

COMPARISON OF WATER VELOCITY PROFILES THROUGH MORPHOLOGICALLY DISSIMILAR SEAGRASSES MEASURED WITH A SIMPLE AND INEXPENSIVE CURRENT METER

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ABSTRACT

The influence of seagrass morphology on water flow was studied by measuring water velocity profiles through natural seagrass meadows. An array of eight solid-state electronic current meters was used to obtain profiles through meadows of *Amphibolis griffithii* (Cymodoceaceae), a seagrass which possesses a profusely-branched erect stem with terminal leaf clusters, and two strap-like seagrasses, *Posidonia australis* and *P. sinuosa* (Posidoniaceae). Significant differences were observed in the shapes of velocity profiles of the different seagrass species; in particular, a region of high water velocity was observed beneath the leafy canopy of *Amphibolis*, but not in the *Posidonia* canopy. There is a strong correlation between the water velocity profile of *Amphibolis* plants and the distribution of leaf biomass, highlighting the influence of the 'stem-and-leaf cluster' morphology on the velocity profile. The unusual velocity profile of *Amphibolis* has implications for the ecology of these ecosystems, and sediment stability in particular. The solid-state electronic current meters used in this study were found to be an effective and inexpensive means of measuring water velocity profiles in seagrass canopies.

While there has been considerable interest in the community structure of seagrasses, and how they occur together, little work has been done on hydrodynamic differences between species. Most studies of the physical ecology of seagrasses have concentrated only on *Zostera marina* (Ackerman, 1983; Gambi et al., 1990; Ackerman and Okubo, 1993), although there have been some notable exceptions. Fonseca and co-workers have studied the physical environment of a variety of seagrasses (Fonseca et al., 1982, 1983; Fonseca and Fisher, 1986; Fonseca and Kenworthy, 1987; Fonseca and Cahalan, 1992) while Koch and co-workers have focused on different populations of *Thalassia testudinum* and *Cymodocea nodosa* (Koch 1994, 1996, 1999a,b; Koch and Gust, 1999). Their work to date has included an assortment of hydrodynamic studies, physiological and geochemical work, wave attenuation and sediment entrapment studies.

While these studies have begun to address important questions about the physical environment of seagrass meadows, the majority of south-Western Australian seagrass habitats are markedly different to those occurring on the east coast of the United States, where most work has taken place. One of the major differences is the hydrology of the sea in which these plants grow: while many of the studies from the USA deal with seagrasses from sheltered, tidal flow regimes, the majority of south-Western Australian seagrasses grow in oceanic environments, and are exposed to orbital swell waves (Kirkman and Kuo, 1990). The physical processes in tide- versus wave-dominated seagrass can differ significantly (Koch and Gust, 1999).

A second difference between seagrass studies in the USA and Australia is the morphology of the plants. Major meadow-forming seagrasses in the USA, such as *Z. marina* and *T. testudinum*, have strap-like leaves. Although strap-leafed seagrass species, such as *Posidonia sinuosa* and *P. australis*, comprise a proportion of Western Australian seagrasses, the genus *Amphibolis* is also common and widespread in southern Australia.

