

Biology HL Internal Assessment

Theme: Ecology

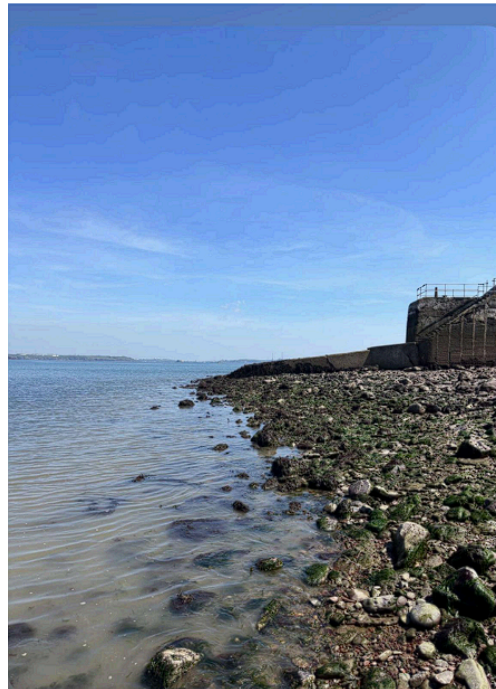
Research Question: How does the height above chart datum affect the height-to-width ratio of common limpets (*Patella vulgata*) on Jetty Beach (SM 822 053)?

Word count: 2967

Introduction:

Jetty Beach (Grid reference: SM 822 053) is a sheltered rocky shore in Pembrokeshire with low wave exposure and a red sandstone substrate (Pembrokeshire Coast National Park Authority). Its consistent limpet population and accessibility made it suitable for vertical sampling (Fig. 1).

Figure 1. Photo taken by a student. Jetty Beach, Pembrokeshire, Wales.



The common Limpet (*Patella vulgata*) is a frequently occurring intertidal marine gastropod common to Western European rocky shores, whose grazing activity on algae plays a crucial role in shaping rocky shore communities (JD and S Fish, 1996). Due to a natural gradient in height above the chart datum caused by tidal changes, limpets are exposed to differing environmental conditions depending on their positions above the chart datum. The height at which limpets are located causes variations in emersion time, temperature, wave action, and food availability. The aforementioned abiotic factors can cause morphological adaptations, mainly seen in the height and width of the limpet's shell.

While limpets can be found at all tidal heights, the common limpet tends to be most concentrated around the middle shore, balancing feeding opportunity and desiccation stress (JD and S Fish, 1996). Limpets that are found on the higher shore tend to experience greater desiccation stress and reduced access to food, which can affect their growth and lead to taller, but narrower shells. Differences in shell size are thought to occur due to less tissue pressure from under the shell as a result of a lack of nutrition. In contrast, limpets that are located on the lower shore tend to be submerged for a longer period in areas where they have greater access to algae and can grow wider and shorter shells that can resist stronger wave action (Thomson and Cremona, 2019).

The shell morphology of common limpets is also influenced by age, with older limpets tending to be larger and found on the lower shore. (JD and S Fish, 1996). Other factors that are known to impact the morphology of limpets are the hardness and slope of the rock on which they reside; however, it is commonly accepted that height above chart datum is the most significant factor regarding shell shape (JD and S Fish, 1996). It is also known that there is a correlation between temperature extremes and the shape of a Limpet's shell, which is mainly seen in the upper shore, where the shore is exposed to air and direct sunlight more so than the lower shore. Temperature contributes to increased desiccation stress and may limit feeding opportunities, influencing shell development (Fretter and Graham, 1976). However, it is important to note that temperature is mainly influenced by height above chart datum on the rocky shore; thus, chart datum remains the most significant factor in shell morphology, and it can be tied to various kinds of environmental stressors.

This investigation aims to determine how height above the chart datum affects the height-to-width ratio of *Patella vulgata* on Jetty Beach. The method chosen and described below allowed for systematic sampling over a range of tidal zones to assess if the trend in a shell morphology corresponds with varying exposure based on height above chart datum.

