags was evaluated using a single reader and two different antennas. The reader and antennas were commercial products designed for fish tagging applications.

Tags differed primarily in size and encapsulation material (glass or plastic). The four contemporary, commercial tags tested were all detected at greater distances than a tag from the 2002/03 SNA 8 tagging programme. The largest (23 mm long) tag was generally detected at the greatest distance from the antenna, although this was less evident when tags were scanned across the face of the antenna (‘scan tests’) than when a tag was moved towards a specific point on the face of the antenna (‘approach tests’).

Detection probability and range varied with tag orientation. Scanning a tag across the face of the antenna mitigates the variation in detection probability at different points across the antenna surface. Some variation in detectability of individual tags within a tag type was evident.

All contemporary tags were reliably detected in the base of a fish bin using an antenna scanned across the top of the bin. This suggests scanning for tagged fish in bins using modern tags and readers should be reliable, and exceed the detection probability of 85% reported from the previous SNA 8 programme. Further testing with fish and ice in the bins, and in factory environments, would be required to verify this in a ‘real world’ setting. If multiple tags are in close proximity then some or all of the tags may be undetected, although such circumstances are expected to be rare in a tagging programme focussed on estimating fish stock abundance.

Various sources of interference can affect reader performance, indicating that the performance of individual reader systems must be tested *in situ*, taking into account the potential for ephemeral sources of interference.

1. TERMINOLOGY

This report uses the following terminology:

tags refers to the physical device that is inserted in the fish to provide a unique label. Passive integrated transponder (PIT) tags are an electronic transponder consisting of an antenna and microchip that returns a unique code to a tag reader. The *passive* nature of the tags means that they do not contain a power source but are instead energised by the reader.

reader refers to the transceiver used to detect PIT tags and read the tag's unique code. Readers consist of an antenna, required circuitry, and a power source. Handheld readers combine these three components in a single device (often referred to as a 'wand') designed for moving over the surface of an animal. Here, unless a handheld device is explicitly stated, the term 'reader' (or 'scanner') refer to a static device, with an external antenna separated from the tag reading circuitry. The expectation is that fish move (or are moved) past (the antenna of) such readers.

detection of a tag is used interchangeably with 'reading' a tag. In both cases this refers to reading the unique code from the tag, in addition to detecting the physical presence of the tag.

2. INTRODUCTION

The most recent tagging programme for estimating the abundance of a New Zealand snapper (*Pagrus auratus*) stock was carried out for SNA 8 in 2002 and 2003 (Ministry for Primary Industries 2016). For that programme a plastic-coated PIT tag was developed (McKenzie et al. 2006). Testing suggested that scanners developed for detecting PIT tagged fish in fish bins in the SNA 8 programme were about 85% effective (McKenzie et al. 2015).

The use of PIT tags for a new SNA 1 tagging programme has been proposed. Maximising the detection rate of tags in scanned fish is important for two reasons:

- maximising the efficiency of the tagging programme, as the accuracy of tag-based estimates of movement and abundance depends on the number of tags recovered; and
- minimising the number of undetected tags that remain in fish products for human consumption.

McKenzie et al. (2015) considered that it is 'highly likely that advances in PIT scanning technology since 2001 mean that scanning success will be significantly improved.' However, an initial review of available technology indicated that this is not, in fact, the case. While there have been advances in the performance of some radio frequency ID (RFID) technologies driven by a range of applications, the technologies used in PIT tags suitable for fish have not changed and are subject to physical limitations on detection range (Gibbons & Andrews 2004, Weis 2007).

PIT tags for animal identification are expected to meet ISO 11784 & 11785, which are international standards that regulate the radio frequency identification of animals. The carrier frequency for animal identification is 134.2 kHz. A range of PIT tags is available for use in fish; key differences include:

- whether the tags are full- or half-duplex[1];
- whether the electronic components of the tag are encapsulated in glass or plastic; and
- tag size.

[1] For half-duplex systems the reader alternates between generating pulses to energise the tags, and listening for a response. In full-duplex systems, a continuous magnetic field is generated to power nearby tags whilst the reader simultaneously listens for a response.

Detection of tags varies with distance from the tag reader antenna, and also depends on the orientation of the tag to the antenna. In an evaluation of a range of tags and readers used in fisheries tagging programmes, Fuller et al. (2008) found that the maximum read distance across all tags and tag readers averaged 9.5 cm, and ranged from 2.0 to 31.3 cm.

Successful implementation of a SNA 1 tagging programme will require appropriate choices of tag and tag reader hardware to ensure that tags are reliably read whenever a tagged fish is scanned. In many animal identification programmes animals are known to have an implanted chip and the operator of the scanner will therefore continue scanning until a reading is obtained. In contrast, in the snapper tagging programme only a small proportion of fish scanned will be tagged; operators will generally scan a fish once only and equipment and procedures must therefore ensure that tagged fish are reliably detected amongst a large number of untagged fish.

In addition to informing technology choices, a baseline understanding of tag detectability in benign operating conditions is required in order to assess whether tag detection performance is impacted by environmental factors (such as radio frequency interference) in factory or vessel installations.

This report systematically evaluates the read range of a number of different tag types, and considers the effect of tag orientation. There are few published studies where tag range is determined systematically; Fuller et al. (2008) is an exception, but that study only evaluated read range with the reader antenna parallel to the tag.

A comprehensive PIT tag evaluation procedure is in place to determine if candidate tags can be acceptably detected by the PIT tag detection systems installed throughout the Columbia River Basin (Axel et al. 2017). This procedure focusses on tag performance in respect of detecting tags in live fish by the very large antenna installed in the corner-collector detection system at Bonneville Dam. For the SNA 1 programme the focus is on reliably scanning snapper from commercial catches on fishing vessels and in fish processing facilities, such that the rare tags in fish have a consistently high probability of detection.

Here we focus primarily on ‘approach tests’, where tags were presented to a grid of positions across the plane of the antenna and in a variety of orientations, but also consider detection when tags are scanned at varying heights, including in bins.

3. METHODS

After some initial tests of RFID reader components in the detection of plastic coated PIT tags supplied by Hallprint (initially considered the natural successor for the plastic coated tags used in the 2002 SNA 8 programme, J. McKenzie, NIWA, pers. comm.), which amply illustrated the low read ranges that could be obtained, we focussed attention on ‘off-the-shelf’ antennas and readers designed specifically for fisheries applications. In particular, based on a non-exhaustive search of specifications on manufacturers’ websites, we found that the read ranges quoted by Biomark tended to be greater than those of other manufacturers.

Biomark Inc. (https://www.biomark.com/) is an Idaho-based company that claims to be ‘the only fisheries and wildlife specific RFID Company in the world that manufactures and distributes its own tags, readers, antennas and accessory items’. Biomark’s product catalogue (Biomark 2016) quotes pass-by read ranges of 32–42 cm and 44–55 cm respectively for 12 mm and 23 mm full-duplex tags, for different sizes and shapes of antenna (Appendix A).

3.1 Tag reader and antennas

The tag reader used in the trials reported here was a Biomark IS1001-24V Antenna Control Node (serial number 1550.1399), operating as a standalone reader. An LED User Interface Board was installed to allow visual confirmation of tag readings.

The reader was running firmware version IS1001 1.5.2. Fastag tag detection was disabled, and the exciter voltage was 12 V, except when otherwise noted. Detection of half-duplex (HDX) tags was disabled except when half-duplex tags were specifically tested.

Two Biomark antennas were available:

- a 12 x 32 inch rectangular antenna (serial no. 16-082); and
- a 12 inch circular antenna (serial no. 16-091).

The manufacturer's dimensions refer to the internal diameter. The circular antenna has external dimensions of 435 x 410 mm, whilst the rectangular antenna is 985 x 475 mm.

The majority of testing was carried out with the circular antenna as this was considered more suitable for installation on vessels scanning fish at the point of capture (i.e. at the haul station, in the case of bottom longline vessels).

3.2 Tags tested

A range of tags was tested (Table 1). Four (tags A–D) were contemporary, commercially available tags whilst one (tag E) was a residual tag from the SNA 8 tagging programme (Figure 1).

Table 1: Passive integrated transponder tags tested. Full-duplex tags are indicated by FDX and half-duplex by HDX.

