

Guide to Writing Scientific Papers



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This guide is based on an online resource provided by the Bamfield Marine Sciences Centre (<http://www.bms.bc.ca/resources/library/pdf/GuidelinesScientificPapers.pdf>). It was modified and appended by Peter Smith, Douglas Fudge and the W12 Undergraduate Curriculum Committee of the Dept. of Integrative Biology at the University of Guelph.

Note to Instructors: If you wish to modify this document to suit your course, please make clear (in your document) that your version is only for your course. This will help avoid confusion among students who might otherwise encounter multiple versions with contradictory guidelines.

Note to Students: The following is a general guide for the writing of scientific papers for Integrative Biology students. While the rules presented here will apply to most courses, check with your instructor if he or she wants you to follow a different set of guidelines.

A scientific paper is divided into the following sections:

- 1) Title
- 2) Abstract
- 3) Introduction
- 4) Materials and Methods
- 5) Results
- 6) Discussion
- 7) Literature Cited

1) Title

The title often contains the following elements:

- The name of the organism(s) involved
- The question answered or the hypothesis tested
- The focus of the study (most often the variable(s) manipulated and measured)

Here are some examples of titles from some real scientific papers published in 2012:

Does habitat specialization by seedlings contribute to the high diversity of a lowland rainforest?

Active echolocation beam focusing in the false killer whale (*Pseudorca crassidens*)

Biomass partitioning and root morphology of savanna trees across a water gradient

Sometimes it is possible to include the principal result or conclusion in the title:

Tree cover–fire interactions promote the persistence of a fire-sensitive conifer in a highly flammable savanna

Blue-light-receptive cryptochrome is expressed in a sponge eye lacking neurons and opsin

Note that only the initial word of the title is capitalized while all other words are lower case, with only a few exceptions. The scientific name of the subject species should always be included, and if it follows the common name, it should be in parentheses and italicized. The genus name of the subject is always capitalized.

The title always appears on a cover page, along with identifying information about the authors (in this case your name, your partner's name (if any), student number(s), the name of the course, your section, and the due date). In published scientific papers, author affiliations include the authors' department, university, and contact information.

2) Abstract

The abstract is a short summary of your entire paper. It should include the essential components from all of the sections of your paper, and generally should not exceed 250 words. Most scientists write the abstract last, mostly because the act of writing the paper often leads to significant insights that cannot be predicted at the outset. Scientists spend a lot of time polishing the abstract, because they know that it is the only part of their paper that many people will ever read. A good abstract will often convince a potential reader to go on and read the entire paper. The abstract should contain the following components: 1) Motivation for the study (why did you carry out this study, what is interesting about it?) 2) Question or problem statement (what question were you trying to answer or what problem were you trying to solve?) 3) Approach (how did you go about answering the question or solving the problem? 4) Results (what did you find?), and 5) Conclusions (what does it all mean and what are the implications?).

3) Introduction

Two important functions of the Introduction are to present the question that was asked and the hypothesis that was tested. References to what is already known about the topic (from the published literature, properly cited) should be presented in a way that leads logically to the question that the study aimed to answer. If the question was tackled by testing a particular hypothesis, it is important to clearly lay out the hypothesis in the Introduction and explain any predictions of the hypothesis that were tested. Remember, a hypothesis is not just an "educated guess," it is a "A testable statement about the natural world that can be used to build more complex inferences and explanations." (from Teaching About Evolution and the Nature of Science, The National Academy of Sciences, 1998).

A very common mistake that students make is to confuse hypotheses and predictions. The hypothesis is a testable statement that should provide a satisfying potential answer to the question you have posed. The validity of a hypothesis is tested by evaluating whether the predictions the hypothesis makes are true. Another common mistake is to say “I predict...” when what is most important is what the hypothesis predicts. You can predict anything you want, but the hypothesis is constrained to predict only things that are consistent with the worldview it proposes. The logical connection between hypothesis and predictions is arguably the most important part of the scientific method, and also the one that most often trips up students. A good litmus test for checking whether a prediction follows logically from a hypothesis is to form an if-then sentence of the following structure: If (hypothesis), then (prediction). For example:

“If competition lowers reproductive output, **then** fruit size should be smaller when tree density increases.”

Sometimes studies are descriptive in nature and in these cases it is best not to try and force a hypothesis into the Introduction, which usually creates confusion. For example, a detailed study of the jaw morphology of a newly described fish might provide all kinds of new information about this species, but it might not test the predictions of any hypothesis. In cases like this, it is best to simply state the objective of the study rather than to force a hypothesis onto it.