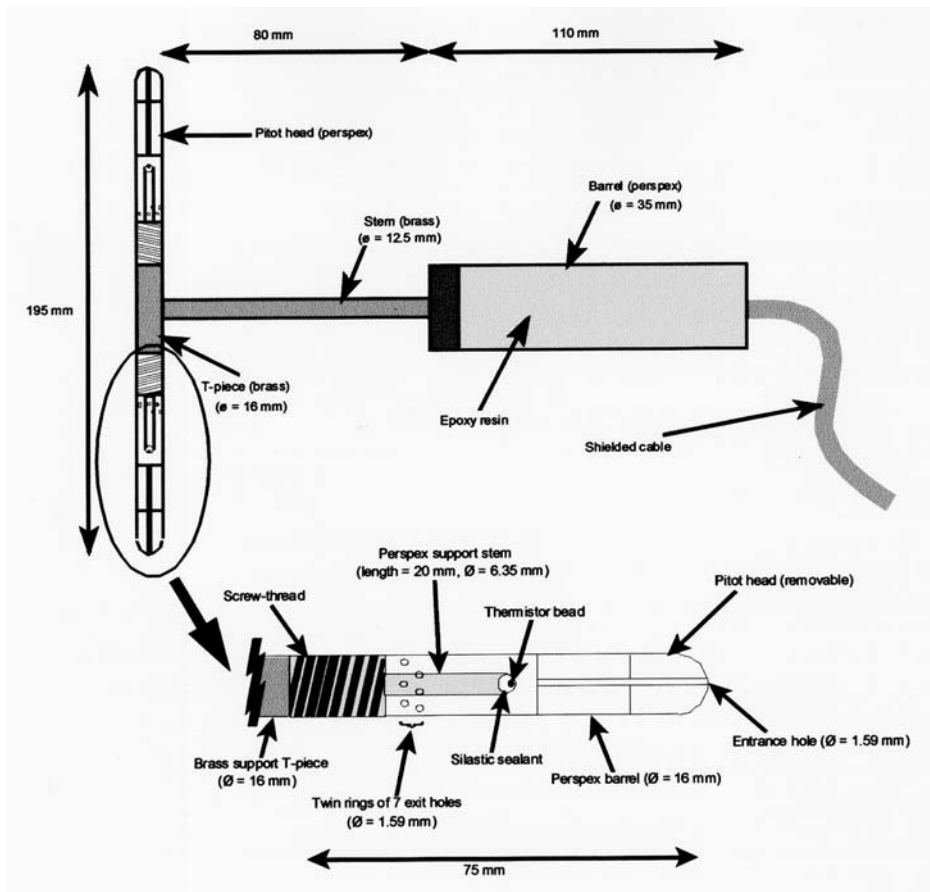


Figure 1. Plan diagram of electronic current meter with detail of pitot head.

Posidonia leaves occur as bundles of several strap-like blades, emerging from a sheath; relatively minor differences in leaf morphology, such as leaf width and curvature, are observed in different species (Cambridge and Kuo, 1979). By contrast, *Amphibolis* possesses a profusely branched erect stem with terminal leaf clusters (Phillips and Meñez, 1988). The unusual morphology of this seagrass may have significant implications for its hydrodynamic behaviour. *Amphibolis* meadows have been described as influencing sediment stability, especially in sediment bank formation in Shark Bay (Walker and Woelkerling, 1988; Walker, 1989).

Borowitzka and co-workers (Borowitzka and Lethbridge, 1989; Borowitzka et al., 1990) noted significant differences in epiphyte abundance and distribution between *Posidonia* and *Amphibolis*, and suggested that water motion may be a contributing factor in causing these differences. Trautman and Borowitzka (1999) observed that the relatively minor morphological differences between *P. sinuosa* and *P. australis* produced differences in water flow over the leaf surface, and postulated that this was responsible for observed differences in epiphyte distribution in the two species.

Most flow studies in the laboratory have been undertaken in unidirectional flumes, which can only approximate the hydrodynamic environment. Davis (1986) emphasised

