How to read and get the most out of scientific papers

Papers are the end result of the scientific method and each contains the results and interpretation of a tested hypothesis(es). The knowledge gained from these papers ultimately ends up in textbooks and is presented as “scientific fact” (A reasonable observation or method that best explains the known data). You can imagine that as more and more data are generated some hypotheses are continually supported while others lose support and are replaced by newer hypotheses. In this sense science is an iterative and, most importantly, a self-correcting process! It weeds out “bad” hypotheses (ones not supported by newer data) and keeps “good” hypotheses that are continually supported by all available data. With new data constantly being generated, it becomes important to read scientific papers as you generate and test your own hypotheses. Therefore, you can tailor your study design to test the most current hypotheses.

With that said I have to be completely honest with you; scientific papers are not easy to read! They are filled with technical jargon and are VERY dense to decrease their length. Initially it will take some time to get through a paper, which is why we will spend time in this class reading them with some help interpreting what it means for the field of marine ecology in general. This guide is designed to help you in this process.

Parts of a scientific paper

1. Title- self-explanatory (Often will have a brief description of the findings, study location, and study organism)

2. Abstract- This is a brief (usually 100-400 word) summary of all the remaining (3-6) parts of the scientific paper. Imagine the difficulty trying to cram the gist of an 8,000 word essay into 100 words! Scientists are extremely busy and abstracts are the ultimate time savers to determine if the paper will be helpful to read. Here you should find:

1) the rationale for the study (why was it done?)
2) brief study design (How it was accomplished?)
3) results (What was found?) and
4) Interpretation of results (what do their data mean?)

You should ask yourself these 4 questions each time you read an abstract!

3. Introduction- This is where the authors try to get you interested in their study and catch readers up to speed on background information that is needed to understand how they formulated their hypotheses. Introductions can vary, but generally start by describing the question they hope to address and a brief synopsis of previous work done that is applicable to the question. Next, they usually describe the study system (organism and location) and why they chose it. Finally, they end on their hypotheses that they will formally test.

4. Methods- This section describes in detail how the experiment(s) were done. Again, this will vary a little depending on the paper, but generally start out with a description of where, when, and how the data were collected. This is supposed to be given in enough detail that anyone could replicate what was done. Next the paper will outline the statistics, which will be used to "test their hypothesis". For those of you with a statistics background, this will be much easier to follow (Ecology really is just a math class with more interesting word problems…).

5. Results- Here the results of the experiments are described in order they were presented in the methods. This section comes with pictures and graphs (Figures) and data tables that summarize their data.

6. Discussion-In the discussion the authors will tie their study into the rest of the field. This generally describes if the hypotheses were supported or rejected and **WHY** this likely occurred based on the best available data (from their paper and everyone else's).

7. References-This is a list of other papers and books the authors read and incorporated into their study design and used to interpret their results after the experiment.

The easiest way to lose interest and get confused (and quite possibly angry at me) is to read the paper like you would a magazine article!!!! Therefore, I recommend starting with the title and trying to determine 1) what was the point of the study/paper and 2) where and on what was the experiment conducted (for example, was it done on Fish? In Hawaii?)? At this point I recommend looking at a copy of the first assigned paper as you finish this guide (also available on blackboard). Although this guide is greatly simplified, you should be able to follow along in the real paper as well.

Here is an example title from (Swearingen and Pawlik, 1998):

"Variability in the chemical defense of the sponge *Chondrilla nucula* against predatory reef fishes"

From the title, we know that fishes eat sponges (Italics mean the sponge species used: it will be abbreviated *C. nucula* after written once) and that sponges differ in their ability to prevent this.

Next I would read the abstract and try to answer the 4 questions listed above under the "abstract" section (and right below). At this point in reading, you don't want details (yet). You just need to know the basics. Here is the abstract from Swearingen and Pawlik: I have interjected (In bold) where you should have gathered answers to these questions.

"Chondrilla nucula is a common Caribbean demosponge (**type of sponge**) that grows in a range of habitats, from coral reefs to mangrove swamps. On reefs, *C. nucula* grows as a thinly encrusting sheet, while in mangrove habitats it surrounds submerged mangrove roots as fleshy, lobate clumps.” **Here the authors have given background on the study system. There are two ways to grow, big and fleshy (Lobate) in mangroves or small and close to the ground (encrusting) on reefs.**

“Previous feeding experiments using predatory reef fish revealed a high degree of variability in the chemical defenses of *C. nucula*. The present study was undertaken to determine whether a relationship exists between habitat, growth form, and chemical defense of *C. nucula*.”