Do not get lost in reviewing background information. Remember that the Introduction is meant to introduce the reader to your topic, not summarize and evaluate all past literature on the subject (which is the purpose of a review paper). Focus on key concepts and background. Save the more specific papers for the Discussion, where they become a powerful tool for comparing and interpreting your results. Include only enough background information to allow your reader to understand why you are asking the questions you are and why your hypothesis is a reasonable one.

4) Materials and Methods

The function of this section is to describe all experimental procedures, including controls. The description should be complete enough to enable someone else to repeat your work. If there is more than one part to the experiment, it is a good idea to describe your methods and present your results in the same order in each section. This may not be the same order in which the experiments were performed - it is up to you to decide what order of presentation will make the most sense to your reader.

- Dividing the text into sub-sections makes it easier to read lengthy Methods sections. The following are common sub-titles (although they will of course depend on the nature of the study): Experimental organisms, Experimental protocols, and Statistical methods.
- Explain why each procedure was done in the Experimental protocols sub-section, i.e., what you were measuring and why.

- Mathematical equations and statistical tests are considered mathematical methods and should be described in sufficient detail.
- Be as specific as possible when describing equipment, reagents, chemicals, commercial products, tools, etc. Typically, this will also include manufacturer name, location, and model numbers. For example: “Model 3210 dual-channel oscillograph (Harvard Apparatus, Cambridge Mass.)” or “TRIS HCl buffer (Sigma Chem. Corp., St. Louis)”
- Be as specific as possible with identification of experimental subjects including (where appropriate): number used ($n=$), Genus and species, sex, age, size (dimensions, mass), physical condition, and conditioning prior to experimentation. This may include source (supplier or geographic location of sampling), housing length and conditions (temperature, light, etc.), what and how often fed. Where appropriate, include commercial supplier’s names as you would for equipment.
- If any of your methods is fully described in a previous publication, you can cite that paper instead of describing the procedure again. For example, it is not customary to provide all details of a standard laboratory or field procedure in the Materials and Methods section. In these cases, cite the appropriate reference.
- When citing methods from another source, be sure to include details and changes to the cited method as they apply to your work (e.g. specifics about the number and kind of organisms used in your study).

5) Results

The Results section typically has two different components - a written description of the study’s findings, as well tables and figures that help the reader grasp the results in a more visual form. The results of statistical tests applied to your data are reported in this section although you need not say anything about their implications for the viability of the hypothesis you tested; save this for the Discussion. The following guidelines will help you to write a strong Results section that conforms to the stylistic conventions of many scientific journals.

- Do not present raw data (data in the same form as collected or provided) in your reports. You must analyze data mathematically/statistically for proper presentation.
- In the text of the Results section, you should present the major trends (if any) in the data and indicate whether these trends are statistically significant. You can also make quantitative comparisons to give the reader an indication of the strength of an effect, for example “Testosterone injected males were about three times more likely than controls to be selected by a female.” While it is important to provide means and standard errors for each of your treatments, this is often most efficiently done in the

form of a table. If these numbers are presented in a table, there is no need to repeat them in the text of the Results section, just make sure you cite the table.

- All results should be presented, including those that do not support the hypothesis.
- Results contained in figures and tables must be introduced in the text, and in the order in which they are presented. Example: Incorrect: The results are given in Figure 1. Correct: Metabolic rate was directly proportional to temperature (Fig. 1).
- The results of statistical tests can be presented in parentheses following a verbal description. For example, you might say “Testosterone treatment had a significant positive effect on strutting behavior in males ($t = 2.4$, $df = 198$, $p = 0.02$).”
- See also “Tables and Figures” and “The Formatting of Line Figures” below.

Tables and Figures

Tables and figures should be used when they are a more efficient way to convey information than a written description. Tables and figures must be accompanied by explanatory captions that allow them to be understood by someone who has not read the text. Information in the tables and figures should not be repeated in the text, but do cite the tables and figures, with a summary statement when that is appropriate (see above).

Tables. Do not repeat information in a table that you depict in a graph; include a table only if it presents new information. It is easier to compare numbers by reading down a column rather than across a row. Therefore, list sets of data you want your reader to compare in vertical form. Provide each table with a number (Table 1, Table 2, etc.) and a title. The numbered title is placed above the table. Tables should only be delineated by horizontal lines, and these may only separate headings from data (not rows of data from each other). Vertical lines are not typically used.