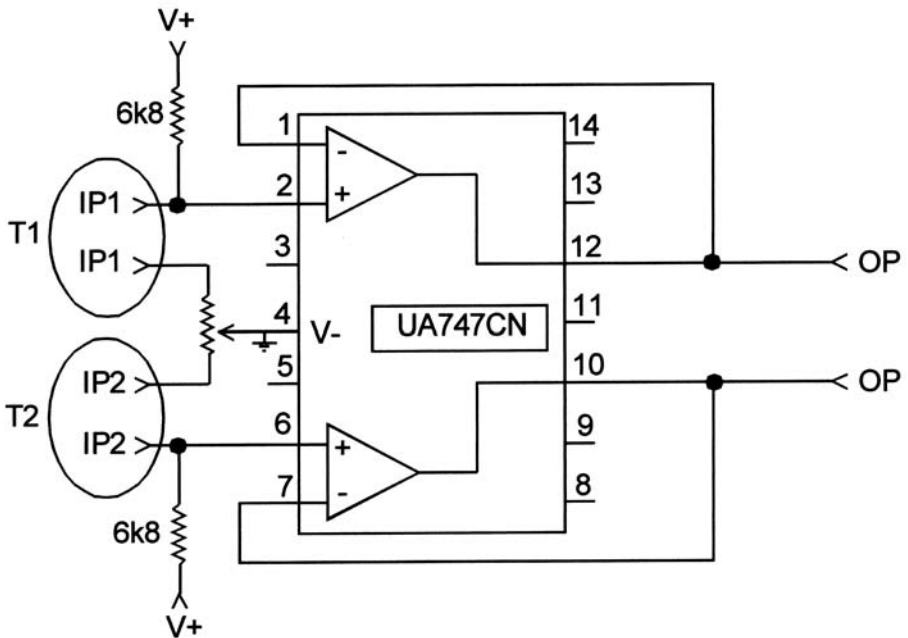


Figure 2. Diagram of amplification circuitry for the electronic current meters. T1 and T2 represent the thermistor sensors, IP and OP represent input and output respectively.

the need for ecologists to characterize water flow as part of their field measurements. An obvious solution is to conduct field experiments under controlled conditions. Recent work has employed a variety of instruments that can accurately measure water flow in the field (Koch, 1994; Verduin, 1996; Verduin and Backhaus, 2000), representing an important step forward in field studies of seagrasses.

Many of the instruments used to make these field measurements are complicated and very expensive, therefore placing them out of reach of students and researchers, especially in developing countries. Their expense also precludes the simultaneous deployment of several instruments, to characterise water velocity profiles through seagrass canopies. There is a clear need for less expensive methods of measuring water flow in the field. Vogel (1981) described a variety of inexpensive instruments that can be easily manufactured in non-sophisticated workshops; a particularly appropriate field instrument he described was a solid-state electronic current meter.

Solid-state electronic current meters were introduced for oceanographic work in the late 1960s (Caldwell, 1968) and have more recently been used in ecological applications (LaBarbera and Vogel, 1976; Vogel, 1981). Steedman (1972, 1975) designed a solid-state electronic current meter that used transistors as sensing elements, and a pitot-head to provide spatial resolution. This design enabled accurate measurements of three-dimensional current flow within shallow sea boundary layers as part of a remotely deployed oceanographic instrumentation package. A dual-head design enabled the measurement of bi-directional flow, as commonly observed in shallow coastal environments, and an array of several meters can be deployed to measure orbital velocities and obtain water velocity profiles. Steedman's (1972, 1975) design was modified for use in this study.

This paper quantifies differences in the in situ flow environment of local, morphologically dissimilar seagrasses, using an array of electronic thermistor-based current meters. Three species, *Amphibolis griffithii*, *P. sinuosa* and *P. australis*, were chosen for this study, to examine the influence of both large-scale (*Amphibolis* vs *Posidonia*) and small-scale (*P. sinuosa* vs *P. australis*) morphological differences on water velocity profiles through the canopy. The water flow regime of seagrass meadows can have a significant bearing on several environmental variables, including sediment and meadow stability. Characterisation of the flow environment is an important first step in the understanding of a number of ecological processes and functions in seagrass habitats.

METHODS

Patches of *P. australis* Hook f. and *P. sinuosa* Cambridge & Kuo were chosen in Shoalwater Bay (approximately 6427800 mN, 3771100 mE, AMG), and a patch of *A. griffithii* (J. M. Black) den Hartog was selected in northern Warnbro Sound near Penguin Island (approximately 6424500 mN, 376800 mE, AMG), all south of Perth, Western. A homogeneous seagrass meadow produces maximum reduction of flow within approximately 1 m of the meadow edge (Fonseca and Kenworthy, 1987). Patches of at least 5 × 5 m were therefore selected, to avoid any possible edge effects. Water depth over the patches was between 1.5 and 2.5 m. Tides in the region are diurnal, and amplitude is approximately ± 0.5 m. This region is exposed to orbital swell waves, and waves generated by the prevailing winds. In summer, shallow coastal areas are dominated by waves generated by a sea breeze coming from the south-west.

