

METHODOLOGY

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# Receiver tilt: a scourge for aquatic telemetry or useful predictor variable

Alistair Becker\*, Michael B. Lowry and Matthew D. Taylor

## Abstract

**Background:** Water current data can be a useful predictor variable to include in acoustic telemetry studies given its link to changes in fish behaviour. While there are a range of sensors which can measure currents, they are often expensive and logistically difficult to deploy and maintain. Contemporary acoustic receivers measure tilt angle which may act as a proxy for water current data if the receiver is moored on a rope and buoy system and allowed to sway in the direction of water flow. We tested the relationship between tilt angle and water current by co-locating two types of commonly deployed receivers with current meters.

**Results:** Both receivers (Vemco VR4 and VR2AR) displayed similar ranges in tilt angle. While the VR4 could only measure tilt on a daily basis, the VR2AR measurements were taken hourly; these data were then also aggregated on a daily scale. A positive relationship was found between the tilt angle for both types of receivers and current speed, including for both aggregated daily and hourly data for the VR2AR. Both receivers tended to slightly over-estimate current at lower speeds and underestimate it at high speeds.

**Conclusions:** These data show tilt angles recorded by commonly deployed receivers could be incorporated as a proxy for current flow where dedicated current loggers are absent. We would recommend programming receivers to record tilt as frequently as possible to account for short-term variability in environmental conditions.

**Keywords:** Acoustic receivers, tilt angle, Environmental variables, Water currents

## Background

Acoustic telemetry is widely used to study movements, connectivity, behaviour and residency of fish and crustaceans [1]. Understanding these patterns, and their drivers, is important for both managing fish stocks and for determining the impacts of stressors and anthropogenic change [2–5]. Movement and activity trends of fish can often follow cyclic patterns, such as those related to diel, tidal and thermal/seasonal cycles [6–9]. However, other influences can affect movement ecology such as environmental factors [10–13]. Consequently, acoustic telemetry studies often seek to collect accompanying environmental data (e.g. through point measurements, deployment

of loggers, or remote sensing), such that the influence of these environmental variables on fish behaviour can be modelled.

Water movement is a variable environmental factor that has the potential to greatly influence fish behaviour. In estuaries and rivers, water movement can include outward flow forced by freshwater inputs, which may be critical for driving spawning aggregation, migration and other important behaviours [14–16]. In open coastal systems, current flow and wave action interact to create a high-energy environment in which fish may be seeking to minimise the energetic expenditure associated with their behaviours (whether it be maintaining position, moving, foraging, or migrating), and can, thus, have substantial influences on fish movement patterns [17, 18]. Various magnetometer/accelerometer-based, or acoustic-based (e.g. ADCP) logger systems can be employed to monitor

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water movement; however, financial and logistical burdens of deploying and servicing additional current mooring infrastructure in high-energy coastal waters may preclude their inclusion in studies on the open coast.

Contemporary acoustic receivers often include internal hardware which measures ancillary variables such as temperature, depth and tilt angle, and logs these measurements in memory. Tilt angle is typically used to determine if the receivers remain in an upright position, thereby providing a proxy for the efficiency of an omnidirectional hydrophone to detect nearby transmitters. However, if receivers are deployed on freely moving mooring lines that allow them to sway with water movement, they will tilt in the direction of current flow, with increased speeds likely to tilt receivers at greater angles. Thus, these sensors that are already incorporated within receiver hardware may provide an alternate means of deriving a time-series of data that reflect relative changes in water movement at the receiver location. To our knowledge, no study has yet utilised tilt angle as a relative measure of water movement in their analysis of species movement patterns and behaviour. The aim of this methodology paper is to evaluate whether receiver-logged tilt angle data may provide a viable proxy for water movement in acoustic telemetry studies, such that researchers may consider incorporation of these data into the design or analysis of future research.

## Methods

### Study design and site description

Our study employed co-located proprietary tilt current meters (TCM-1, containing a MAT-1 Data Logger, Lowell Instruments LLC, East Falmouth, Massachusetts, USA) and acoustic telemetry receivers with integrated tilt angle sensors (Vemco VR4 or VR2AR; Innovasea, Bedford, Nova Scotia, Canada), to compare water measurements derived from the current meter and acoustic receiver hardware. Two receiver types were evaluated, since the frequency at which receivers log tilt angle information differs among receiver types. The VR4 receiver logs a single instantaneous measurement of tilt angle at midnight (with fixed programming), whereas the more modern VR2AR can log tilt angle as frequently as every minute in 'fast logging mode' for 14 days, but the default settings will log an instantaneous reading once an hour. Data collection was conducted at two locations in Australia off the New South Wales coastline, with VR4s deployed adjacent to the Shoalhaven River and VR2ARs deployed at an artificial reef site near Botany Bay. Receivers at both locations were deployed at depths of ~30 m, on bare sand (Fig. 1). Three VR2AR stations were used, whereas two VR4 stations were used, with both receiver types attached to moorings with rope, stainless steel