TagID	Manufacturer	Model	Length	Type	Material
A	Hallprint	FDX-B	11.4mm	FDX	Polymer
B	Biomark	HPT23	23mm	FDX	Glass
C	Biomark	HPT12	12.5mm	FDX	Glass
D	Biomark	HDX12	12mm	HDX	Glass
E	Ensid		11mm	FDX	Polymer

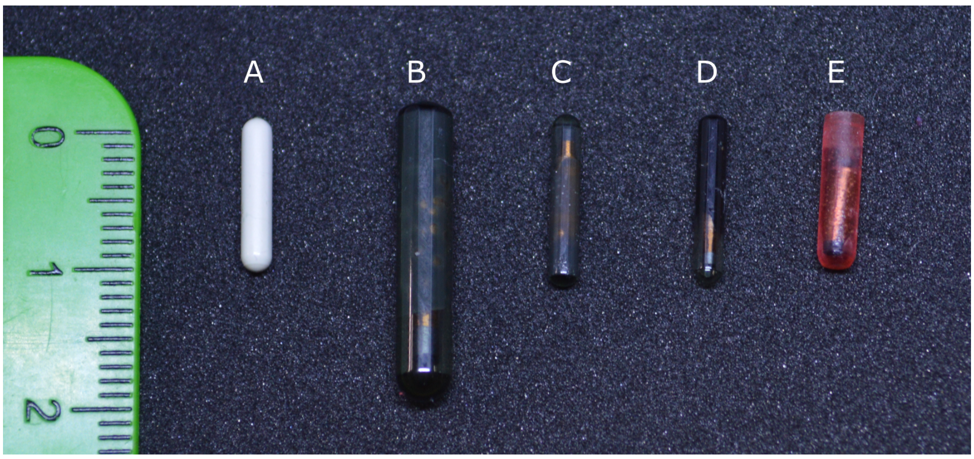

Figure 1: Passive integrated transponder tags tested.

3.3 Approach tests

'Approach' tests were carried out with the Biomark circular antenna. The antenna was fixed to a 16 mm deep medium-density fibreboard (MDF) panel marked with a 20 mm grid (Figure 2). The antenna and board were mounted vertically, and a robot (`tagbot`; https://github.com/trident-systems/tagbot) was used to repeatedly bring the tag horizontally towards the antenna at the different points on the grid. The distance at which the tag was detected was recorded with an infrared distance sensor. All distances refer to distance from the opposite surface of the mounting board from the antenna, i.e. the antenna face is 16 mm further than the measured detection distance.

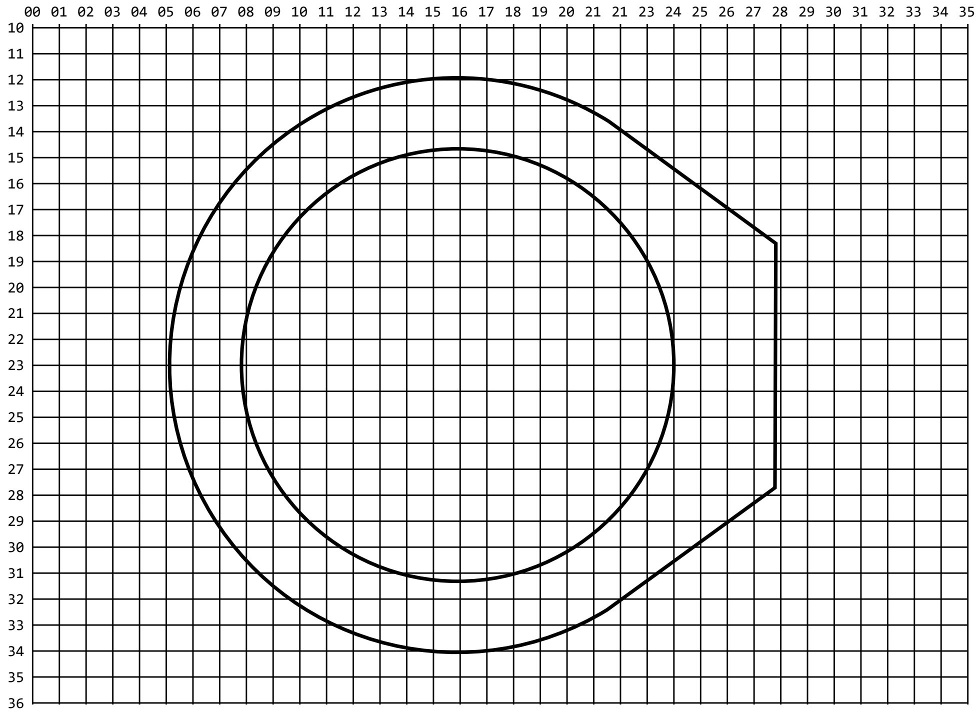

Figure 2: The outline of the circular antenna shown relative to the 20 mm grid used for approach tests. Grid labelling takes into account the dimensions of the `tagbot`, so indicates the relative position of the tag to the antenna.

The `tagbot` was able to rotate the tag around two axes. A rotation increment of 30° was used, which allowed tags to be presented to the antenna in 31 different orientations. For each orientation five replicate approaches to the antenna were made.

Approach tests were time consuming and so the grid of positions across the antenna was initially evaluated for a single example of each tag type. A 400 x 320 mm grid was evaluated for each tag, representing approximately half of the circular antenna's surface.

For tag types B and C, between-tag variation was evaluated by repeating the approach tests for nine different tags of each type. Testing was restricted to a single row of the grid, approximately through the centre of the circular antenna.

For each set of approach tests, two statistics were calculated:

probability of detection the proportion of approaches where the tag was detected; and
mean detection distance in millimetres, for each detection that occured.

3.4 Scan tests

'Scan' tests aimed to more closely emulate the action of scanning a fish past an antenna. In this case the circular antenna was mounted horizontally underneath a 20 mm deep plastic tabletop. A manual tag scanning frame with a range of mounting positions was used to scan a tag over the antenna at a fixed height. Scans were across the centre of the antenna; approximately following row 23 in Figure 2.

Tags were scanned in three different orientations: with the long axis parallel to the antenna face and both parallel to and perpendicular to the scanning axis, and with the tag vertical (perpendicular to the antenna face). Five scans across the antenna were carried out in each test with the results expressed as probability of detection: the proportion of scans where the tag was detected.

3.5 Fish bin tests

To assess the potential for detecting tagged fish in fish bins, a tag was fixed to the base of a standard fish bin (maximum external dimensions: 630 x 385 x 245 mm). The long axis of the tag was aligned to the long axis of the bin. Each antenna was passed over the bin, using the bin itself to maintain a consistent scanning height. Antennas were passed over the bin twice, rotating the antenna through 90° between passes.

4. RESULTS

4.1 Approach tests

The probability of detection, and mean detection distance, for each tag was calculated across all tag presentation orientations (Figure 3). Unsurprisingly, the larger tag (tag B) shows the best performance, i.e. the highest probability of detection over the grid, and the greatest mean detection distance.