Measurements of the water velocity profiles within the selected patches were carried out using thermistor-based electronic current meters, as described in detail in the Appendix. The current meters were arranged on an aluminium frame, in perpendicular pairs at heights of 5, 20, 35 and 65 cm above the seabed, to enable measurement of flow direction and velocity through the canopy. Flow measurements at the different sites were conducted as close together as possible to minimize the time difference (and hence sea and weather conditions). Sampling was conducted at a frequency of approximately 2 Hz, for a period of approximately 5 min in each patch of seagrass; the flow data was averaged over this period. The measurements presented here were made on a single occasion (early afternoon, March 18, 1993), to prevent different weather conditions confounding the data.

RESULTS

Weather conditions during the sampling period consisted of moderate WSW winds, with a 1–1.5 m swell. The raw field data were converted to velocities in cm s^{-1} using a four-parameter logistic function, based on each meter's specific characteristics, as determined by laboratory calibration (van Keulen, 1998). Water velocity data were then combined into overall velocity and direction for the four heights at which measurements were made.

The combined velocity measurements were plotted as mean velocity profiles through the four seagrass meadows (Fig. 3). These plots reveal differences between the meadows, and a particularly striking difference between *Posidonia* and the *Amphibolis* meadows. The profile through the *Amphibolis* meadow shows a clear peak in water velocity at approximately 20 cm above the seabed, which is markedly different from the relatively smooth decrease in water velocity with increasing depth shown by the three *Posidonia* profiles. Differences in overall velocity between meadows are not clearly discernible

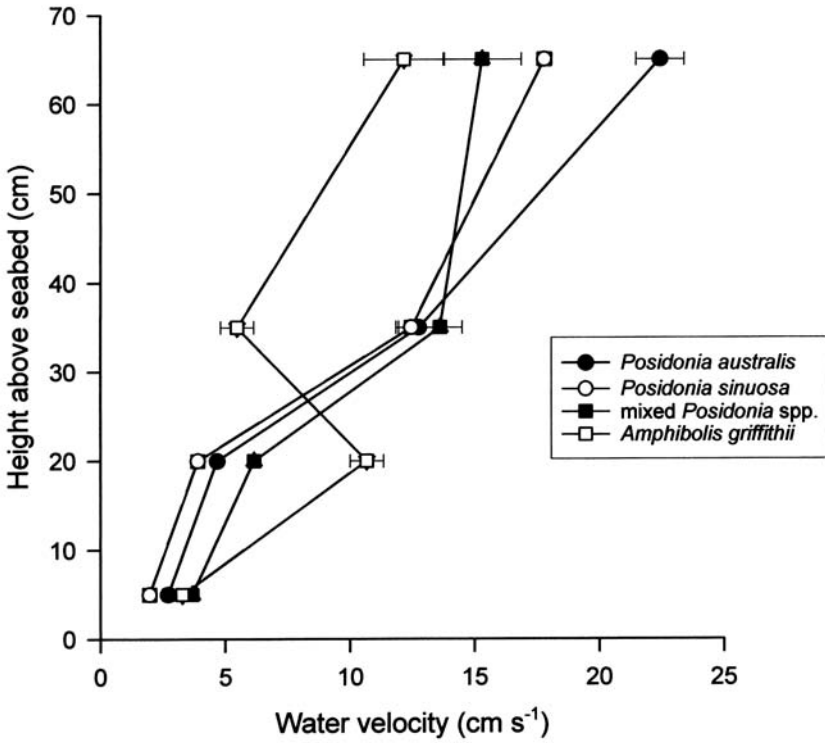


Figure 3. Mean velocity profiles (\pm SE) of seagrasses tested. Each curve represents the velocity profile for that seagrass. Approximate canopy heights were: *Posidonia sinuosa* 70 cm, *Posidonia australis* 35 cm, *Amphibolis griffithii* 45 cm.

from Figure 3, due to the different shapes of the profiles. A two-way ANOVA was conducted on the velocity profiles of the different meadows, and revealed clear differences between the profiles of the different species. A significant two-way interaction between height above the seabed and species ($F_{9,772} = 20.19$, $P < 0.001$) showed that the profiles are different between species. Figure 4 clearly shows an important difference between *A. griffithii* and the *Posidonia* spp. velocity profiles, with a peak in flow beneath the canopy.