Biological Hypothesis:

As the height above the chart datum increases, it is expected that the height-to-width ratio of *Patella vulgata* also increases. This is because common limpets located on the upper shore will experience a longer period of emersion, higher temperature fluctuations, and therefore, greater desiccation stress. This will limit their feeding time and reduce tissue pressure from inside the shell, resulting in a narrower and taller shell (Thomson and Cremona, 2019). To account for the fact that limpet size is also largely dependent on age, the method of a height-to-width ratio will allow us to get a quantitative value for shell shape rather than a measurement of absolute size, which will allow the investigation to focus on differences in morphological adaptations rather than differences in growth, concordant with the methodology used in Fretter and Graham's (1976) work.

Pilot investigation:

Jetty Beach was visited before to observe limpet distribution on the shore. The qualitative observation was made that with bigger tidal heights, the shape of the shells of *Patella vulgata* had noticeable differences. Limpets on the lower shore appeared broader and flatter, while those that were higher up had a taller, yet narrower shell. This observation led to an investigation of the pattern between tidal height and morphological adaptations, choosing a height-to-width ratio as a method of measuring these differences.

Main Experiment:

Variables:

Independent: Height above chart datum (m)

Height above chart datum refers to the vertical distance (in meters) between the location of sampled limpets and the baseline sea level used to calculate tide height. This variable reflects the vertical position on the rocky shore of Jetty beach of a limpet, which is also directly related to the environmental conditions and abiotic factors that impact *Patella vulgata*. The main abiotic factors that vertical positioning affects are immersion time, desiccation stress, and temperature extremes; These abiotic factors primarily result in changes in food availability which allow the morphology of limpets to change as outlined in previously cited research.

Dependent: Height-to-width ratio of *Patella vulgata* shells (no unit of measurement)

The height-to-width ratio reflects the overall shape of *Patella vulgata* and quantitatively describes the morphological adaptations to environmental stress associated with varying vertical position on the rocky shore of Jetty beach. A higher overall ratio indicates a shell that is taller and narrower; meanwhile, a smaller ratio would be indicative of a flatter and wider shell. This method of measurement was chosen as it is more accurate and representative of the common limpet's adaptations to its environment, and not age, which is correlated with a proportional increase in both height and weight (Fretter and Graham, 1976).

Each individual's height-to-width ratio was calculated by dividing the height by the width, using the following formula:

$$\text{height to width ratio} = \frac{\text{Height}}{\text{width}}$$

The height-to-width ratios were averaged for every single quadrat, producing one value per data point (50x50 cm quadrat placed in 30 cm intervals).

Controlled:

- Tidal conditions and Sampling time: All samples were collected on the same day (15th of May, 2025) and during a low tide period; similar conditions were present during the entire data collection process.
- Quadrat size and placement: The same 0.25 m^2 quadrat was used at each sampling point, standardizing sample area for better comparability.

- General location and habitat: All samples were collected from the same vertical stretch of Jetty Beach. It is important to note that the slope and texture of the rock surface were not controlled in the investigation. The choice was made to take measurements within the same area (quadrat) to minimize any inconsistency, see evaluation for discussion.
- Wave exposure and climate: The measured section of Jetty Beach is a highly sheltered beach with relatively low wave action, measured at a 6 on the Ballantine scale, a scale to measure exposure to wave action in the local area (Ballantine, 1961).
- Temperature: measurements at locations of samples showed very slight variation of 0.1-0.3 °C (see appendix table A.1) that proved not correlated with height, indicating that height above chart datum was the primary independent environmental variable. While potentially significant, long term data necessary for significant trend to be seen.
- Limpet species identification: All sampled individuals of *Parella vulgata* were visually identified as such.

Equipment and uncertainty:

Table 1. Equipment, equipment uncertainties, and a short description of instruments.