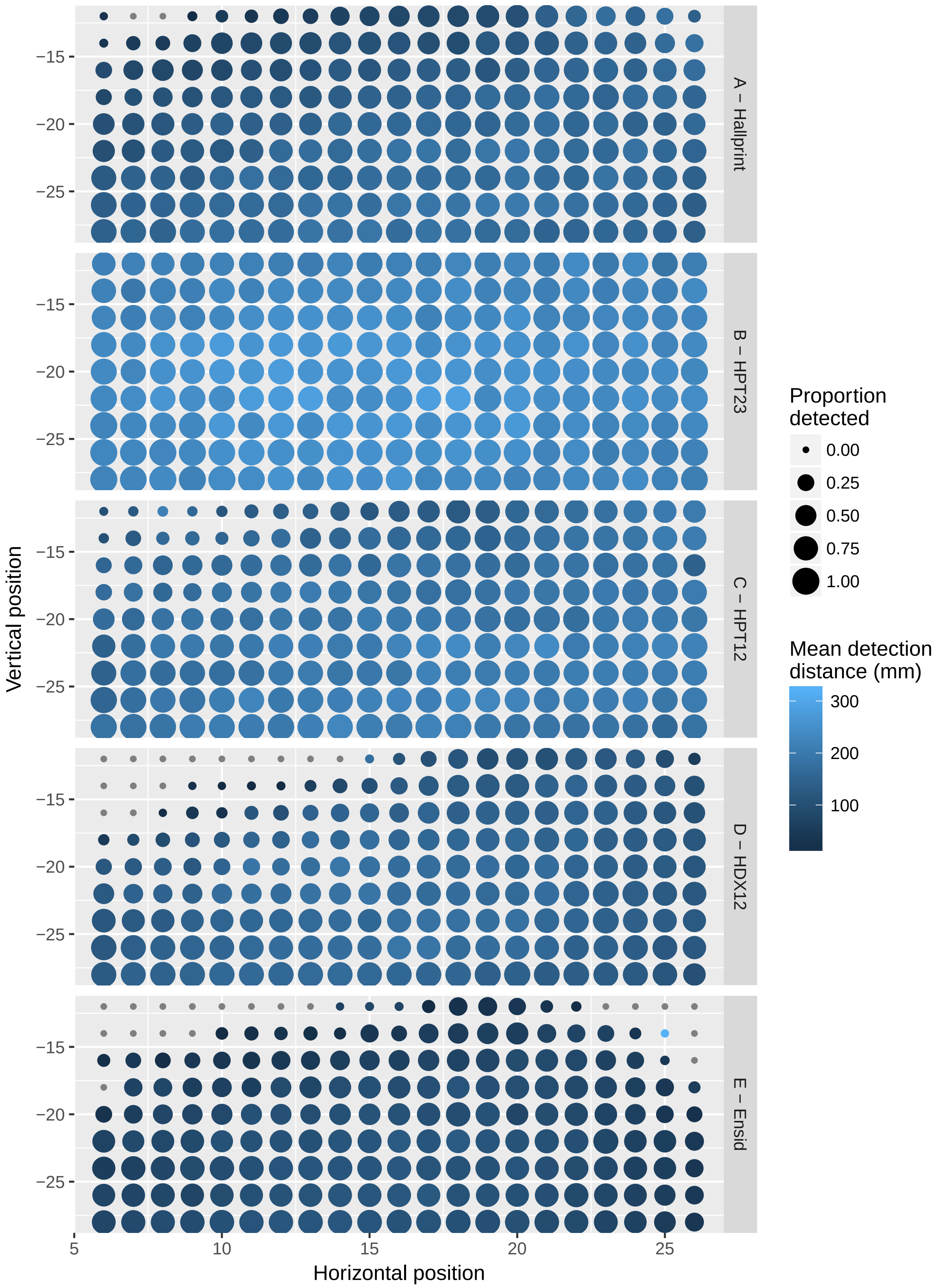

Figure 3: Mean read distance and probability of detection for different tag types at different positions on the antenna surface. Results are aggregated across all tag orientations.

Differences in mean detection distance are more clearly illustrated for approach tests carried out along the grid row that lies approximately across the centre of the circular antenna (Figure 4). Read range is greatest for the 23 mm tag (tag B), with the Biomark HPT12 tag (tag C) achieving the next greatest mean detection distance. Mean read range was similar for the Hallprint tag (tag A), and the Biomark half-duplex tag (tag D). The lowest read ranges were observed for the older Ensid tag (tag E).

The impact of tag orientation on mean read range is illustrated in Figures 5 to 9. These results illustrate that tag detectability varies considerably with both tag orientation and the position in the antenna field.

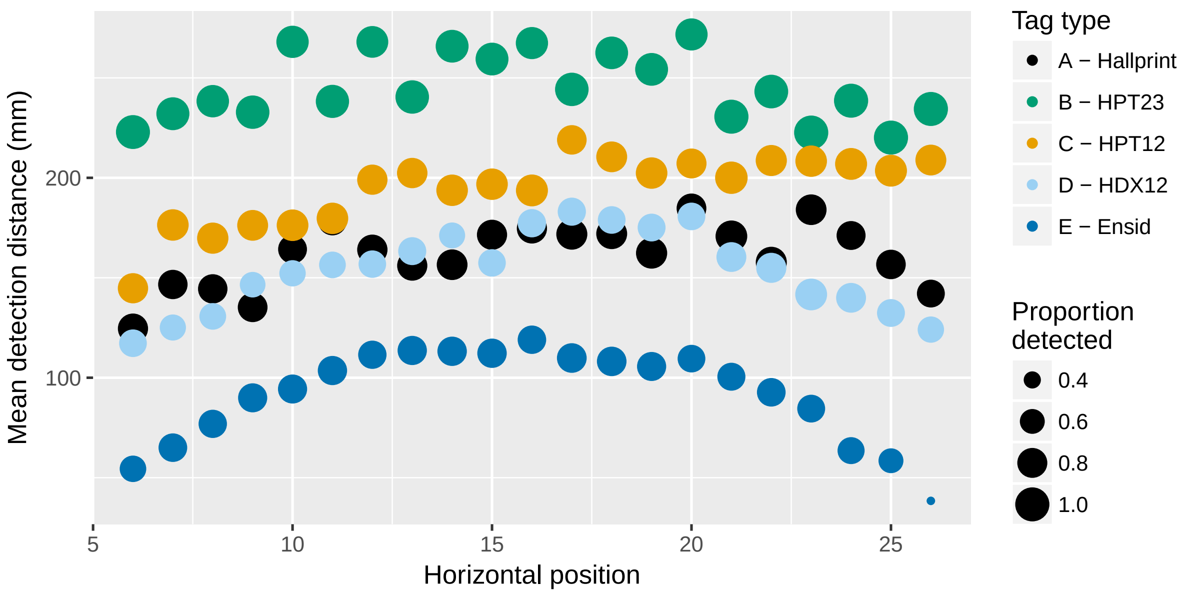

Figure 4: Mean read distance and probability of detection for different tag types at different positions across row 24 of the antenna grid. Results are aggregated across all tag orientations.

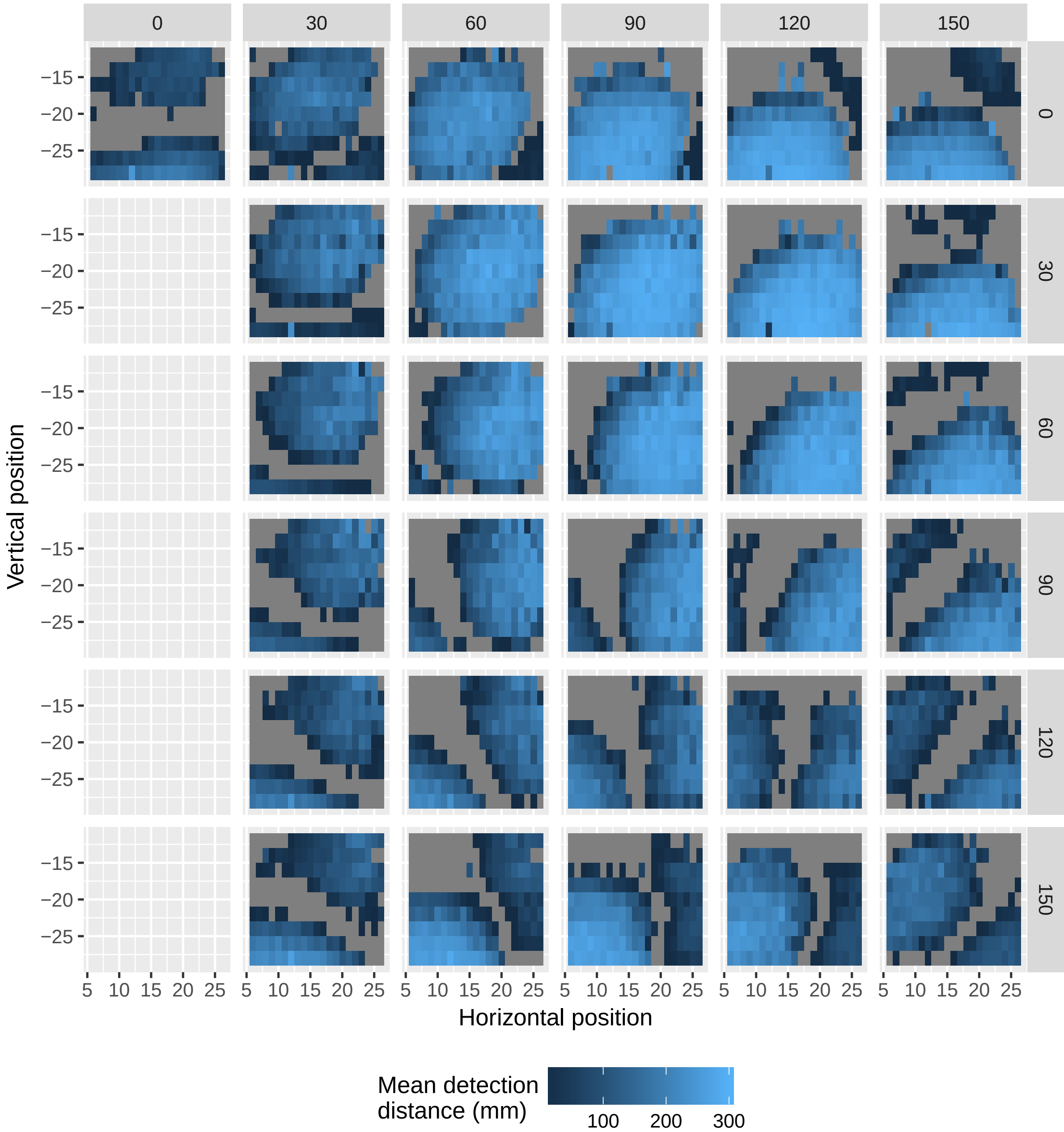

Figure 5: Mean read distance for tag type A (Hallprint, plastic encapsulated) at different positions on the antenna surface and with different tag orientations.