Figures. These may include graphs and illustrations (drawings), and photos. Provide each figure with a number (Fig. 1, Fig. 2, etc.), a short title and a caption that explains what the figure shows. The numbered caption is placed below the figure. In general, figures should be computer generated and not hand drawn. Do not crowd too many figures onto one page - no more than two is a good rule of thumb. Some formats allow for figures and tables to be embedded in the text, others require them to be on separate pages. Check with your instructor on this issue.

Graphs can be used to compare two (or sometimes more) variables. Line graphs and scatterplots show continuous change, whereas bar graphs show discrete variables only. You can compare groups of data by plotting two or even three lines on one graph, but avoid cluttered graphs that are difficult to read, and do not plot unrelated trends on the same graph. Plot the independent variable on the horizontal (x) axis and the dependent variable on the vertical (y) axis. Label both axes and include units of measurement.

There are many online sources on how to make high quality graphs. Here is one that describes how to make different kinds of graphs in MS Excel:
<<http://ilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm>>. For more specific guidelines about generating effective graphs, refer to the section “The Formatting of Graphs” below and the effective examples of line, scatter, and bar graphs that follow.

Drawings are used to illustrate organisms, experimental apparatus, models of structures, cellular and sub-cellular structure, and results of procedures.

Photos may make up an entire figure or a panel within a multi-panel figure. Most journals have strict rules about how photos in figures may or may not be manipulated. For example, cutting and pasting of bands from scans of electrophoresis gels is strictly forbidden if it misrepresents the data in any way. It is good practice to include a scale bar that gives the reader an indication of the size of the objects in a picture. This is especially important for pictures taken with microscopes. Most journals have minimum requirements about the resolution of photos used in figures.

6) Discussion

The function of this section is to present the analysis you have done and convey what the data mean in the context of the question you have asked and the predictions you have tested. You should also consider your data in the context of other studies. The Discussion should contain at least:

- an interpretation of results and a presentation of argument(s) about the significance of the results. Also discuss the relationship between the results and the original hypothesis, i.e., whether they support the hypothesis, or cause it to be rejected or modified.
- an integration of your results and those of previous studies (the primary literature) into arguments to arrive at explanations for the observed phenomena. Avoid long descriptions of other studies unless you are directly relating the findings to your own data.
- possible explanations for unexpected results and observations, phrased as hypotheses, which generate predictions that can be tested. These must be realistic experimental procedures, which you should briefly describe.
- a statement of limitations of experimental design. If you suspect that your results may have been affected by a confounding variable that you did not control, you should discuss that here. If you failed to find a significant effect of your treatment, was this due to a lack of statistical power or the fact that the treatment actually had no effect?

- Trends that are not statistically significant can still be discussed if they are suggestive or interesting, but cannot be made the basis for conclusions as if they were significant.
- Avoid redundancy between the Results and the Discussion section. Do not repeat detailed descriptions of the data and results in the Discussion. The best way to appreciate how authors accomplish this is by reading and emulating published papers. Be sure, however, to discuss each trend you identify in the results.
- End the Discussion with a statement of conclusions and a summary of the principal points you want the reader to remember. This is also the appropriate place to propose specific further study if that will serve some purpose, but do not end with the cliché that "this problem needs more study." Some journals require that the last paragraph of the paper be a short conclusion section that is set off by the sub-heading "Conclusions," but many do not. You should check with your instructor to determine whether or not to include a Conclusion section.

Literature Cited

Each reference cited in the text must be listed in the Literature Cited section and vice versa. Remember that copying text or even presenting ideas from published works without citing them is a form of plagiarism and must be avoided. Please consult the University guidelines regarding academic misconduct for more information.

Scientific journals differ widely in the format in which references are cited in the text and listed at the end of the paper. Some use the "author, year" format for in-text citations, while others use numbers (in brackets, parentheses, or superscripted) for the same. Be sure to check with your instructor to determine which format you should use for your paper.

Most scientists use some sort of reference software for managing references in their papers. Some of the more popular ones are EndNote, Reference Manager, and RefWorks (which is an online citation manager available for free through the UofG library website). These programs can be incredibly useful for managing references in papers with large numbers of references or just building a library of useful references for a particular project.

Scientific journals also differ in the general format they require for submitted manuscripts. The following are some common formatting rules, but you should check with your instructor about the specific format you should use for your paper.