Equipment	Purpose	Uncertainty / Precision
Vernier caliper	Measuring the height (apex to base) and width (widest point) of limpets	± 0.25 mm
Digital temperature probe	Monitoring ambient temperature at each sampling height (for context only)	± 0.1 °C
50 × 50 cm plastic quadrat	Defining a consistent 0.25 m ² sampling area at each tidal height	N/A (systematic error if deformed)
Meter ruler (1 m)	Measuring 30 cm vertical intervals along the shore, using the chart datum and tidal data as references	± 0.5 mm
Simple wooden level with groove (seen in figure 2)	Ensuring vertical alignment when moving up in 30 cm height intervals	Qualitative alignment
Field notebook and pencil	Recording all measurement data and other field observations	N/A

Calculator/spreadsheet	Calculating height-to-width ratios and averaging data	N/A
Protective gloves	Personal safety while handling rocky surfaces covered in barnacles	N/A
Cleaning materials (cloth)	Used to clean the caliper between limpet measurements	N/A

Uncertainty propagation:

Shell width and height were measured via a vernier caliper with the uncertainty of ± 0.25 mm. For each limpet, height to width ratio was calculated as follows:

$$\text{height to width ratio} = \frac{\text{Height}}{\text{width}}$$

To propagate measurement uncertainty into the ratio, fractional uncertainties were adopted as it was impossible to use the standard error of the mean (SEM) methodology. This was because mean values in multiple cases were calculated using fewer than 3 values due to the lack of availability of limpets in the quadrat placement. The result ΔR was obtained (uncertainty for each ratio, done for all heights), where h stands for height, w for width, Δh and Δw are uncertainties for the measurements (± 0.25 mm).

$$\frac{\Delta R}{R} = \frac{\Delta h}{h} + \frac{\Delta w}{w} \Rightarrow \Delta R = R \left(\frac{\Delta h}{h} + \frac{\Delta w}{w} \right)$$

Because one mean value was per tidal height, uncertainty was propagated into the mean ratio at each tidal height. This was done by the following formula, $\overline{\Delta R}$ which represents the mean propagated uncertainty for the ratio at tidal height (used in formal analysis in Figure 4 as error bars), and n is the number of ratios per tidal height. All values were computed using spreadsheet software, raw data can be found in Appendix A:

$$\overline{\Delta R} = \frac{\sqrt{(\Delta R_1)^2 + (\Delta R_2)^2 + (\Delta R_3)^2 + \dots + (\Delta R_n)^2}}{n}$$

Worked example of uncertainty:

At tidal height of 1.4 m, $n = 4$ limpets.

Instrument uncertainty: $\Delta h = \Delta w = 0.025 \text{ cm}$

Step 1: Calculate the ratio, $R_i = h_i/w_i$

- Limpet 1: $R_1 = \frac{1.04}{2.15} = 0.4837$
- Limpet 2: $R_2 = \frac{0.80}{2.70} = 0.2963$
- Limpet 3: $R_3 = \frac{1.39}{2.90} = 0.4793$
- Limpet 4: $R_4 = \frac{1.10}{2.80} = 0.3929$

Step 2: Propagate uncertainty into each ratio by adding percentage uncertainties:

$$\Delta R_i = R_i \left(\frac{0.025}{h_i} + \frac{0.025}{w_i} \right)$$

- $\Delta R_1 = 0.01725$
- $\Delta R_2 = 0.01200$
- $\Delta R_3 = 0.01275$
- $\Delta R_4 = 0.01244$

Step 3: Calculate the mean ratio at 1.4 m

$$\bar{R} = \frac{R_1 + R_2 + R_3 + R_4}{4} = \frac{0.4837 + 0.2963 + 0.4793 + 0.3929}{4} = 0.4130$$

Step 4: Propagate uncertainty into the mean

$$\Delta \bar{R} = \frac{\sqrt{(\Delta R_1)^2 + (\Delta R_2)^2 + (\Delta R_3)^2 + (\Delta R_4)^2}}{4} = 0.00689$$
$$\Delta \bar{R} \approx \pm 0.007$$
$$\bar{R} = 0.413 \pm 0.007$$

Methodology:

The investigation was carried out on Jetty Beach (Grid reference: SM 822 053). Samples were collected at 21 varying heights. Starting at 1.4 m (the neap tide level on the 15th of May, 2025) and increasing in 30 cm intervals up to 7.4 m. The heights were measured using a meter ruler and a simple wooden level with a groove to align the exact positions of the height above the chart datum, ensuring a consistent elevation change throughout sampling.