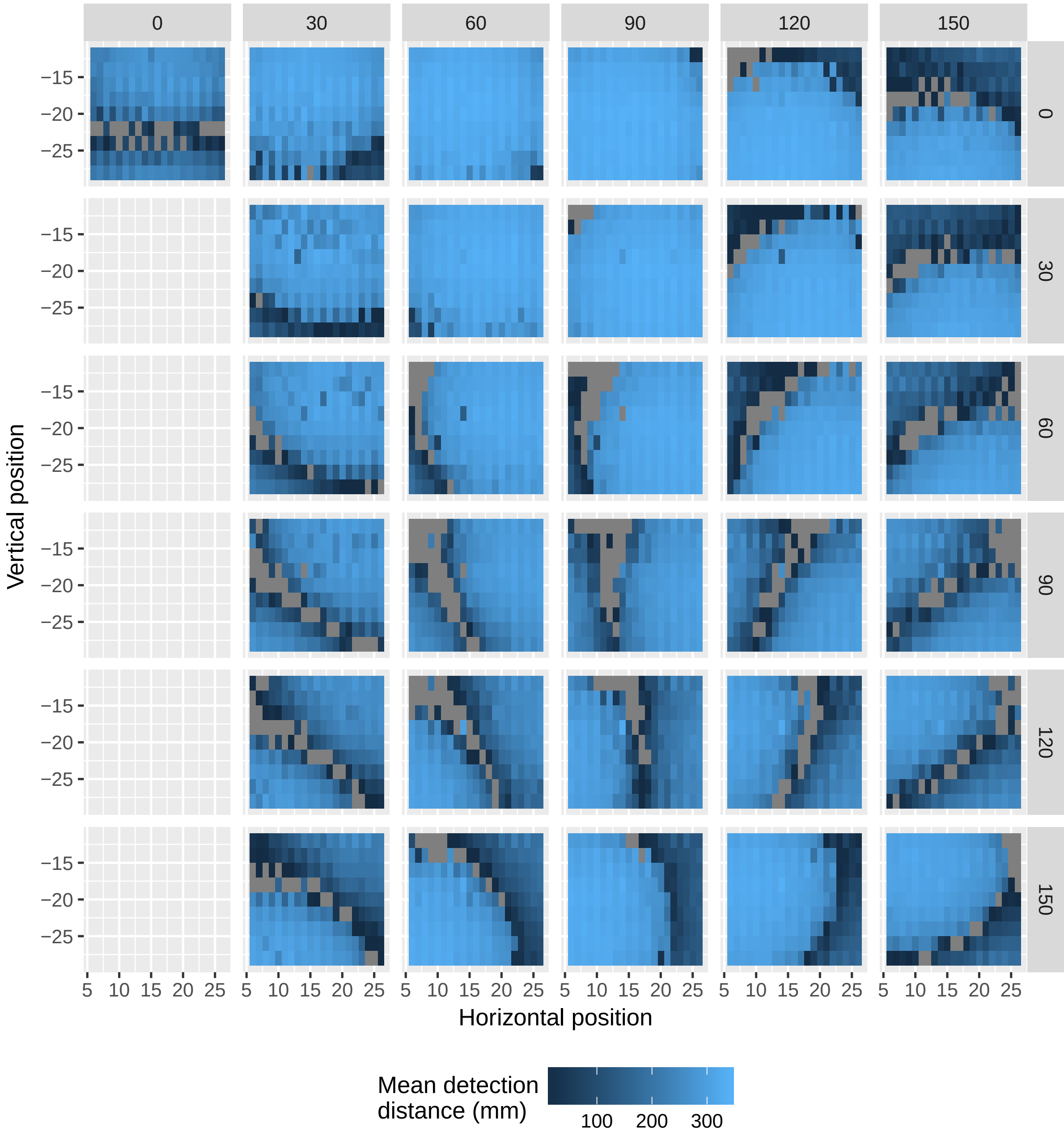

Figure 6: Mean read distance for tag type B (Biomark HPT23) at different positions on the antenna surface and with different tag orientations.

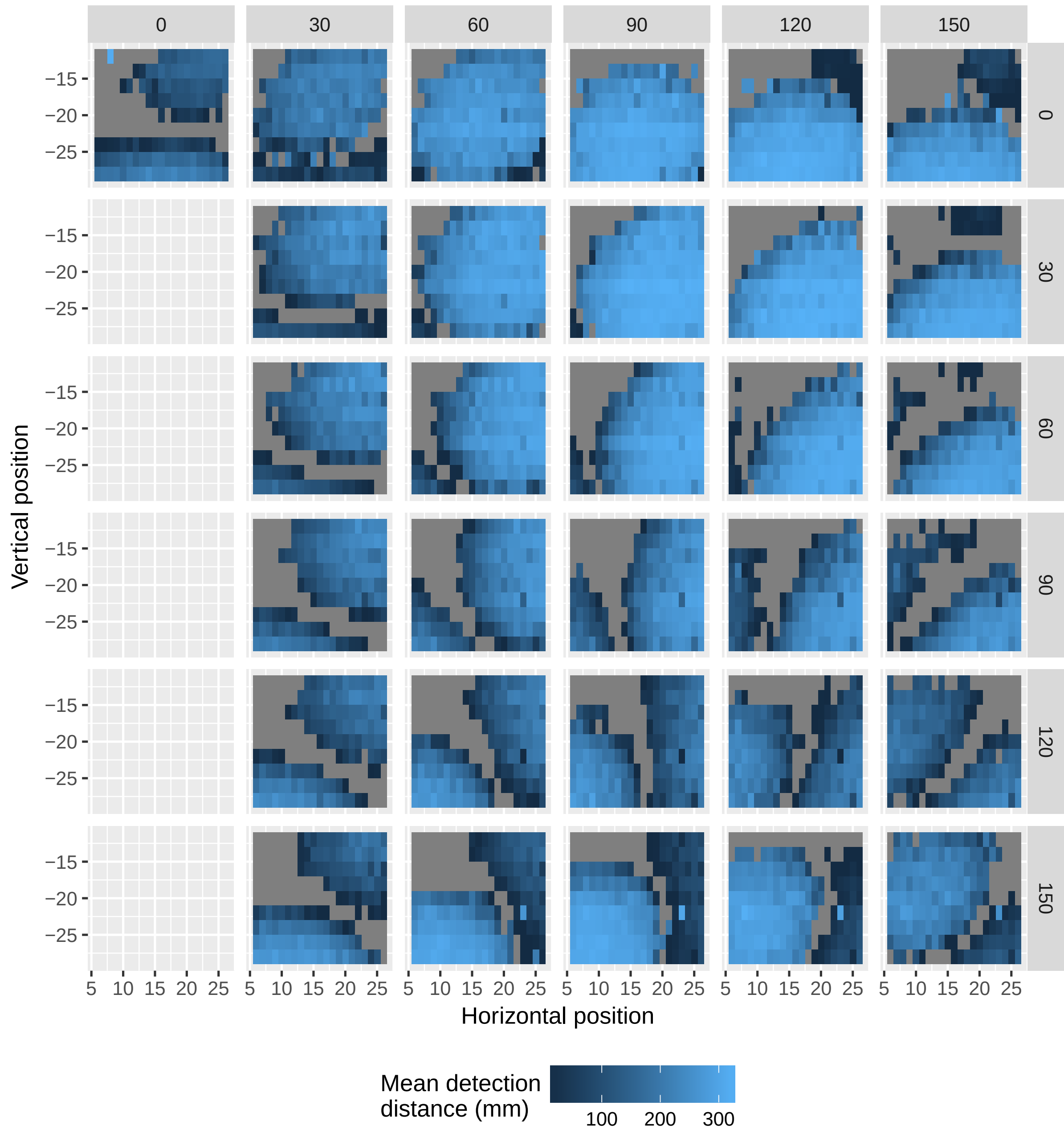

Figure 7: Mean read distance for tag type C (Biomark HPT12) at different positions on the antenna surface and with different tag orientations.