General formatting information:

- 1) Use a standard font like Times New Roman, size 12.
- 2) Use 1.5 line spacing for text
- 3) Cite each figure and table in the text in numerical order. For example, “Fig. 5” or “Figs. 8, 9”.
- 4) Italicize Latin words
- 5) Give the Latin name for species in parentheses after the common name.
- 6) Abbreviations should be defined the first time they are used in the text
- 7) Uppercase should be typed without periods (USA, UK); lowercase with periods (u.v.)
- 8) Type a space between a numeral and a unit e.g. 1 mm (exceptions 1%, 4°C)
- 9) Use s.e.m. and s.d. for standard error and standard deviation.
- 10) Use appropriate super- and sub-scripts: Ca^{2+} , MgCl_2 , X^2
- 11) Whole numbers less than 10 are spelled (one frog, two seeds, etc.) Use the numerical symbol for numbers larger than nine (10, 11, etc.). All decimals are expressed with numerical symbols. Do not start a sentence with a numerical symbol.
- 12) Table captions appear above the table, figure captions below the figure.
- 13) Do not use vertical lines in tables.
- 14) Make sure you use the words “affect” and “effect” appropriately.
- 15) Make use of the spellcheck and grammar check features of your word processing software before submitting your paper.

Formatting of Graphs:

- 1) Hand drawn figures are not allowed; use Excel, SigmaPlot, etc.
- 2) Ensure that figures are large enough to be read easily. A good rule of thumb is that no more than two figures should occur on one page. Check with your instructor to determine whether you should embed figures in the text or include them on separate pages.
- 3) Plot your data so that the independent variable is on the x-axis and the dependent variable is on the y-axis.
- 4) Use appropriately spaced and labeled “tick marks” to indicate the scale of an axis. Tick marks can point outward or inward, although inward pointing tick marks tend to give graphs a cleaner look.
- 5) A label with the name of the variable and units for the axis must appear beside the axis (as in “Time (seconds)” or “Serum Glucose (mg/dL)”).
- 6) Do not place a title over the figure.
- 7) A legend identifying what the symbols represent (if there is more than one) is typically located to the right of the figure.
- 8) Use line graphs for plotting continuous data and connect the points with a line. Only “smooth” the line if you have good justification for doing so.
- 9) Use scatter plots to graph independent data points. For example, if you measured wingspan and beak length for a population of birds, you can depict this relationship

using a scatterplot. It is not appropriate to connect the data points on your graph with a line, but you may want to include a trend line (aka a “line of best fit”). Excel can do this for you.

- 10) Use bar graphs for presenting discontinuous data. For example if you had four distinct treatments, use a bar graph with four bars to plot the response of your independent variable to each of the treatments.
- 11) Where points represent a mean, you must give a graphic representation of the variability of the measurements that were used to calculate that mean. One way to do this is to provide error bars that show the standard error of the mean. Error bars should be drawn in both directions, unless they clutter and confuse the figure. Excel will plot error bars, but make sure you select the “custom” error bar option, otherwise it will apply the same error bar to all data points. Another way to convey the variability within a dataset is to create a boxplot, which provides more information than a simple bar graph with error bars. Boxplots are becoming more common in scientific papers. At this time, Excel does not have a boxplot graphing option.
- 12) Figure captions should begin with the figure number followed by a short title that provides a general description of the figure. For example, “Fig. 1. Fitness of red squirrels as a function of food provided.” Sentences that follow the title should explain the details of the figure that aren't immediately apparent from a cursory examination. A caption (figure or table heading) should contain sufficient information so that a reader can understand a table or figure, in most cases, without reference to the text. Captions should also briefly summarize the main result presented in the table or figure. In a multi-panel figure, make sure you indicate what each panel is. It is also important to explain any symbols used to represent statistical significance. Before you submit your paper, ensure that all figures are cited in the text and that figures are numbered according to the order in which they appear in the text.
- 13) In general, keep it simple. Don't add shading, gridlines or other extraneous features that aren't essential to the figure.

On the following pages are examples of three of the most common types of graphs in scientific papers: bar graphs, line graphs, and scatterplots. These graphs were generated in Excel, which has many features that can help guide you in choosing the type of graph that is most appropriate for presenting your data in a format that is easy for the reader to understand.

1) Example of a bar graph. In this case, a continuous dependent variable (height) is plotted for two categorical independent variables (light source and pot size).