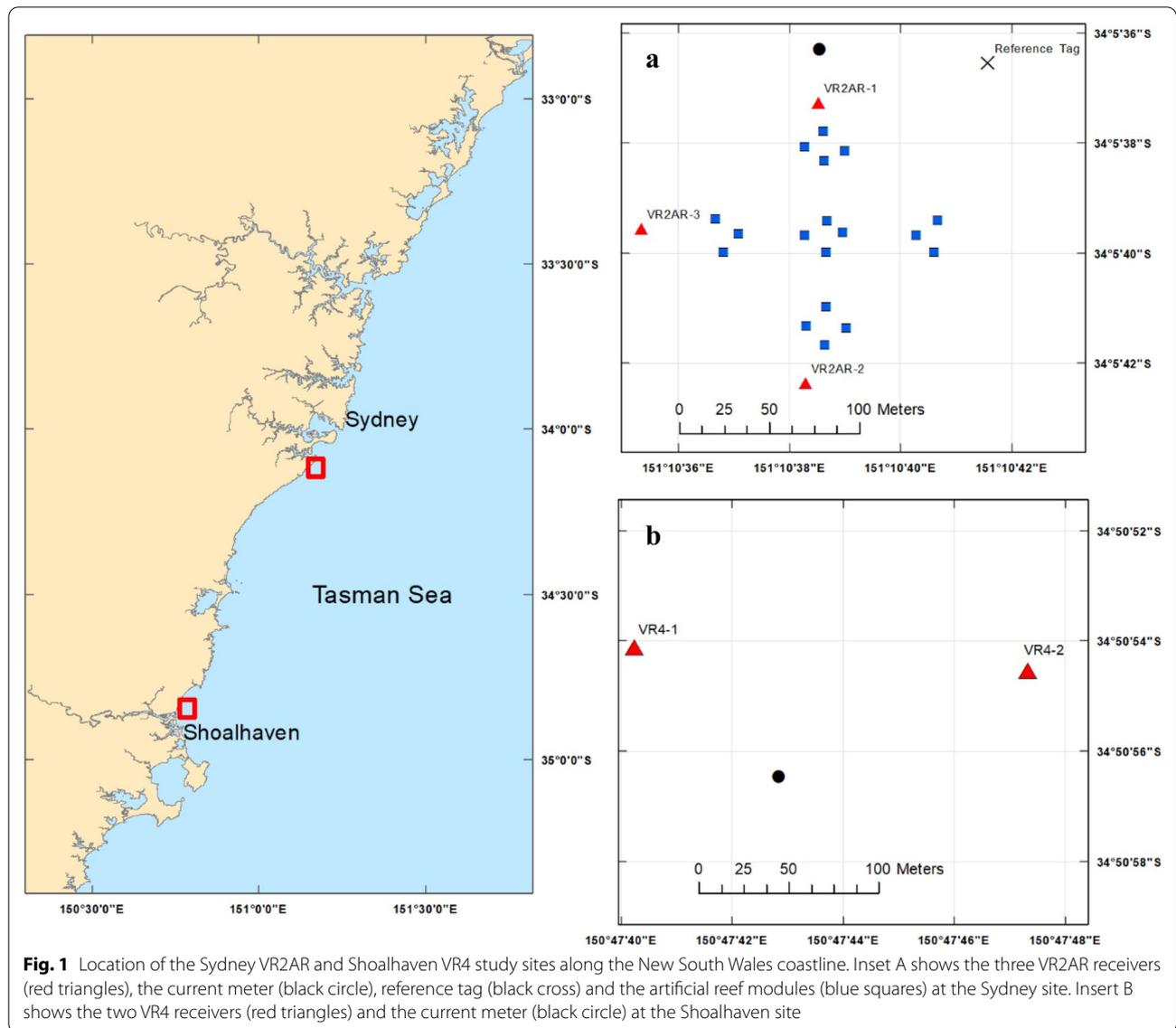
swivels and shackles, and suspended with a float so they were positioned 1.2 m above the substratum (Fig. 2). This mooring design represents a common mooring apparatus for acoustic receivers in coastal areas, and receivers have the ability to sway and tilt when subjected to currents. The TCM-1 current meter was moored following the manufacturers recommendations, which included attaching the unit to a mooring with a 2 cm flexible lanyard (Fig. 2). The Botany Bay site also included a V9 reference tag, programmed to ping with a random delay between 500 and 700 s to determine the detection efficiency of the VR2AR stations.