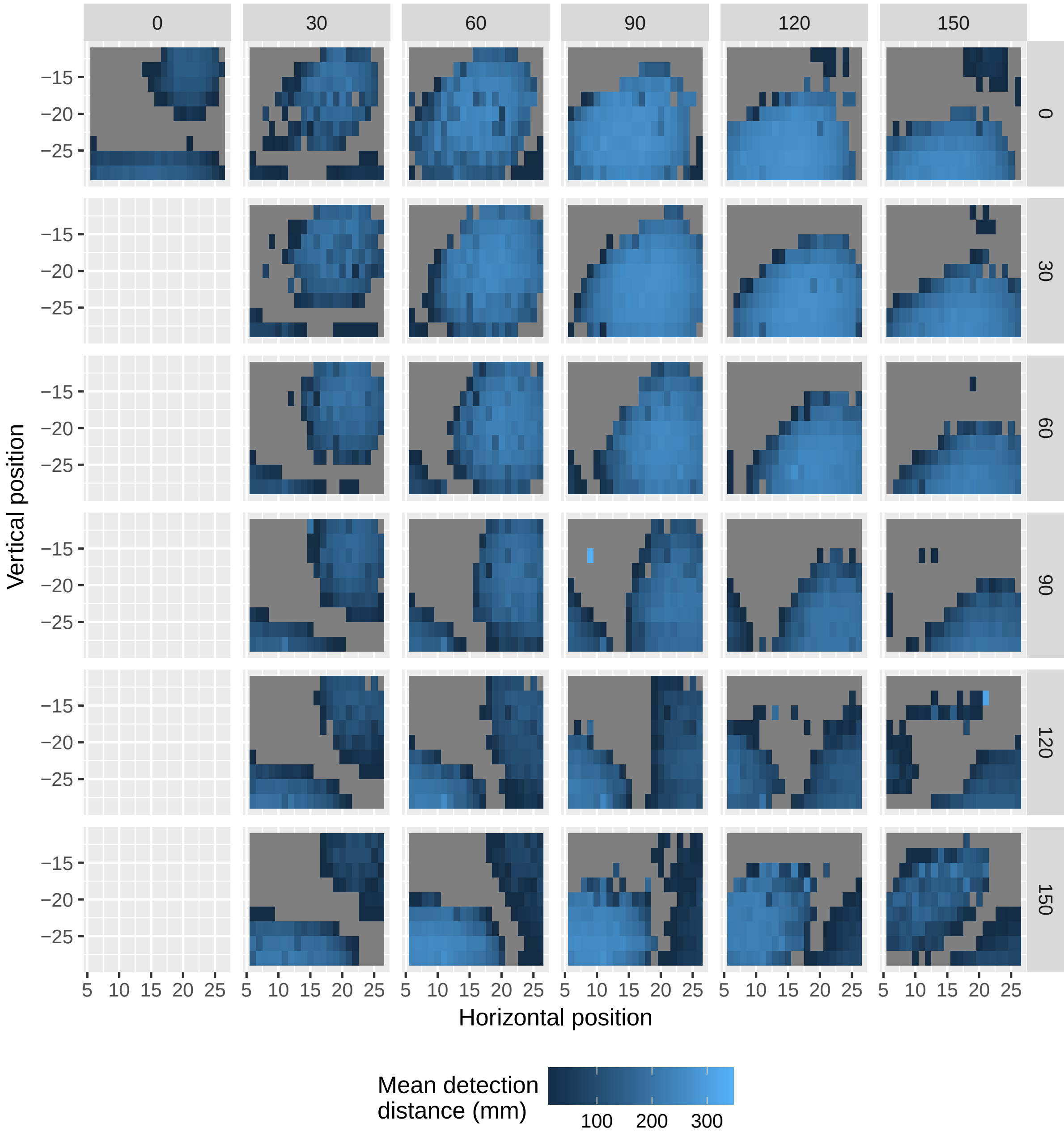

Figure 8: Mean read distance for tag type D (Biomark HDX12) at different positions on the antenna surface and with different tag orientations.

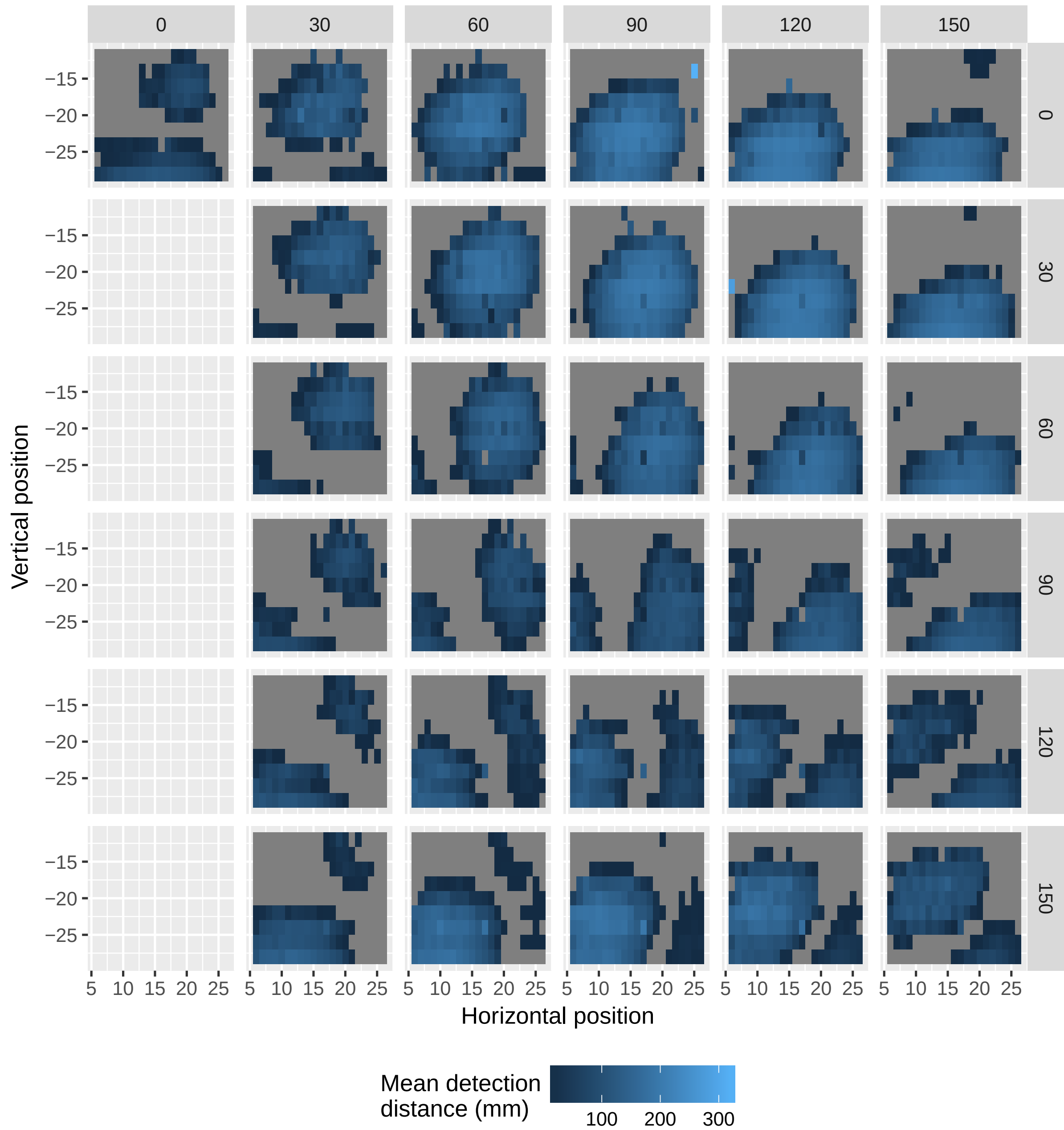

Figure 9: Mean read distance for tag type E (Ensid plastic encapsulated) at different positions on the antenna surface and with different tag orientations.

4.2 Between-tag variation

Between-tag variation in detection probability and detection distance is evident for both tag type B (Figure 10) and tag type C (Figure 11), with mean tag read range varying by around 20 mm between different tags.