At each height, a 0.25 m² plastic quadrat was placed on the rocky surface to standardize the sample area (Figs. 2 and 3). It is important to note that the placed quadrats indicating the sampling area

were intended to be placed in a straight vertical line across the beach. However, deviation occurred (up to 5 cm to the left or right) due to uneven and sloped rock surfaces making it impossible to place quadrat.

Within each placed quadrat, up to 2 limpets closest to each corner were selected for measurement. Measurement followed a clockwise direction to ensure a consistent sampling technique and to avoid accidental repetition of samples. Given the circumstance that fewer than 8 limpets were present in the placed quadrat, all available limpets were measured using the same method.

The height (from base of shell to the apex) and width (maximum span across the shell measured by observing from above) of each individual were measured using a vernier caliper, accurate to ± 0.025 cm (Figs. 2 and 3). Data was recorded in a data sheet. For each quadrat, the height-to-width ratio of each individual was calculated, and the mean of these ratios was used as the representative value for that tidal height.

Ambient temperature was measured at each sampling point using a digital thermometer probe with a $\pm 0.1^\circ\text{C}$ uncertainty to provide environmental context (Fig. 2, Appendix A). All measurements were taken within a 3.5-hour low-tide window, only taking above-water measurements, on mostly dry shores.

Figures 2 and 3, Quadrat placement showing caliper, ruler, data sheet, and limpets on an upper-shore rock surface. Photo taken during fieldwork.



Risk assessment:

Table 2. Possible risk assessment and measures taken to minimize risk.

Identified hazard	Severity	Likelihood	Risk Score (SxL)	Controls	Likelihood after controls	Risk after controls
Slips, trips, and falls	2	4	2 x 4 = 8	1. Ankle supporting footwear. 2. No running. 3. Using a 3-point of contact technique while climbing.	2	2 x 2 = 4
Cuts and scratches from jagged surfaces, such as barnacles	1	3	1 x 3 = 3	2. Wearing gloves when moving around.	1	1 x 1 = 1

Ethics and Environment:

When measuring Limpets on the rocky shore of Jetty Beach, it is important to minimize environmental disturbances and ensure ethical gathering of data to protect wildlife. To reduce potential harm, limpets were not removed from their habitats, nor were any organisms displaced or interfered with. This is especially important, as limpets develop a home scar over time, essentially a groove in the shape of their shell, which allows them to retain water more effectively and possibly protect them from predators (Field Studies Council, n.d). To mitigate the possibility of trampling, great care was taken to avoid stepping on areas with visible life.

Statistical hypothesis:

To test the relationship between height above the chart datum and the height-to-width ratio of *Patella vulgata*, a choice was made to use Spearman's rank correlation test. More specifically, the choice was made since the test is best used when looking for a pattern between two sets of mean values that increase or decrease together. The following formula was used to obtain results via spreadsheet software:

$$r_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)}$$

Since it was hypothesized that common limpets on the higher shore would be taller and narrower (i.e., have a larger height-to-width ratio), the statistical analysis seeks a positive correlation between the two variables, which would confirm this trend.

The following hypotheses were determined:

- **Null Hypothesis (H0):** There is no positive relationship between height above chart datum and the height-to-width ratio of *Patella vulgata*. Any pattern seen in the data is likely due to pure chance. ($p > 0.05$, $r_s < 0.45$).
- **Alternative Hypothesis (H1):** There is a positive relationship between height above chart datum and the height-to-width ratio of *Patella vulgata*. Limpets found higher on the rocky shore have taller shells than their width. ($p < 0.05$, $r_s \geq 0.45$)

The critical value method was used to determine statistical significance. Based on the same sample size ($n = 21$) and a significance level of $p = 0.05$, the critical value was determined to be 0.45.