### Data collection and analysis

The VR4 evaluation was conducted between 29/09/2015 and 11/03/2016, while the VR2AR evaluation was conducted between 21/09/2018 and 30/11/2018. Both locations fall within a region that experiences the same oceanographical conditions [19] which includes a high-energy wave regime and a highly variable wind-wave climate. Conditions during both study periods were typical with no unseasonal weather patterns. For the VR4 evaluation, the current meter was programmed to log both direction (heading) and speed ( $\text{cm s}^{-1}$ ) at 2-min intervals; whereas for the VR2AR evaluation, the current meter was programmed to log at 5-min intervals. Tilt angle and current velocity data were variously aggregated and compared in different analyses to investigate correlations between tilt angle and actual current speed. Only a single daily reading was obtained from VR4 receivers, but for VR2AR receivers, the frequency distribution of tilt angles were compared between hourly readings and daily aggregates for individual receivers. The relationship between tilt angle for each receiver, and current speed, was evaluated using simple linear regression. Equivalency between tilt angle and current speed was evaluated by first standardising both variables for scale and spread, and conducting a Wald's test for an alternative null hypothesis of  $\beta=1$ , indicating that a change in a standardised unit of tilt angle is matched by a standardised unit of current speed. All analyses were undertaken in R [20]

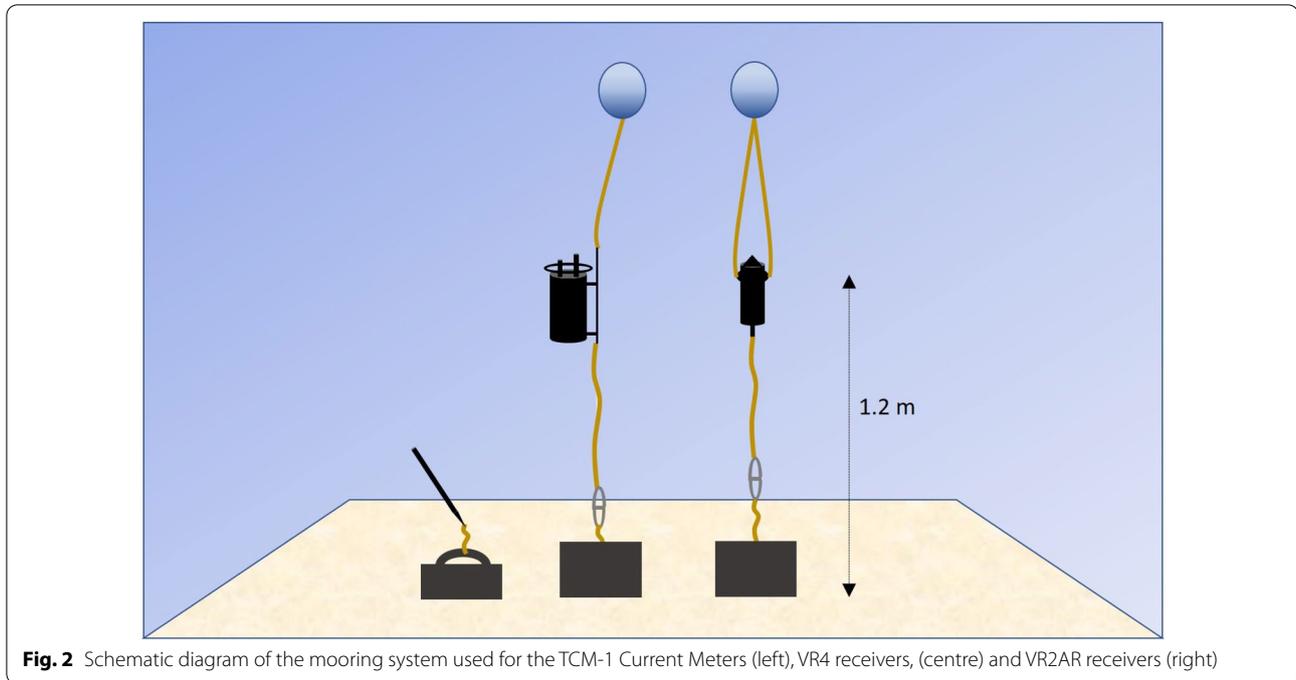
## Results

Current readings (expressed as the daily median) for the VR4 experiment were significantly greater than those observed during the VR2AR study (ANOVA;  $F_{1, 234} = 24.9$ ,  $P < 0.001$ ); there was also an increased number of high outliers during the VR4 deployment where current speed was recorded as high as  $26 \text{ cm s}^{-1}$ . Generally, receivers displayed a similar range of tilt values; however, VR4 receivers appeared to have both larger tilt angles and greater variability, compared to VR2AR receivers (Fig. 3). For VR2AR receivers, Kolmogorov-Smirnov (K-S) tests



revealed significant differences in the frequency distribution of daily and hourly aggregates (VR2AR-1,  $D=0.294$ ,  $P<0.001$ ; VR2AR-2,  $D=0.281$ ,  $P<0.001$ ; VR2AR-3,  $D=0.285$ ,  $P<0.001$ ), suggesting that aggregating readings altered the shape of the distribution. Linear regression showed significant positive relationships between mean daily current speed ( $\text{cm s}^{-1}$ ) and the tilt angle for all receivers, regardless of receiver type or frequency of measurement (Fig. 4; Table 1). Collectively, for the daily aggregated VR2AR and VR4 results suggest changes in current will result in smaller changes in tilt angle for VR2AR receiver compared to the VR4. Overall variability increased when hourly VR2AR tilt data were used (Fig. 4), although a significant positive relationship was still present (Table 1).