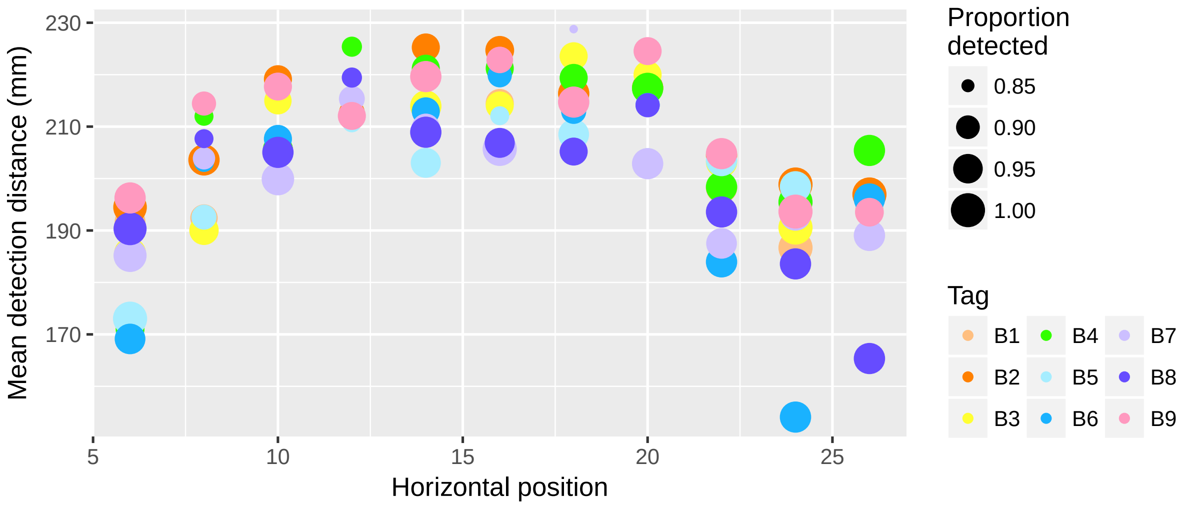

Figure 10: Mean read distance and probability of detection for nine different tags of tag type B (Biomark HPT23) at different positions across row 24 of the antenna grid. Results are aggregated across all tag orientations.

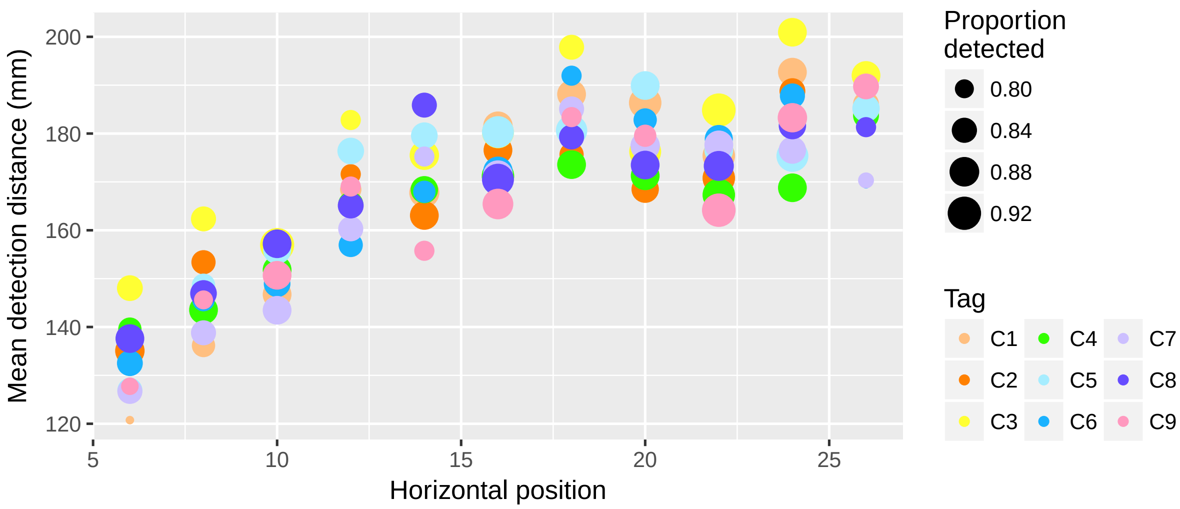

Figure 11: Mean read distance and probability of detection for nine different tags of tag type C (Biomark HPT12) at different positions across row 24 of the antenna grid. Results are aggregated across all tag orientations.

4.3 Scan tests

The probability of detection, for a tag scanned across the antenna face at a given height, and in different orientations, rapidly drops from one to zero when a critical height above the antenna is reached (Figure 12). For the four full-duplex tags, the Ensid tag has the lowest detection height, followed by the Hallprint tag. Detection of the two Biomark tags ceases at a similar height above the antenna. All tags had the highest detection ranges when scanned with the tag perpendicular to the antenna face.

The effect of increasing the exciter voltage of the tag reader from 12 to 20 V was tested for the two Biomark glass full-duplex tags, with the tags in the least detectable orientation (parallel to the antenna face, and perpendicular to the direction of scanning). The increased antenna power resulted in an increase in the detection distance (Figure 13).

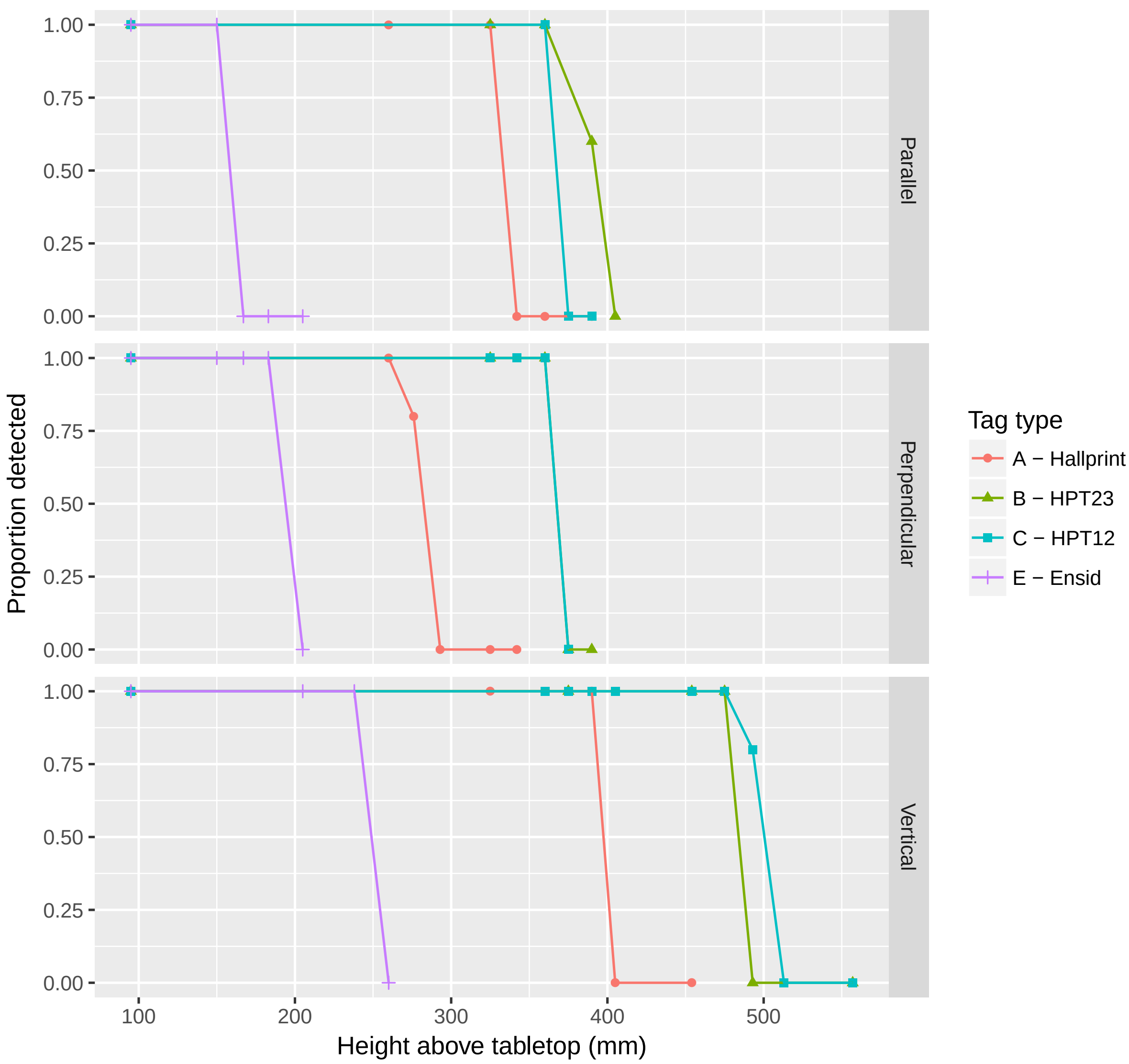

Figure 12: Probability of detection for different tag types when scanned at different heights across the antenna face. Note that in the middle (Perpendicular) panel, the lines for tag types B and C are overlaid reflecting similar performance by these tags in this orientation.