Results

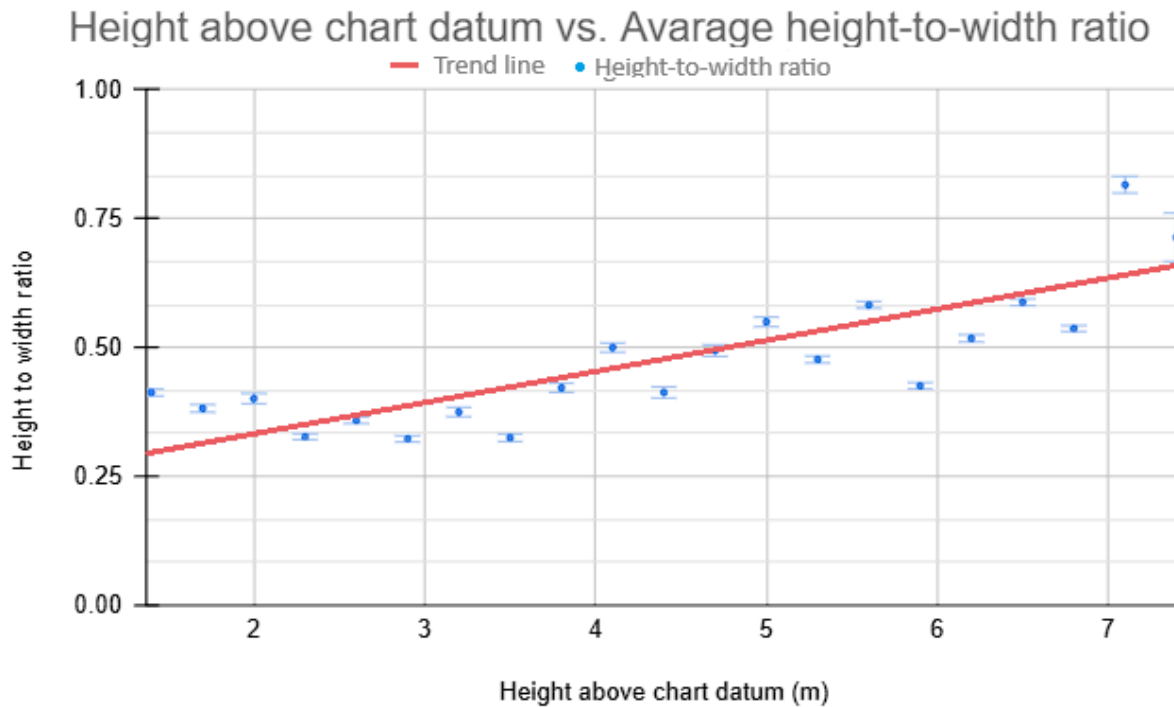
Table and Legend:

Table 3, Mean height-to-width ratio of *Patella vulgata*, used for Spearman's Rank, created using primary data.

Height above chart datum (m)	Height-to-width ratio
1.4	0.413
1.7	0.3819
2	0.4013
2.3	0.3265
2.6	0.3593
2.9	0.3228
3.2	0.3747
3.5	0.3248
3.8	0.422
4.1	0.4995
4.4	0.4125
4.7	0.4937
5	0.5498
5.3	0.4767
5.6	0.58272
5.9	0.4258
6.2	0.5178
6.5	0.5979
6.8	0.5366
7.1	0.8157
7.4	0.7142

Graph and Legend:

Figure 4. Scatter plot showing the relationship between height above the chart datum and average height-to-width ratio of *Patella vulgata*. Graph created using primary data.



Statistical calculations and values:

Table 3. Spearman's rank correlation test results, a statistical test performed using student-collected data using spreadsheet software.

Statistical Output	Value
Sample size (n)	21
Mean height-to-width ratio	0.474
Standard deviation (SD) of height-to-width	0.129
Sum of d^2 (for Spearman's rank)	354
Spearman's rank correlation coefficient (r_s)	0.770
Critical value (at $p = 0.05$, one-tailed)	0.45
Interpretation (from spreadsheet)	$r_s > \text{critical value}$; Significant positive correlation

Conclusions and Discussion:

The investigation showed a statistically significant positive correlation between height-above chart datum and the height-to-width ratio of the common limpet (*Patella vulgata*) on the shore of Jetty Beach (shown in Fig. 4). The Spearman's rank correlation coefficient was $r_s = 0.770$, much greater than the critical value of 0.45 at $p = 0.05$, giving reason to reject the null hypothesis. The rejection of the null hypothesis indicated that the higher the limpets are on the shore, the narrower their shells will be.