Standardised receiver tilt and current speed data showed a departure from a slope of equivalency ( $\beta=1$ ) for both VR4 receivers (Fig. 5; VR4 1 Walds  $F=21.69$ ,  $P<0.001$ ; VR4 2 Walds  $F=8.22$ ,  $P=0.005$ ). At lower tilt angles, the VR4 appears to over-estimate current speed; while at higher angles, current speed is underestimated. For hourly VR2AR data, VR2AR-1 standardised tilt was equivalent to current speed ( $\beta=1$ , Walds  $F=1.722$ ,  $P=0.189$ ; Fig. 5); however, VR2AR-2 and VR2AR-3 showed similar patterns to the VR4, with significant departures from equivalency (VR2AR-2 Walds  $F=1182$ ,  $P<0.001$ ; VR2AR-3 Walds  $F=1294$ ,  $P<0.001$ ), and similarly overestimating current speed at lower tilt angles, and underestimating at higher angles (Fig. 5). Detection efficiency was not affected by tilt angle, VR2AR-1 and



**Fig. 2** Schematic diagram of the mooring system used for the TCM-1 Current Meters (left), VR4 receivers, (centre) and VR2AR receivers (right)

VR2AR-3 showed only a very slight increase in hourly detection counts from the reference tag, while VR2AR-2 had a slightly negative relationship (Fig. 6). However, the fitted relationships had poor explanatory power (VR2AR-1,  $F=7.37$ ,  $R^2=0.003$ ; VR2AR-2,  $F=89.76$ ,  $R^2=0.049$ ; VR2AR-3,  $F=6.58$ ,  $R^2=0.010$ ).