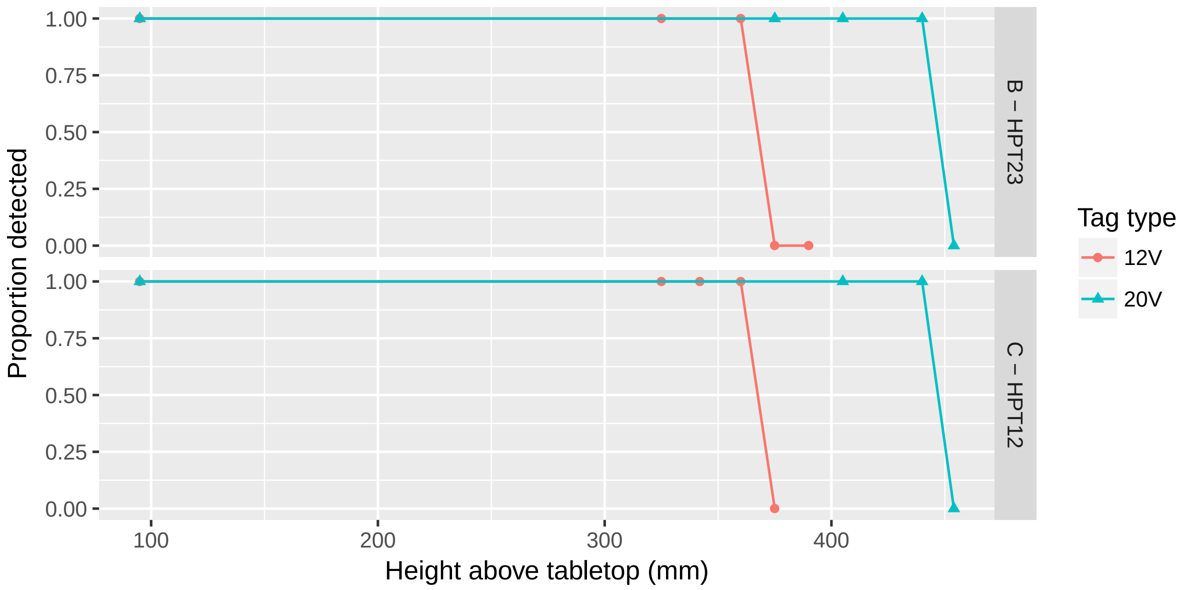

Figure 13: Probability of detection for the Biomark full-duplex tags when scanned at different heights across the antenna face with different antenna exciter voltages.

4.4 Fish bin tests

For tags affixed in the bottom of a fish bin, both antennas detected all three modern full-duplex tags in each antenna orientation (Table 2). In contrast, the Ensid tag could not be detected in the bottom of the fish bin using either antenna.

Table 2: Full-duplex tags detected by scanning antennas over the top of a fish bin with a tag affixed to the bottom centre of the bin. Two passes per antenna were made, with each tag detected 0, 1 or 2 times.

TagID	Manufacturer	Model	Circular	Rectangular
A	Hallprint	FDX-B	2	2
B	Biomark	HPT23	2	2
C	Biomark	HPT12	2	2
E	Ensid		0	0

Some preliminary testing of the ability to detect multiple tags in the same bin was carried out by affixing multiple tags in the bottom of the fish bin. Tags were placed side by side, within a centimetre of each other. The tag reader was operated with the exciter voltage set at 20 V.

The circular antenna detected two HPT23 (tag B) tags side by side in the bin, but only one tag when three or four tags were in the bin. When two HPT12 tags were in the bin neither was detected. With the rectangular antenna, typically only one of two tags was detected. However, with two HPT12 tags in the bottom centre of the bin, neither was detected when the bin was passed through the antenna.

The reader typically registered high noise levels when multiple tags were scanned. The procedures for testing tags for use in the Columbia River tagging programme (Axel et al. 2017) tests scanning for multiple tags with larger distances (3 or 6 inches) between the tags. For groups of three tags, tags are separated by 8 or 12 inches.

5. DISCUSSION

Testing of a range of PIT tags with a modern tag reader and antennas designed for fisheries research applications demonstrated:

- variation in detection probability and range between tag types;
- variation in detection probability and range due to tag orientation; and
- between-tag variation in detection probability and range within a tag type.

Between-tag variation in detectability within a tag type was generally smaller than the variation between tag types. The variation in detectability that arises due to tag orientation differs depending where the tag is over the antenna face. Thus, scanning a tagged fish across an antenna should mitigate poorer detectability in some areas of the antenna field.

Tag detectability in scanning trials showed a knife-edge boundary between distances at which tags were detected, and distances at which the tag was not detected. In the scanning tests reported here, the horizontal orientation of the tag to the antenna face was an unfavourable orientation for tag detection. Re-orientating the tag from a parallel orientation to a perpendicular orientation relative to the antenna face, when at the limits of detection for the parallel orientation, led to the tag being detected again.

The Ensid tag from the SNA 8 programme had the poorest detectability in all tests. All the modern tags performed better, and notably all modern full-duplex tags could be detected in the bottom centre of a fish bin with the antennas passed over the top. The Biomark full-duplex tags had better detection ranges than the Hallprint tag, and the larger Biomark tag was detected at a greater mean range than the smaller tag. The half-duplex Biomark tag had a lower detection range than the full-duplex tag of similar size.

The results reported here are somewhat contrary to those of Fuller et al. (2008) who found that matching tags and readers produced by the same manufacturer did not appear to offer any measurable advantage in terms of read distance. However, our tests were limited to a single manufacturer's reader and antennas.

The superior performance of the modern tags, compared to the tag from the SNA 8 programme, appears to justify the optimism of McKenzie et al. (2015) that tag detection has improved since 2002, despite the fact that the basic technology remains the same. Furthermore, it is evident that 'off the shelf' antennas and readers are likely suitable for on-vessel and in-factory scanning, so long as appropriate care is taken in avoiding or mitigating sources of interference.

6. ACKNOWLEDGEMENTS

This work was completed under Ministry for Primary Industries contract SEA2016-31: Food Safety Testing of PIT tags for SNA 1 tagging programme. Early testing of tag reader components, prior to the adoption of the Biomark reader, was carried out in collaboration with Snap Information Technologies Ltd. Members of MPI's Northern Inshore Fisheries Assessment Working Group, and Peter de Joux (NIWA), provided useful feedback on an earlier version of this report. Review of the draft FAR by John Taunton-Clark led to a clearer specification of the terminology used. Dragonfly Data Science provided the LaTeX template used for this report.

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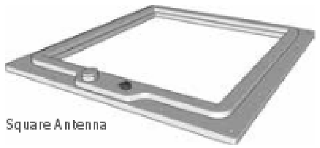
APPENDIX A: BIOMARK ANTENNA AND TAG SPECIFICATIONS

The table below is extracted from the 2016 Biomark product catalogue.

Biomark
SPECIALISTS IN IDENTIFICATION SOLUTIONS

Circular Antenna

Square Antenna



Rectangular Antenna

ANTENNA READ RANGES

		10" Round		12" Round		18" Round		18" Square		24" Square		12" x 24" Rectangle		12" x 32" Rectangle	
		Pass-by	Pass-through	Pass-by	Pass-through	Pass-by	Pass-through	Pass-by	Pass-through	Pass-by	Pass-through	Pass-by	Pass-through	Pass-by	Pass-through
Biomark MiniHPT8, 8 mm 134.2 kHz	in.	8	11.25	9	12.25	10.25	14.25	8.75	13	8	11.25	8	12.5	7.75	10.5
	cm	20	29	23	31	26	36	22	33	20	29	20	32	20	27
Biomark HPT9, 9 mm 134.2 kHz	in.	10.25	14	10.75	15	12.75	18.5	11.75	17.25	12.5	17	11.5	16.25	10	14.75
	cm	26	36	27	38	32	47	30	44	32	43	29	41	25	37
Biomark MiniHPT10, 10 mm 134.2 kHz	in.	9.5	13.5	10	14	11.75	17	10.75	16	11	15	10.25	15.25	9.25	13
	cm	24	34	25	36	30	43	27	41	28	38	26	39	23	33
Biomark HPT12, 12 mm 134.2 kHz	in.	12.75	17.25	13.5	18.25	16.5	22.25	14.75	21.75	15.5	21.5	14.5	20.75	14.5	19.25
	cm	32	44	34	46	42	57	37	55	39	55	37	53	37	49
Biomark HPT23, 23 mm 134.2 kHz	in.	17.25	22.5	18	23.75	21.75	29	21.75	28.75	22	30.5	19	27.5	18.75	26.5
	cm	44	57	46	60	55	74	55	73	56	77	48	70	48	67
Biomark BioTherm13, 13 mm 134.2 kHz	in.	11.75	15.5	11.75	16.25	15.75	21	12.75	18.25	12	17.5	11.75	17.25	11.25	15.25
	cm	30	39	30	41	40	53	32	46	30	44	30	44	29	39
Biomark HDX12, 12 mm 134.2 kHz HDX	in.	11	16	11	17	15	21	13	19	14	20	13	19	12	17
	cm	28	41	28	43	38	53	33	48	36	50	33	48	30	43
Biomark HDX23, 23 mm 134.2 kHz HDX	in.	16.5	21	17	22.5	24	28	20.5	27	21	16.5	18	26.5	17	25.5
	cm	42	53	43	57	61	71	52	69	53	42	46	67	43	65

* Using an HPR Plus reader configured as follows: FDX-B & HDX on; antenna power 100%; battery fully charged in a low noise environment with a 20 foot antenna cable.