At this point you should be able to answer 1) why was it done? Does the habitat in which it is found or the growth form change how the sponge defends itself from sponge-eating (spongivorous) fishes?

“Both laboratory and field feeding-assays of crude extracts confirmed that *C. nucula* possesses a chemical defense with high intercolony variability, but there was no significant variation in feeding deterrency between reef and mangrove habitats at either geographic location (Bahamas and Florida).”

So they cheated! In the abstract often authors will combine methods and results as just written. However, we can answer 2) How was the study done? They did field and lab experiments. At the moment, we do not care how these were done, that will come later. A good reason why you should not stop at the abstract if you are interested in the paper.

“Extracts of *C. nucul*a collected during September and October 1994 from the Bahamas were significantly more deterrent (**to fish**) than those collected during August 1993, May 1994, and May 1995 from Florida, and extracts of these spring and summer Florida collections were more deterrent than extracts of *C. nucula* collected in December 1994 and February 1995 in the same locations.”

3) What was found? This is a bit complicated, but it seems like Bahamas sponges were eaten by fish less than Florida sponges.

“There was no evidence that deterrent compounds were concentrated in the surface tissues of the sponge, or that chemical defense could be induced by simulated predation. Laboratory and field assays of the fractionated crude extract (=**ground up sponges**) revealed that feeding deterrency was contained to the most polar metabolites in the extract (**This is a biochemisty thing. Polar vs. non-polar fractions can be separated. You may do this in organic chem lab, but we won’t go into more detail here**). Field transplants were used to determine whether predation influenced the growth form of *C. nucula*. Uncaged sponges transplanted from the mangrove to the reef were readily consumed by spongivorous reef fishes. Lobate mangrove sponges became thinner after being caged (**prevents fish from eating even though they would normally**) on the reef for 3 mo, but encrusting reef sponges did not become thicker after being caged in the mangroves for the same period of time.”

3) (continued) Fleshy sponges (not normally found on reefs) are eaten almost immediately when moved from sheltered mangroves.

“Reef sponges that were caged for 3 to 15 mo thickened by only a small amount (<1 mm) compared to uncaged and open-caged (i.e. in cages lacking tops) sponges.”

3) (continued) Even if you prevent fish from eating the flat reef sponges, they don’t become fleshy

“Simulated bite marks on both reef and mangrove sponges were repaired at a rapid rate (0.8 to 1.6 mm d^{-1}). Fish predation has an important impact on the distribution and abundance of *C. nucula*, but the thin growth form common to reef environments may be more the result of hydrodynamics than of grazing by spongivorous fishes.”

4) What do their data mean? Fish will rapidly eat fleshy sponges, but that is NOT the only reason they are flat (encrusting) on the reef. Why? Because if you prevented the fish from eating them (with cages) they should have become fleshy on the reef if that was so.

All in all, they do not state their hypotheses specifically, but can you determine them? One was “Fish predation causes sponges to be flat on the reef”. Was it supported or not?

Once you have a brief idea of these questions, I recommend looking at the Figures and Tables. The figure and table legends should be enough for you to understand the data you are being shown. Here is a figure, and legend, from the paper above:

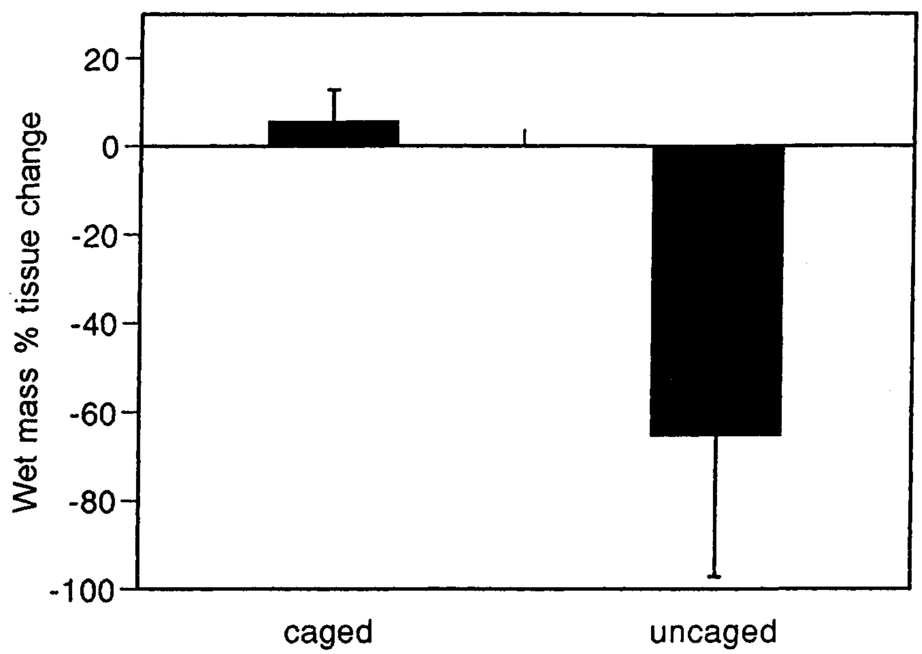

Fig. 4 *Chondrilla nucula*. Predation on mangrove sponges transplanted to reef. Percentage (mean + SD) change in wet mass of sponge transplanted from mangroves to shallow patch reefs in paired assay of caged and uncaged colonies ($N = 30$). Experiment ran for 3 d. Percentage change was significant ($p < 0.0001$; Wilcoxon paired-sample test)

Can you tell what this means? There are two treatments: caged (protected from fish) and uncaged (not protected, fish can eat it). Which one of these (caged or uncaged) is the control and why? The y axis (vertical) is % change in biomass (size) from when the fleshy sponges were moved from the mangrove to the reef. One grew, one shrank. Then statistics were used to determine if they were the same or they differed (Wilcoxon paired-sample test). They were different ($p < 0.0001$). The p value is essentially the probability that they were different solely due to chance. Since it is really small, they are "statistically significantly" different.

After this, I would go back and read the introduction and fill in the gaps of what you know about sponges, fish predation, and chemical defenses. Here is the first sentence from the Introduction:

"Tropical marine sponges have yielded a wealth of novel secondary metabolites, which natural-products chemists have been isolating over the past three decades (Faulkner 1996, and previous reviews cited therein), but only recently have the ecological roles of these metabolites been addressed (Paul 1992; Pawlik 1993; Hay 1996; McClintock and Baker 1997)".

Note: Notice that there are lots of citations (example: Faulkner 1996). This is where you can go to find more about what was written. However, when you are reading you should ignore them.

If you are unsure of a word, I would look it up. As we start out reading papers together, we will provide you with a glossary. However, as we learn the terminology in lecture, you will come across less and less that you don't know (a great reason to take classes and study!). From the introduction, try to find their hypotheses. They are usually in the last paragraph…

"Specifically, are encrusting, reef colonies of the sponge more chemically deterrent than lobate, mangrove colonies? Does the encrusting growth form result from the grazing activities of spongivorous predators on the reef ?"

So they present research questions instead of hypotheses. No biggie. Lets look at the first question. They ask if reef sponges deter fish better than mangrove sponges. If they did, what would you expect to happen in an experiment where you presented both to fishes? Fishes would eat more of the mangrove than reef sponges, right? That is the tested hypothesis! The second hypothesis is that grazing causes the sponges to be encrusting (we already figured this from the abstract, remember?)

Now I would read the methods section and make sure you know what they did. What were their experiments? And for each experiment try to figure out…

1) What was the hypothesis they were testing? and why did they do it?
2) What was the control to test against?

And this is the hardest part of all…

3) What would **have to happen** to support the hypothesis??? These are known as the "predictions" and are what students struggle with when starting out. We will practice this all semester long…

Let's practice on one experiment from Swearingen and Pawlik, 1998:

(**From the hypothesis: fish cause sponges to be flat on the reef).**
"Predation on *Chondrilla nucula* was assessed by transplanting caged and uncaged lobate sponges from the mangrove habitat to the reef. Sponges were cut from mangrove prop-roots and transported in pairs to the laboratory, where they were weighed and tagged **(Initial weight, to compare to after the experiment)**, and subsequently transplanted in pairs to a patch reef. Each pair consisted of one sponge that was fixed to a brick with a cable tie, 1 to 2 m distant from another sponge that was tied to a brick; this second sponge was also enclosed in a 40 cm^3 plastic mesh (Vexar) cage with 2 cm^3 openings. **(Lots of detail! Remember this is so someone can repeat it, but not necessary for us.)** This mesh size was small enough to exclude potential fish predators, but large enough not to interfere with the filter-feeding activities of the sponges. **(There we go. The important thing was half were caged (NO fish) and half were uncaged (fish could eat)).** Fifteen sponge pairs were placed haphazardly across the patch reef. After 3 days sponges were collected and reweighed. **(After placed on the reef to look for differences)** A Wilcoxon paired-rank test was performed to determine the significance of differences in tissue loss between caged and uncaged sponges."

Ok, so lets form a prediction. If the hypothesis is correct, what will happen to the caged and uncaged sponges?

After formulating predictions, you are ready to read the results. Nicely enough, the methods and results are in the same order, so you should find the data to test your/their predictions. *Hint: You may find it can be easier to follow if you read the methods for one experiment and then the corresponding results. This can then be repeated for any additional experiments.*

There are often lots and lots of results to control for lots of different things. Why is that? The important thing is not to get too bogged down with little details of how big the cages were, how many times this was replicated, or how they isolated the polar and non-polar fractions. At first just stick to the two big hypotheses and see how they tested them.

Hint: For the purposes of this class, we will simplify the statistically analyses as much as possible. We will introduce you to many different statistics, but we will not expect you to understand how the tests work (This is the purpose of a stats class). I would skim over the statistics in the papers to simply determine what test they used to evaluate each experiment. This is a great way to learn the best tests to use for your own data!

Finally, I would read the discussion. The first paragraph is often the heaviest impact where the hypotheses are evaluated. For example, from Swearingen and Pawlik, 1998:

"It was expected that *Chondrilla nucula* from predator-intensive reef habitats would exhibit higher levels of deterrent chemistry than samples from mangrove habitats, where spongivorous fishes are rare. Our data were not consistent with this expectation. In fact, mangrove samples of *C. nucula* from the Bahamas were, on average, more deterrent than reef samples (Fig. 1)."

This was testing another hypothesis and prediction. Was it supported or rejected? Lets read until we find the discussion for the reef fishes causing the sponges to be flat on a reef…

"What is responsible for the morphological difference in specimens of *Chondrilla nucula* from the two habitats? Spongivorous reef fish readily consume the lobate **(Fleshy)**, mangrove morph (Fig. 4 **This is the figure from above. Doesn't it help show this pattern? That is why figures are nice**); could grazing by fishes result in the encrusting morphology found on reefs? Caging experiments suggest otherwise. **Here it is. The hypothesis is not supported. Now why may this be the case? In the discussion the authors will attempt to explain why. This often leads to new hypotheses that can be tested in the future in new papers. This is why science is never-ending…** The relative difference in thickness of the caged reef colonies vs uncaged colonies averaged <1.0 mm; caged reef colonies came nowhere near to attaining the thickness of colonies found in the mangroves. Some of the colonies were caged for well over a year, and none changed in appearance (color or texture) nor exhibited any morphological change except for the slight increased thickness of caged colonies. The small loss of thickness of uncaged colonies (<0.6 mm) does not appear to have been a caging artifact, because a similar loss occurred in partially caged colonies also (Fig. 5). However, the difference in the flow regime **(Think of this as how fast the current is)** experienced by sponges in full cages vs open cages or no cages may have been sufficient to produce the small (but significant) differences in growth seen in this experiment. **So this is there NEW hypothesis to test**. In any case, the caging data suggest that predation on *Chondrilla nucula* is not the principal factor determining its growth form on the reef, otherwise colonies shielded from predation would probably have grown into the thicker morph common to the mangroves."

Ultimately, there are many reasons why you read a scientific journal article. You may be interested in their work as it sheds light on your own. Or you may simply be interested in how they set up their controls or identified a new species (In which case the methods may be of most interest). However, for most purposes this guide will work.

In class groupwork on Thurs!

How could you test this new hypothesis?

"Water flow speed causes sponges to grow flat (encrusting) instead of fleshy (lobate)."

Design a simple lab or field experiment to test this hypothesis

What would your controls be?

Once you have your simple experiment, what are your predictions if the hypothesis is correct?

Think about these and bring them to class. You can discuss them with your group on Thursday!