The pattern can be explained by environmental stressors such as desiccation, reduced feeding time, and increased temperature variation found at higher tidal heights, concordant with existing research. Due to less growth and thereby less internal pressure, the shell will tend to grow upward and not in a more horizontal way, leading to a more conical shape. This change in shape may also help reduce water loss during long emersion periods, showing a response to environmental challenges higher up the rocky shore and proving to be an adaptation (Fish & Fish, 1996; Thomson & Cremona, 2019).

These conditions may limit shell growth and internal tissue pressure, resulting in morphological adaptation toward a taller shell form. The average height-to-width ratio across all samples was 0.474, with a standard deviation of 0.129, indicating moderate variation across tidal zones.

Error bars in Figure 4 represent propagated instrument uncertainty in the mean height-to-width ratio at each tidal height. Because this uncertainty is small across the entire range of data, the error bars show that the upward trend is not due to measurement imprecision. However, it is important to mention that these error bars do not represent biological variation due to age differences or other factors causing covariance in samples. Since SEM could not be calculated consistently, it can be said that measurement error is unlikely to explain the pattern, while remaining scatter around the trend is more plausibly explained by ecological factors and sampling limitations.

Evaluation:

The conducted investigation had both strengths and weaknesses that should be considered. All data were collected within the same (approximately 3-hour-long) tidal window, minimizing variation in the environmental conditions and thereby keeping them controlled, however, follow up investigations over longer periods are necessary to notice consistent differences in temperature that could explain the trend.

One large limitation was the lack of SEM calculations, which resulted from a small sample size of limpets at upper end of shore. This resulted in needing to propagate equipment uncertainty, leaving covariance at each height impossible to quantify, especially key when height-to-width ratio's sometimes differ significantly. Improvements can be made by doing a full horizontal transect at each height, allowing for SEM from a large sample, allowing to see covariance and if it would be significant enough to invalidate results.

Moreover, the lack of measurements of rock slope, substrate hardness, and limpet age could have affected results, as stated by Fish and Fish (1996), introducing more random variation and making data potentially more scattered than previously thought. A potential follow up investigation into these

variables is necessary to confidently state the scope of their effects, potentially supplemented by equipment such as an inclinometer to directly measure angle of substrate rock formations.

In addition, quadrat placement occasionally deviated laterally ($\pm 10\text{ cm}$) due to uneven rock surfaces, potentially introducing minor variation, potentially making data more scattered and a trend harder to see. This is because uneven rock surfaces may provide more shelter against wave action for specific limpets, or rock pools may reduce dessication stress in a specific location. This limitation can also be accounted for by taking a horizontal transect at each height as explained, would highlight the significance of rock surfaces in affecting morphology.

Despite these limitations, the investigation successfully identified a clear and statistically supported relationship between tidal height and shell shape in *Patella vulgata*, aligning with existing ecological theory and published research by Fish & Fish (1996) and Thomson & Cremona (2019), who noted that shell shape reflects aforementioned environmental pressures, with dessication risk and feeding constraints being key drivers in this process. Key improvements can be made by controlling rock slope, temperate, and using horizontal transects combined with vertical, for bigger sampling sizes, allowing to account for covariance which would likely show a more clear and less scattered trend, increasing observed correlation.