A Tukey test revealed that the differences between the mean water velocities of *P. australis* and *A. griffithii*, and *P. australis* and *P. sinuosa*, were significant at $P = 0.05$. This suggests the existence of a gradient in mean water velocities as follows: *P. australis* $>$ *P. sinuosa* $>$ *A. griffithii*. The implication of this gradient is that *A. griffithii* blocks most flow and *P. australis* the least.

When the water velocity profiles obtained in this experiment are superimposed on a plots of leaf density data obtained from within the same seagrass meadows, a close relationship is evident (Fig. 4). The water velocity profiles can be seen to closely follow the leaf density at each height for each species, with the peak in water velocity in the *A. griffithii* profile matching the reduced leaf density at approximately 20 cm above the seabed. The three *Posidonia* profiles show gradually increasing water velocity with increasing height above the seabed, reflecting the relatively uniform canopy density from leaf base to tip. There is clearly a much higher rate of water flow in the medium-lower

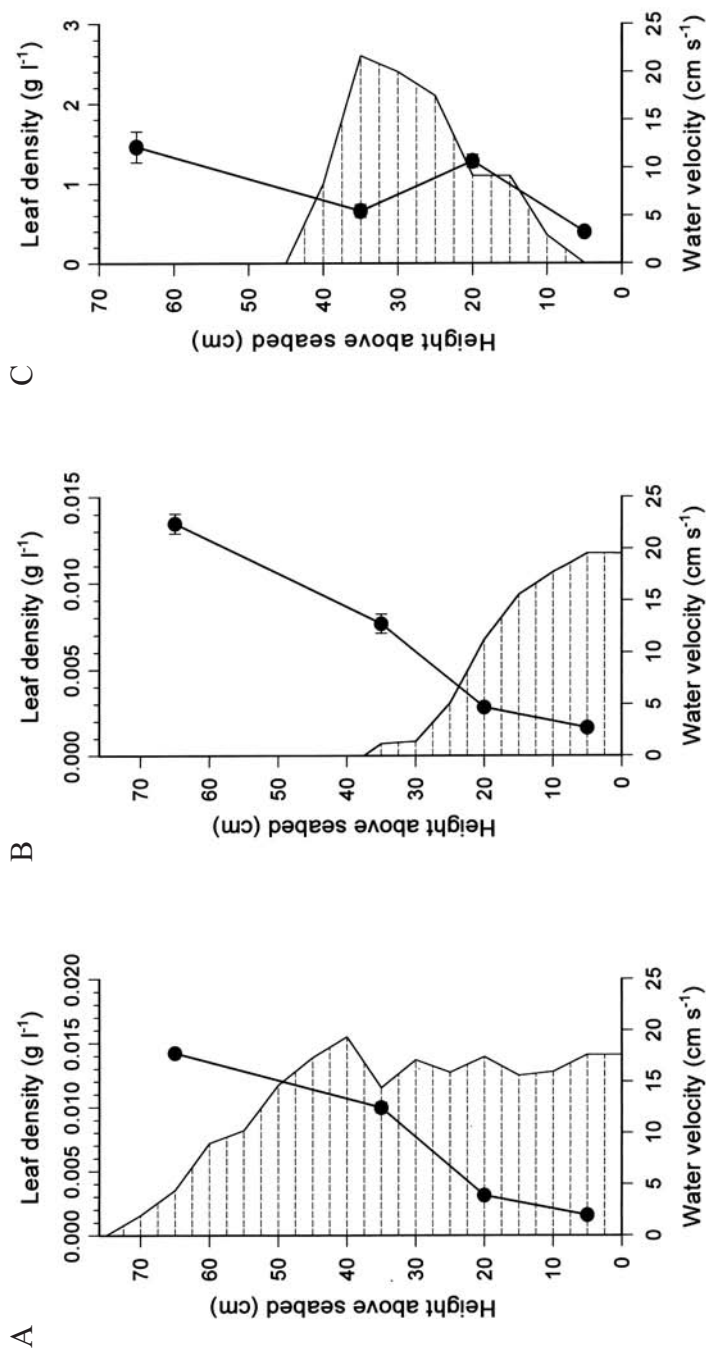


Figure 4. The influence of seagrass canopies on the water velocity profile. A: *Posidonia sinuosa*, B: *Posidonia australis*, C: *Amphibolis griffithii*. The water velocity profiles from this study are superimposed on plots of leaf density (data for *Amphibolis griffithii* after Caruthers & Walker, 1997). (Error bars represent standard error.)

sections of the *Amphibolis* canopy than in the *Posidonia* canopies, before a decrease in water velocity near the seabed, for both *Posidonia* and *Amphibolis*.