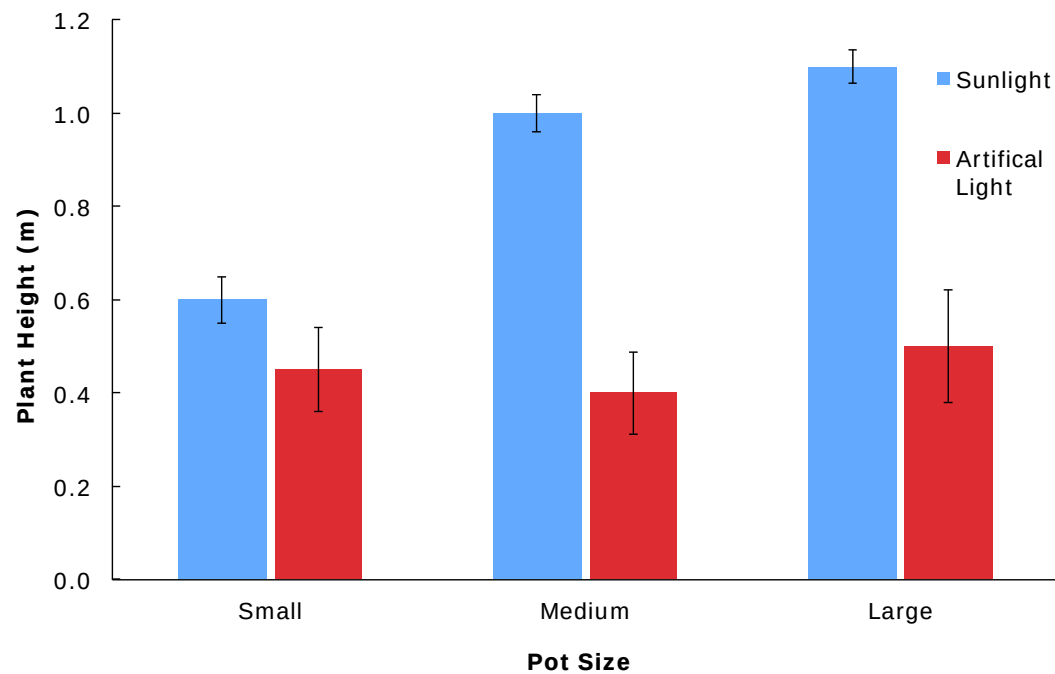


Fig. 1. Average height of plants grown in different pot sizes with sunlight or artificial light after a four-week experimental period. Two-way ANOVA analysis revealed significant main effects of lighting type ($p = 0.0015$) and pot size ($p = 0.042$), and a significant interaction between light source and pot size ($p = 0.0039$). Error bars are s.e.m.

2) Example of a line graph with multiple plots. In this case, a continuous dependent variable (survivorship) is plotted against a continuous independent variable (time) for three different treatments (species).