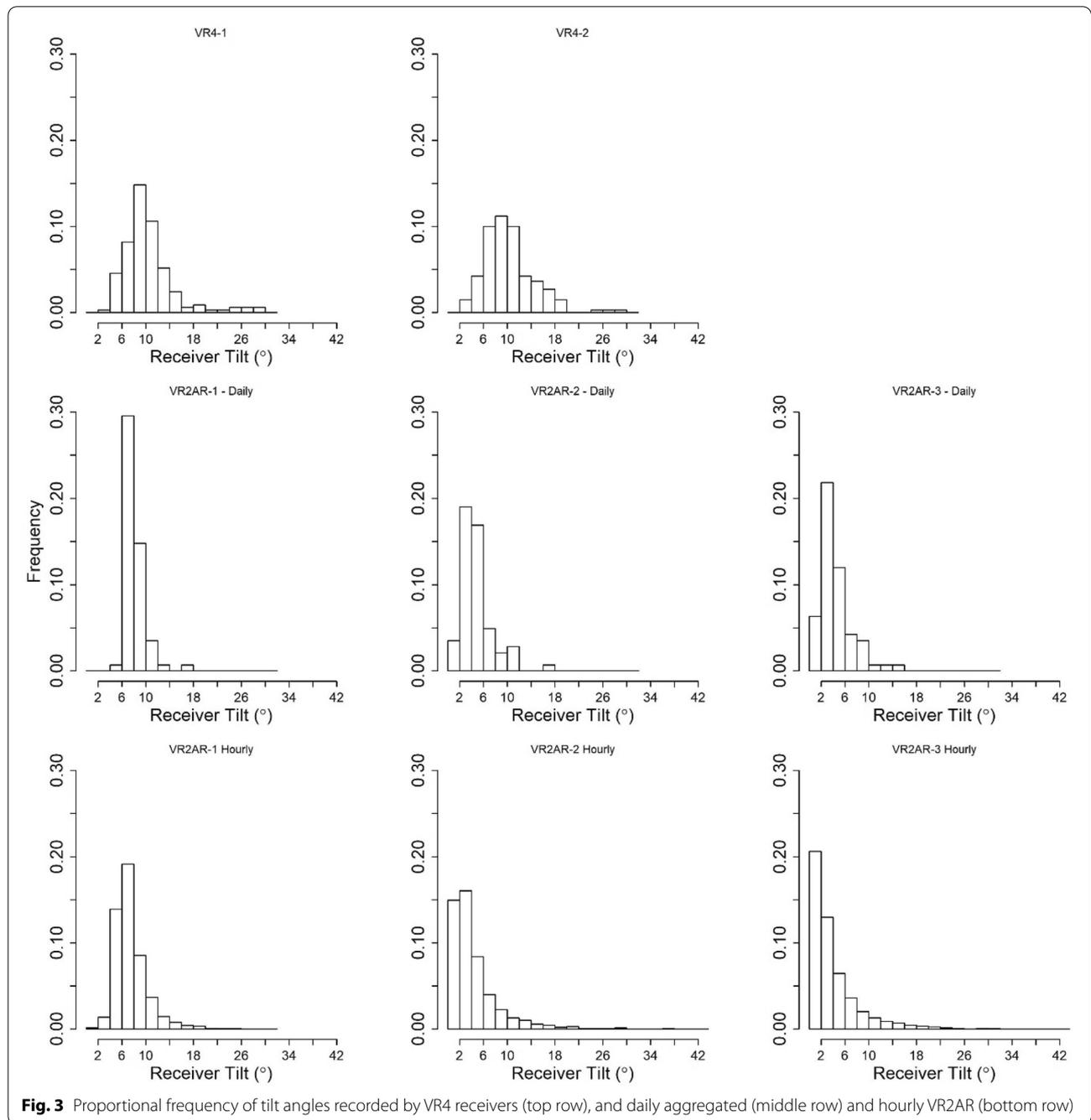
### Discussion

Under all combinations of variables tested, there was a significant positive relationship between water current and tilt angle, although the strength and nature of this relationship varied between the type of receiver used. Current speed appeared to have lesser influence on tilt for VR2AR compared to VR4 receivers. This could be due to a number of factors such as the size, shape or weight of the receiver, with the larger surface area of the VR4 resulting in currents pushing the receiver to greater angles than VR2AR receivers. Despite the nuances identified here, the results suggest that receiver tilt may present a viable proxy for current speed in acoustic telemetry studies, in the absence of dedicated current meters. While VR4 receivers may act as a useful proxy for current flow, the greater flexibility in programming and smaller size of the VR2AR may make them better suited. The increased logging frequency afforded by the VR2AR will have a negligible impact on the battery life of the receiver.

There were some broad differences among the three VR2AR receivers in terms of the slope of the relationship, how well the regression explained the data, and the

equivalency of the two variables. Specifically, VR2AR-1 appeared to display a better relationship between the two variables and showed an equivalent change in tilt in response to current speed. The two other VR2ARs tended to over-estimate current speed at lower tilt angles (similar to VR4 receivers). It is difficult to establish why this occurred, but these two receiver stations were further away from the current meter than VR2AR-1, and there were also artificial reef modules between these receivers and the meter. The modules may have somehow disrupted currents and potentially funnelled water through at greater speeds over VR2AR-2 and -3, causing higher tilt values for the same recorded speeds by the meter. These patterns suggest that differences in micro-current characteristics over short distances may be occurring, so it will be important to consider the potential influence of this over the detection range of the receiver, particularly where reef structure may be present. Furthermore, if receivers are deployed within a river or estuary, where currents can vary significantly across small spatial scales, particular care must be taken when interpreting data outputs and how these may have been influenced by the position of the equipment.