Bibliography:

1. Ballantine, W. J. (1961) A biologically defined exposure scale for the comparative description of rocky shores, *Field Studies*, Vol. 1, No. 3. [Accessed 14 May 2025].
2. Field Studies Council, n.d., “The seashore, the common Limpet”, Retrieved from the Field Studies Council website. [Accessed 12 June 2025].
3. Fish, J.D. and Fish, S., 1996. *A Student's Guide to the Seashore*. 2nd ed. Cambridge: Cambridge University Press, pp. 228–229. [Accessed 15 May 2025].
4. Fretter, V. and Graham, A., 1976. *Prosobranch Molluscs: Britain and Denmark*. London: The Ray Society, pp. 25–27. [Accessed 15 May 2025].
5. Pembrokeshire Coast National Park Authority (n.d.). *Coastal Features – Pembrokeshire Coast*. Retrieved from the Pembrokeshire Coast National Park website. [Accessed 2 July 2025].
6. Queen Mary University of London, n.d., *Geographical techniques, Spearman's Rank correlation test*, Retrieved from Queen Mary University's website. [Accessed 17 May 2025].
7. Thomson, J.A. and Cremona, J., 2019. *Rocky Shores*. London: Bloomsbury Publishing. [Accessed 15 May 2025].

Appendix A – Supplementary Data and Field Documentation:

Table A.1 – Raw limpet measurement data converted to a height-to-width ratio) from all quadrats.
Primary data used to calculate height-to-width ratios and perform statistical analysis.

Height above chart datum (m)	Height-to-width ratio	Average height to width for each tidal height	Temperature (C)	Uncertainty for the mean height-to-width ratio
1.4	0.484	0.413	16.8	0.007
1.4	0.296		16.8	
1.4	0.479		16.8	
1.4	0.393		16.8	
1.7	0.252	0.382	16.7	0.007
1.7	0.360		16.7	
1.7	0.321		16.7	
1.7	0.594		16.7	
2	0.269	0.401	16.8	0.01
2	0.294		16.8	
2	0.252		16.8	
2.3	0.389	0.327	16.9	0.006
2.3	0.231		16.9	
2.3	0.270		16.9	
2.3	0.417		16.9	
2.6	0.428	0.359	16.6	0.006
2.6	0.394		16.6	
2.6	0.289		16.6	
2.6	0.326		16.6	
2.9	0.217	0.323	16.9	0.006
2.9	0.416		16.9	
2.9	0.381		16.9	
2.9	0.277		16.9	

3.2	0.455	0.375	16.7	0.009
3.2	0.414		16.7	
3.2	0.242		16.7	
3.2	0.389		16.7	
3.5	0.357	0.325	16.7	0.007
3.5	0.322		16.7	
3.5	0.316		16.7	
3.5	0.304		16.7	
3.8	0.388	0.422	16.8	0.009
3.8	0.537		16.8	
3.8	0.409		16.8	
3.8	0.357		16.8	
4.1	0.653	0.500	16.9	0.009
4.1	0.505		16.9	
4.1	0.522		16.9	
4.1	0.319		16.9	

4.4	0.488	0.413	16.9	0.011
4.4	0.364		16.9	
4.4	0.480		16.9	
4.4	0.319		16.9	
4.7	0.533	0.494	16.7	0.011
4.7	0.429		16.7	
4.7	0.527		16.7	
4.7	0.486		16.7	
5	0.600	0.550	16.8	0.009
5	0.438		16.8	
5	0.354		16.8	
5	0.809		16.8	
5.3	0.501	0.477	16.6	0.007
5.3	0.601		16.6	
5.3	0.471		16.6	

5.3	0.333		16.6	
5.6	0.727	0.583	16.6	0.006
5.6	0.565		16.6	

5.9	0.569	0.426	16.8	0.006
5.9	0.390		16.8	
5.9	0.318		16.8	
6.2	0.542	0.518	16.7	0.007
6.2	0.492		16.7	
6.2	0.500		16.7	
6.2	0.538		16.7	
6.5	0.552	0.588	16.8	0.006
6.5	0.637		16.8	
6.5	0.629		16.8	
6.5	0.534		16.8	
6.8	0.500	0.537	16.9	0.005
6.8	0.528		16.9	
6.8	0.577		16.9	
6.8	0.542		16.9	
7.1	0.957	0.816	16.7	0.016
7.1	0.675		16.7	
7.4	0.714	0.714	16.7	0.051

Figure A.1 – Conducting field measurements using a vernier caliper, photo taken by the observing teacher.