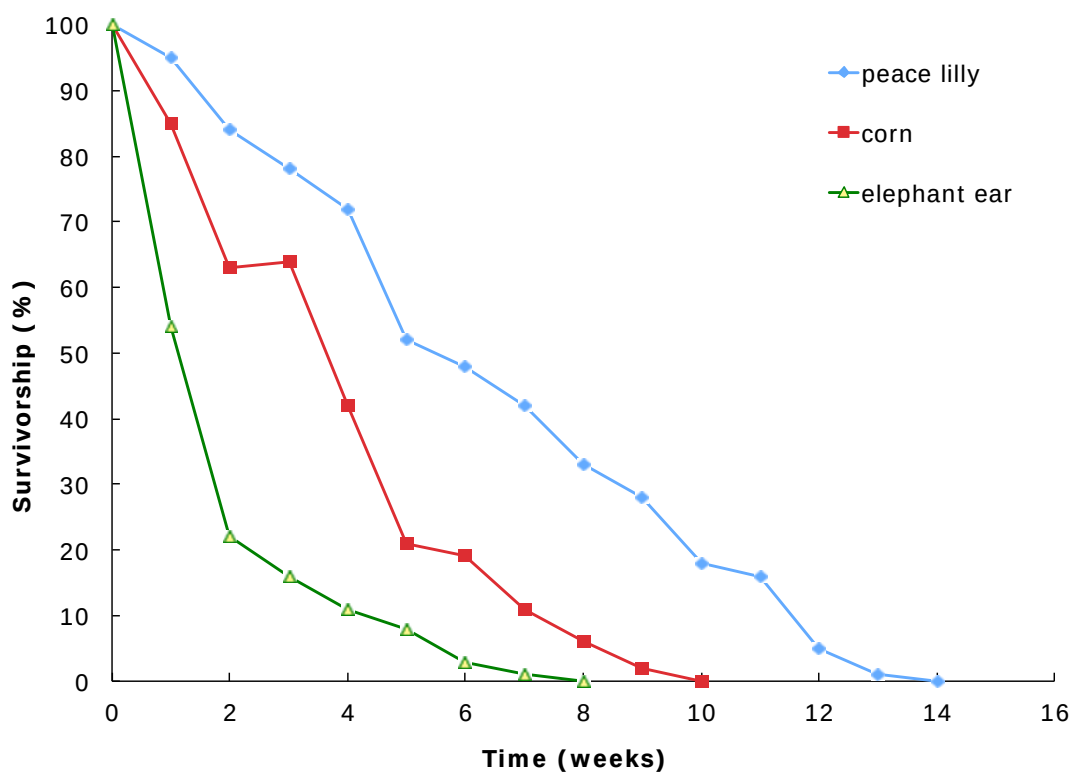


Fig. 2. Percent survivorship of three plant species in full shade over 14 weeks.

3) Example of a scatterplot. In this case, a continuous dependent variable (oxygen consumption rate) is plotted as individual points against a continuous independent variable (weight). Note that the points are not connected by a line as they are in a line graph, but instead a line of best fit is used to show the general trend in the data.

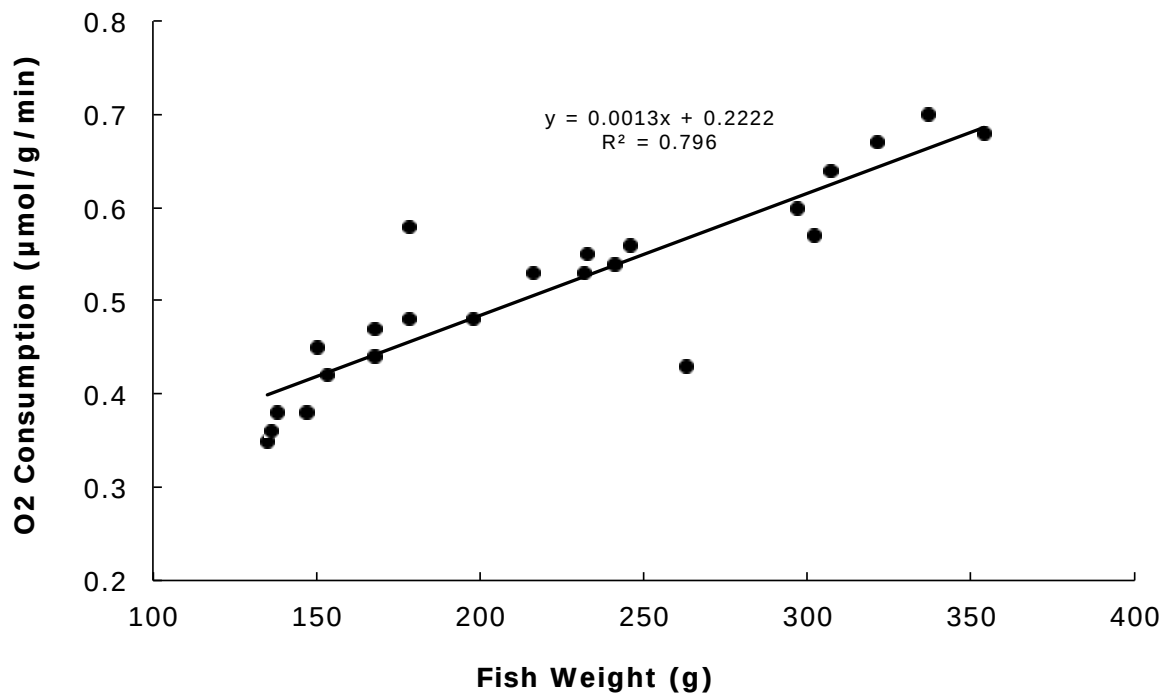


Fig. 3. Effect of fish weight on oxygen consumption. There was a significant positive relationship between fish weight and oxygen consumption ($p < 0.001$, $F_{1,21} = 82.05$).