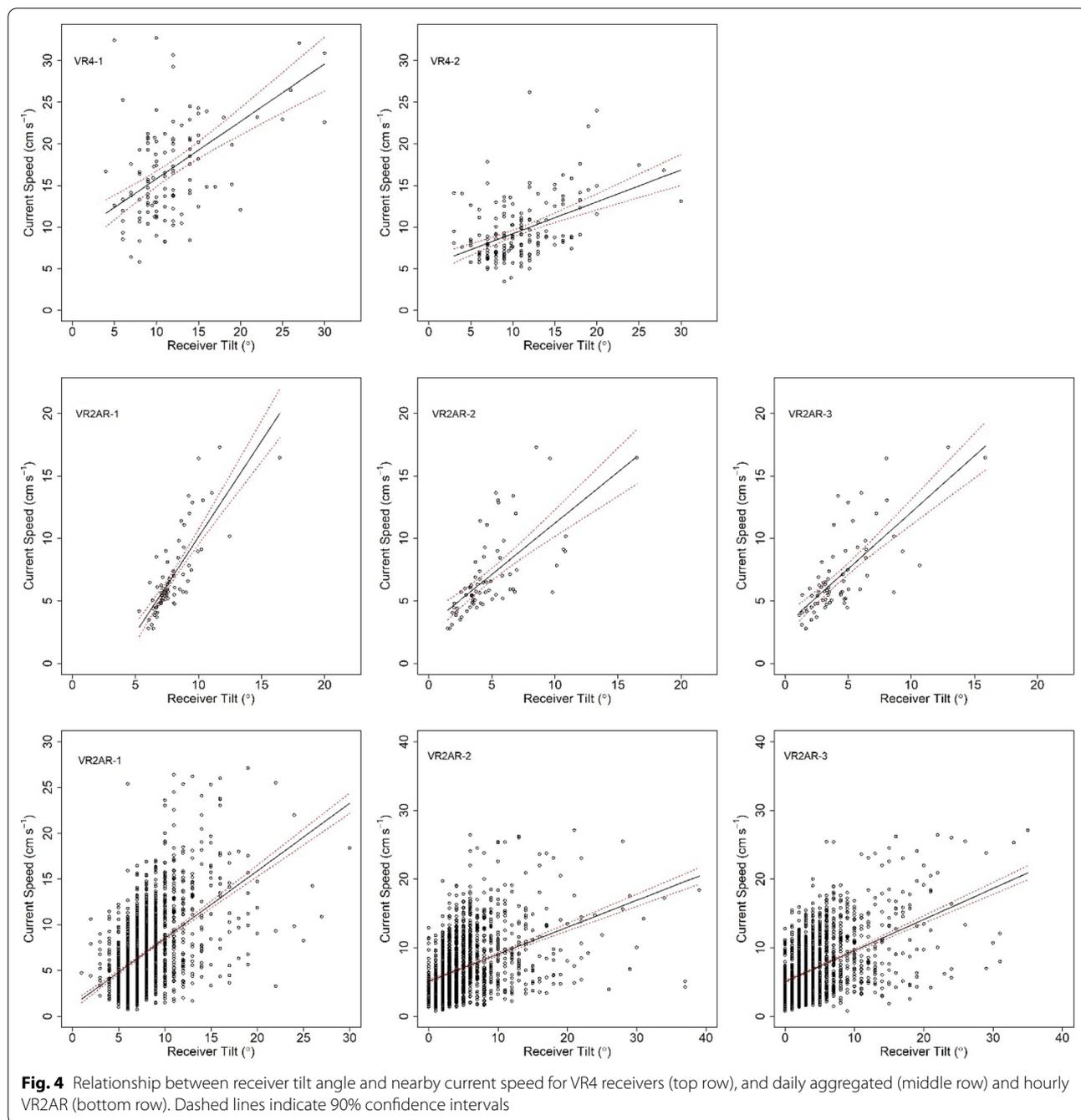
When the VR2AR data were analysed at the hourly scale, there was elevated variability observed in the relationship between current speed and tilt angle. This highlights the impact of aggregating data at different scales. In the example data presented here, there was considerable variance within each hourly bin, and



maximum speeds often exceed  $15 \text{ cm s}^{-1}$ . While the average speed over an hour might be relatively low, the instantaneous recording of the tilt angle may have occurred during a short peak in current speed, thereby increasing the variability within the relationship. We cannot speculate whether such instantaneous peaks in current speed are biologically significant, but averaging tilt over longer time periods to provide a better

aggregate of conditions over relevant temporal windows may provide better current estimates.

Given the broad incorporation of environmental parameters in analyses of acoustic telemetry data [12, 21, 22], there are obvious benefits for collecting multiple environmental variables to model the influence of abiotic factors on fish movement and behaviour. Despite flow being a common variable included in freshwater studies [e.g. 23–25], current data have not been widely