DISCUSSION

Some of the water flow profiles through seagrass canopies which have been published to date (Fonseca and Kenworthy, 1987; Gambi et al., 1990, Koch and Gust 1999) have included profiles which show a relatively smooth transition from open water flow above the canopy to diminished flow within the canopy, akin to the boundary layer over a smooth bed (Davis, 1986). The profiles presented in this study for the *Posidonia* species appear very similar to profiles reported for strap-like species in the USA. The flow appears to be smoothly directed over the canopy, as a result of the more streamlined nature of the canopy. The canopy of *Amphibolis* meadows presents a more abrupt physical profile to the flow, and so acts as more of a 'bluff body'. This would be expected to place a greater strain on the canopy, and may account for the more abrupt decline in water velocity, as seen in the *Amphibolis* water velocity profile (Fig. 3). This study confirms preliminary results from studies by van Keulen (1987) and recent experiments by Verduin and Backhaus (2000), which indicated that *A. griffithii* profiles may be different to those of other seagrasses, as a result of their unusual morphological characteristics. Koch and Gust (1999) attributed the abruptness of the velocity profile to unidirectional flows (tide-dominated) as well as the high density of some *T. testudinum* meadows. The abrupt velocity profile, and the density of the *Amphibolis* canopy studied here supports these conclusions.

Ackerman and Okubo (1993) noted that the velocity profile of *Z. marina* closely matched the relative leaf area, as also shown by Koch (1996), Verduin and Backhaus (2000). The correspondence between leaf density and the water velocity profile observed in Figure 4 confirms these findings. *Amphibolis*, with its characteristic stem and leaf cluster morphology, presents a gap in the canopy, allowing water to flow beneath the main canopy. By contrast, *Posidonia* plants have a uniform leaf shape, maintaining the same leaf width from base to tip (although an increase in canopy density will occur as leaves emerge from their sheaths). This means that there is no gap for water to flow through, and hence results in a smoothly decreasing water velocity profile.

The implications of these findings are of particular interest in terms of the stability of sediments in seagrass meadows. It is likely that the full force of flow on an *Amphibolis* canopy is still somewhat reduced even by the 'leaking' flow beneath the canopy. A relatively high rate of water flow beneath the canopy, as observed in the *A. griffithii* studied here, might be expected to compromise the ability of the meadow to deposit sediment particles, and may have important implications for meadow stability. The amount of flow at the seabed appears to be quite small however, and is comparable to that in the *Posidonia* meadows. This may be sufficient to reduce resuspension of sediment under normal weather conditions. Nonetheless, Walker et al. (1996) reported the presence of large sand waves through meadows of *A. griffithii*. This may be due to storm events, which may be able to more easily penetrate the *Amphibolis* canopy than the *Posidonia* canopy. It is obvious that the hydrodynamic conditions existing within *Amphibolis* meadows are not simple, and the stability of these meadows in the face of turbulent conditions requires further study.

The results presented in this study indicate that clear differences exist between water velocity profiles of different seagrass species. Future studies will address the role of hydrodynamics on these aspects of the seagrass meadow environment, especially sediments and epiphytes.

ACKNOWLEDGMENTS

This study was partially funded by a Murdoch University Research Scholarship to MvK. We are grateful to L. Brain for assistance with the field work.