** Read range is affected by tag orientation and environmental noise. When a range is present in the table the smaller number represents approximate read distance when the tag is parallel to the antenna face (worst orientation) while the larger number represents the approximate read distance when the tag is perpendicular to the antenna face (best orientation). Environmental noise can reduce read range. It can be caused by power lines, dirty AC power, overhead lights, pumps, etc.

APPENDIX B: NOISE AND TUNING

The detection of PIT tags can be influenced by various forms of interference. The Biomark readers implement dynamic auto-tuning that aims to automatically adjust the reader tuning capacitance settings to maintain performance at the level established by a 'full tune' carried out when the system is installed. The reader indicates an alarm state if the antenna is out of tuning range.

Testing with a variety of sources of potential interference (Figure B-1) indicated that the auto-tuning operated for some types of interference, and that electrical devices often caused noise in the reader signal levels.

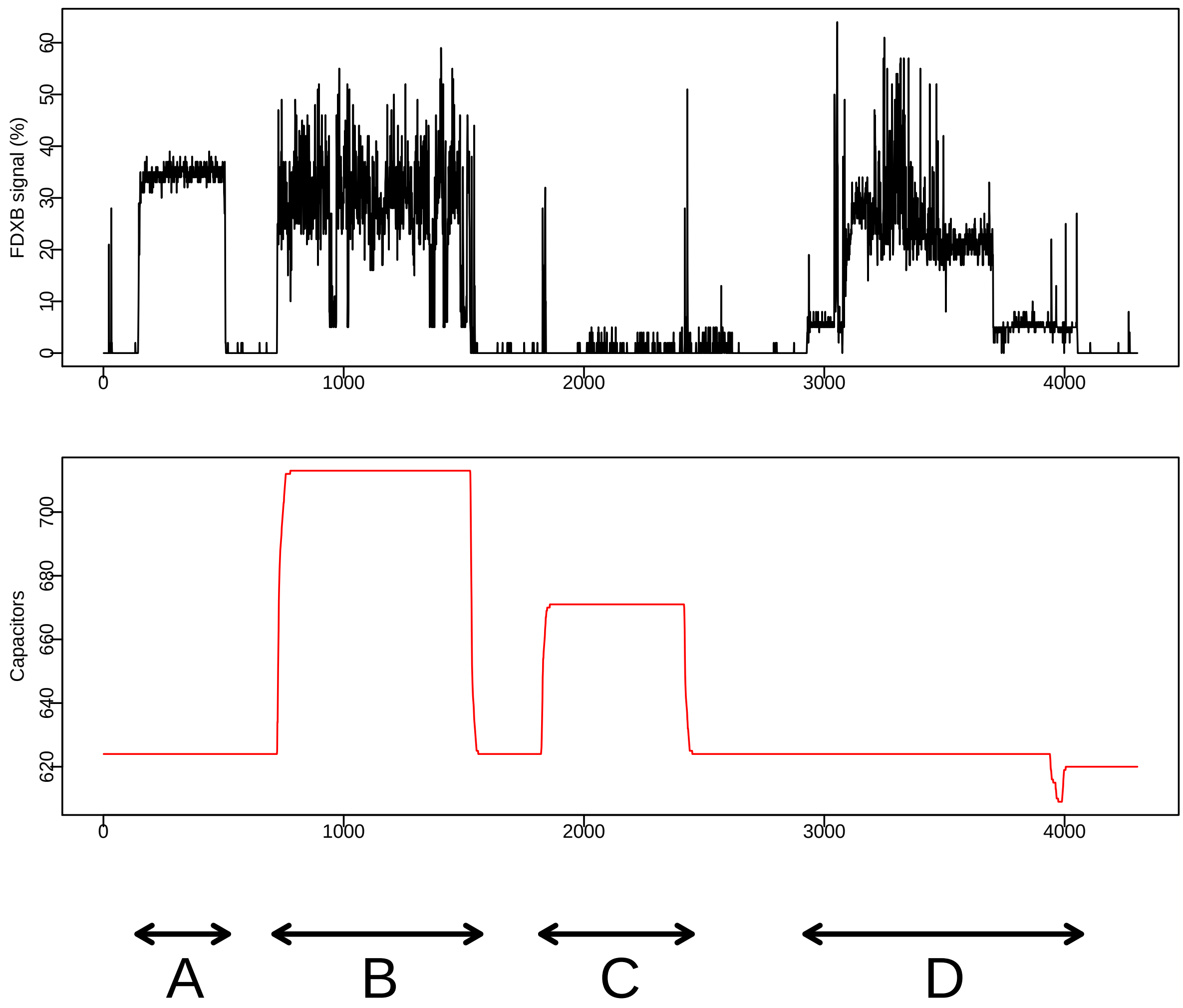


Figure B-1: FDXB signal and auto-tuning capacitor levels in response to four sources of interference with the circular antenna fixed to the underside of the table as per scan tests: A - the `tagbot` (powered) positioned on the table above the centre of the antenna; B - a mobile phone (powered) positioned on the table above the centre of the antenna with an incoming call halfway through the event; C - a 1.5 kg lump hammer placed on the table above the centre of the antenna; D - a laptop powered up, then shut down, whilst on the table 400 mm from the edge of the antenna.

It is evident from Figure B-1, event A, that the `tagbot` used in testing could act as a noise source when close to the antenna. Further testing (Figure B-2) indicated that this would not have significantly impacted the detection distances measured in approach tests, but could have impacted scanning tests had the powered `tagbot`, rather than a manual caddy, been used to scan the tag across the face of the antenna.

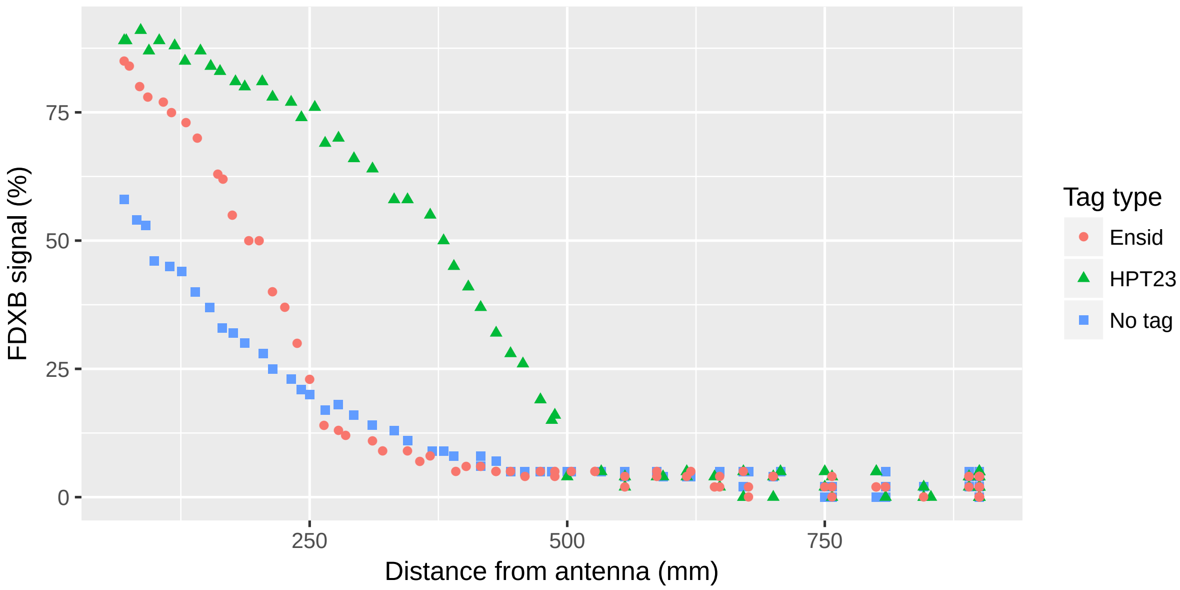


Figure B-2: FDXB signal with distance from the antenna, when using the `tagbot` for antenna approach tests.