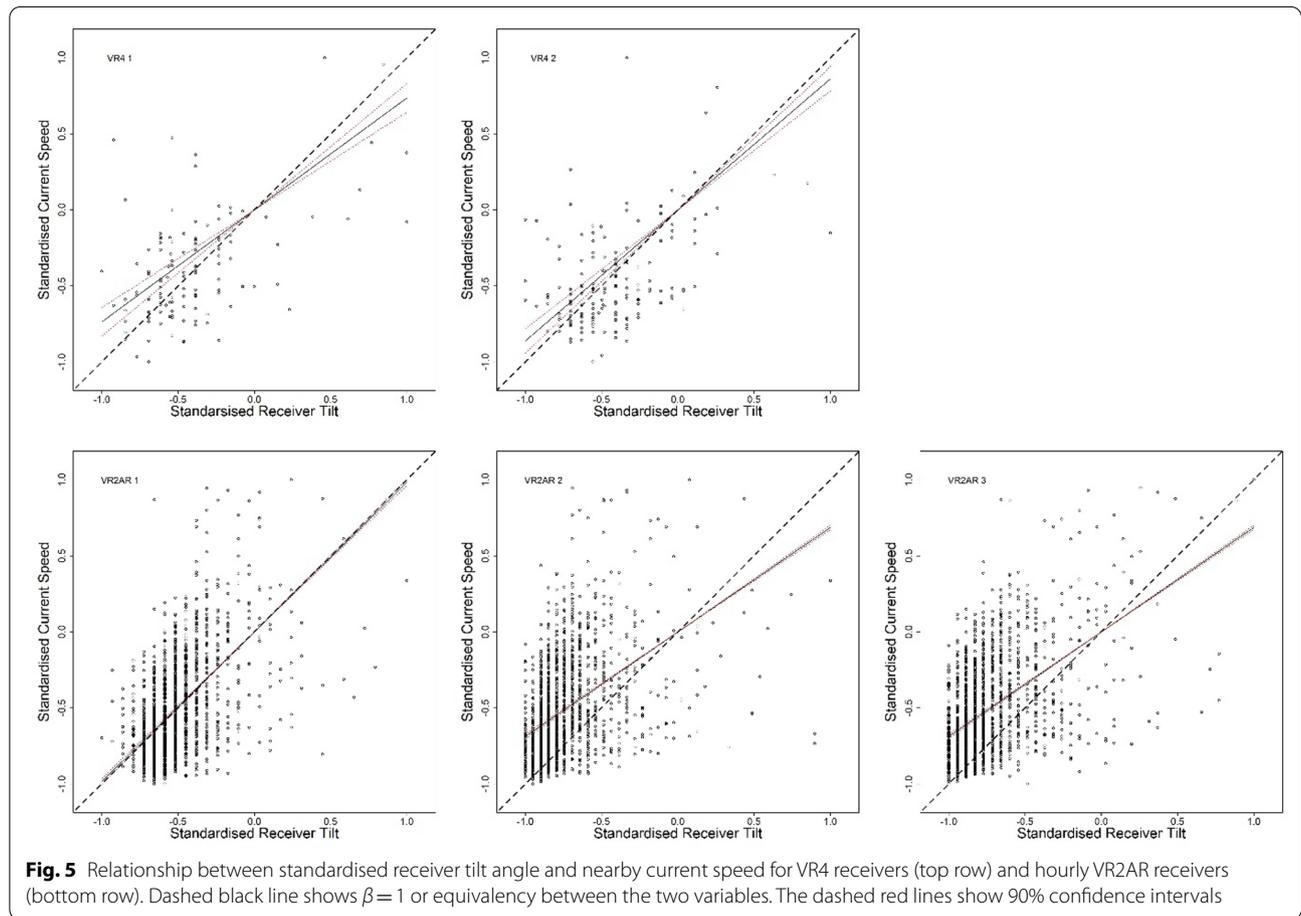


considered in marine acoustic telemetry projects. Combining patterns in relative current activity (e.g. through a proxy such as tilt angle) with fine-scale measurements of animal activity (such as through the use of activity tags) may support novel insights into the influence of water currents on fish position, habitat, movement and behaviour, particularly in open coastal systems. Positioning systems provide some of the best fine-scale data on these variables; however, it is the quality of this fine-scale

data that are most likely to suffer under “high current” conditions. Episodic events such as storms may lead to higher tilt angles due to water turbulence, which impacts tag detection rates [26, 27]. When interpreting detection patterns in relation to tilt angle as a proxy for water currents, it is important to take these effects into consideration. Although, the same caution would also need to be applied when a co-located current meter is deployed. However, the hourly detection counts of the reference

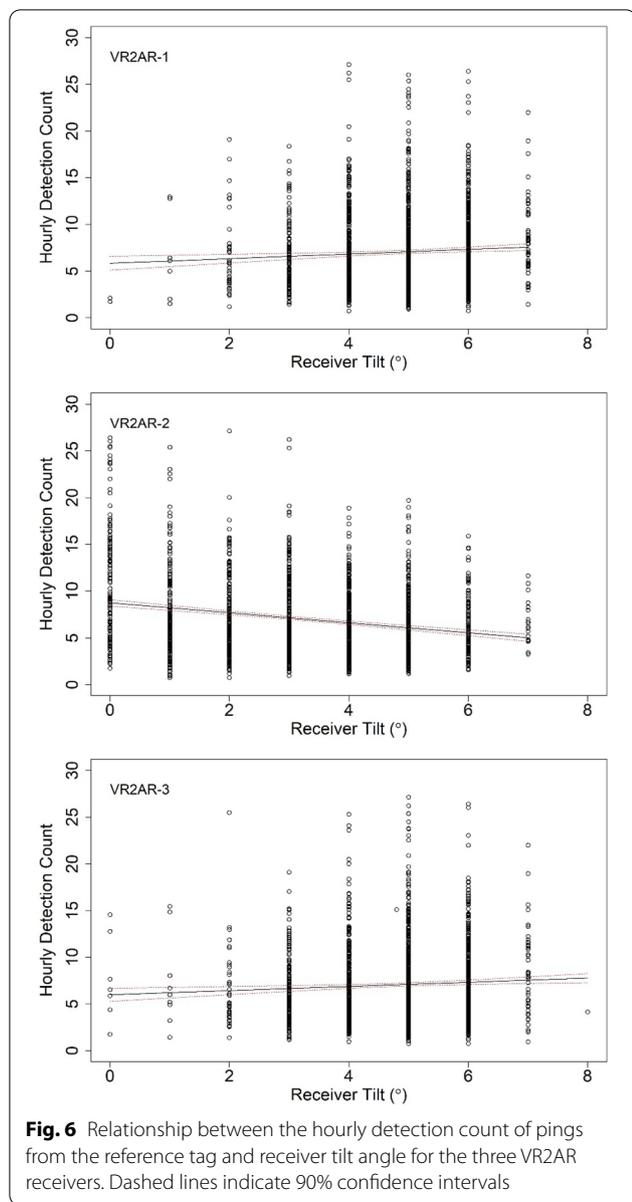
**Table 1** Details of linear regression between receiver tilt angle and nearby current speed for VR4 receivers, daily aggregated and hourly data for VR2AR receivers and standardised VR4 and hourly VR2AR datasets