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APPENDIX

DEVELOPMENT OF THE ELECTRONIC CURRENT METERS.—The solid-state electronic current meters used in this study each comprises of two round-nosed pitot tubes, placed back-to-back (Fig. 1). The current meters operate through a temperature differential acting between the two thermistor sensors, one of which acts as a thermal reference to the other. The difference in power consumption generated by this temperature differential is amplified in a custom signal amplification circuit before logging. The pitot heads were machined from Perspex tubing for the barrel section, and Perspex rod for the round-nosed pitot head, which slid into the barrel (see Fig. 2). The barrel was screwed onto a section of brass tube of the same diameter. This was screwed perpendicularly onto a handle unit, comprising a section of brass tube attached to a Perspex tube filled with epoxy resin. This served the dual purpose of protecting the join between the sensor wires and shielded communication cable, leading to the support vessel, and acting as a convenient point at which the meter could be attached to a deployment frame.

The entry to the pitot head was via an inlet hole in the rounded nose (Fig. 2). The thermistor protruded from the end of a thin Perspex tube within the head. The exits were two parallel rings of seven holes in the barrel of the pitot tube, behind the sensing element. With a large number of exit holes the exit velocity would be low compared to the stream velocity, and hence there would be little effect on the flow being measured by the thermistor probe; that is, a negligible back-pressure within the pitot head.

A negative temperature coefficient thermistor bead (R.S. Components 151-142) was selected as the sensor for this instrument. This was a 'miniature bead' sensor, mounted in glass, with a head diameter of 1.5 mm. The resistance of this class of thermistor ranged from 4.7 kW at 25°C to 271W when hot; the thermal time constant (that is, 63% change) was 5 s (Anon., 1982). Laboratory tests showed that the temperature response of the paired thermistors was linear over the general operating temperatures encountered locally (15–35°C).

The output voltages of the thermistor probes were fed into an amplifier circuit (Fig. 3), with the resulting output voltage being simply the product of the amplifier gain and the voltage differential of the two pitot heads. The circuit comprised a commercially available dual amplifier chip (R.S. Components UA747CN dual μ 741 op-amp chip) with the outputs connected to the analogue input channels of the data logger (Datataker DT100F, Data Electronics (Australia) P/L). The null output of the meter could be trimmed by means of a potentiometer incorporated into the circuit. The amplification circuitry was inserted between the input patch panel and the processing circuitry of the data logger. Interference from the electronics of the data logger required shielding of the amplification circuit; this was achieved by enclosing the circuit board in aluminium foil, which was grounded to the data logger's earth rail. The entire amplifier circuit board was then insulated with anti-static plastic. Power to run the meters (5 V DC) was obtained from the constant power-supply rail of the data logger.

Calibration of the current meters was carried out at a series of known flow regimes in a calibrated variable-speed laboratory flume. Calibration of the flume was carried out using a Marsh-McBirney portable current meter (model 201M, Marsh-McBirney Inc.).

An output stabilisation period of 30 min. was allowed before readings were taken. This enabled the thermistors to stabilise in relation to the ambient temperature. Each meter had its own calibration characteristics, determined by the individual differences between

electrical components, particularly the thermistor sensors. From measured outputs at known water velocities in the laboratory flume, calibration curves were constructed for each meter over a flow range of approximately $0.2\text{--}30\text{ cm s}^{-1}$, which was a velocity range most likely to be encountered in normal (that is, non-storm) conditions within local seagrass meadows (unpublished observations). Because of the very small potentials generated by the meters, shielded communications cables were used to connect the meters to the data logger on the support vessel.

At the end of the stabilisation period, a 5 min sample of all channels was collected, being the temperature-acclimatized calibration data set. This was used to convert the data to velocity in cm s^{-1} in the laboratory. Pre-measurement calibration was carried out in situ, by measuring the null output with each pitot head enclosed within a closed tubular sleeve, preventing water flow through the meter. Samples were then collected over 5 min periods at the maximum sampling rate of the data logger, using a repeated scan.

While water velocity measurements have been traditionally viewed as the domain of engineers and physical oceanographers, there is clearly a need for more aquatic ecologists to consider the influence of water motion on their domain of study. The expense of water velocity measurement techniques typically employed by practitioners of engineering and oceanography has largely precluded their adoption by ecologists, particularly in developing countries and in student projects. The water velocity probes described here are simple to construct, and are sufficiently sensitive and flexible to enable ecologically appropriate flow measurements to be made in a wide variety of aquatic habitats. It is hoped that their low cost will encourage a larger proportion of the ecological community to include flow measurements in their studies.