Receiver	df	F	P	$\beta$	A	R <sup>2</sup>
VR4-1	1, 115	43.8	< 0.001	0.690	8.899	0.269
VR4-2	1, 115	44.4	< 0.001	0.382	5.388	0.209
VR2AR-1 Daily	1, 69	128.8	< 0.001	1.535	-5.236	0.646
VR2AR-2 Daily	1, 69	55.3	< 0.001	0.817	0.608	0.437
VR2AR-3 Daily	1, 69	84.9	< 0.001	0.902	0.502	0.545
VR2AR-1 Hourly	1, 1692	582.3	< 0.001	0.737	1.140	0.255
VR2AR-2 Hourly	1, 1692	345.7	< 0.000	0.393	5.124	0.169
VR2AR-3 Hourly	1, 1692	503.1	< 0.001	0.453	5.049	0.228
VR4-1 Standardised	1, 116	168.9	< 0.001	0.736	0.000	0.593
VR4-2 Standardised	1, 116	321.7	< 0.001	0.862	0.000	0.662
VR2AR-1 Hourly Standardised	1, 1692	6469	< 0.001	0.984	0.000	0.792
VR2AR-2 Hourly Standardised	1, 1692	5696	< 0.001	0.687	0.000	0.770
VR2AR-3 Hourly Standardised	1, 1692	6272	< 0.001	0.687	0.000	0.787



tag on the VR2AR receivers indicated no decrease in rate at higher tilt angles and, therefore, current flow. Though it may have some effect, future studies can reasonably

conclude that fewer detections during periods of higher tilt angles is not a simply artefact of reduced detection capacity of the receiver. Although not measured in this



study, biofouling is also likely to alter the relationship between tilt angle and current flow through time, where growth on the receiver could increase its weight, surface area or both, the influence of biofouling on detection efficiency has previously been demonstrated [28], but anti-fouling coatings are effective in slowing the accumulation of biofouling.

While a relationship between receiver tilt angle and current flow was found to exist, the design of the mooring will likely influence the specific nature of this relationship. For example, changing the height and buoyancy of the float will alter the amount of current

required to tilt a receiver. Therefore, some consideration prior to deployment should be given to the hydrological conditions within which the receiver will be placed, and the mooring adjusted accordingly. The approach described will allow for relative current to be measured; however if more precise data are required, calibrating the gear prior to deployment would be required. This could be achieved a number of ways including placing the receiver and mooring in a location subject to variable flow, such as an estuary or river, with a co-located current meter and measure tilt angle and current under varying conditions, or run a pilot programme in situ with a current meter.

**Conclusions**

Our data indicate that tilt angles recorded by commonly deployed acoustic receivers show promise for use as a proxy for current speed, where angular magnitude relates to increased water movement. Although tilt angle data will never fully compensate for the information current loggers provide, it can provide additional environmental data which are likely to be useful for interpreting patterns in animal movement, particularly when combined with activity tags. This approach will work best in environments that are exposed to at least moderate levels of flow, as the tilt angles may not provide the sensitivity required below speeds of 5 cm s<sup>-1</sup>. If this approach is to be incorporated, we recommended that receivers are programmed to measure and log tilt angle as frequently as possible.

**Acknowledgements**

James McLeod, Tristan New, Mitch Burns, Brad Leach, Aaron Puckeridge and Emma Mitchell assisted with the deployment and maintenance of infrastructure in this study.

**Authors' contributions**

AB, MT and ML conceived the ideas and designed the study; AB and MT analysed the data; AB, MT and ML drafted the manuscript. All authors read and approved the final manuscript.

**Funding**

This work was carried out under a research program funded by the NSW Recreational Fishing Saltwater Trust (project number DPIS037).

**Availability of data and materials**

The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

**Declarations**

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

Received: 1 September 2020 Accepted: 3 March 2021  
Published online: 02 April 2021

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