# Writing fundamental research papers: an informal primer

Important applied research aims to quantify parameters critical to methodology, engineering, conservation, and policy decisions. The focus here is instead on basic research that answers qualitative questions. The importance of a basic science question (and in turn a paper) depends on the current state of a field, so choosing an apt question and sketching your putative Introduction is much of the work.

These are some fundamentals I've discovered, mostly thanks to my advisor Marissa Baskett. I would love to know your experiences and resources (vkaratayev@ucdavis.edu). Also check out link pages by Marissa Baskett and Spencer Hall, and the book *Writing Science*.

## Getting started

What is most fun to you? Writing will be challenging if you don't have a story you want to tell, and a good story usually involves a lot of searching and dead ends, some of which reincarnate (aka research). Make sure you enjoy the shape your search takes. With a bit of adhd, a big literature review to me is scarier than a 10-dimensional model.

Your story will be a set of analyses that closely build on each other to answer a main question, so you'll have 3-4 figures that each answers a sub-question. To get there, one starting point when you're new to a topic/system is to work through a bunch of analyses (power point and RMarkdown are scrap-booking options) until you have a coherent string of 2-4 figures with interesting, compelling, and clear results. So, I hold off writing methods until I have a Results and Introduction I like.

Writing is a part of basic research, and good writing begins with a good outline with a bullet point for each paragraph. From here writing styles differ - many people like to write freely and iteratively reorganize and refine the manuscript. This works well if you're really familiar with a topic/question/study system and have a detailed idea of how things will fit together. If you do not, an underdeveloped outline can mean spending time worrying about sentence/paragraph structure at the same time as you're figuring out what should go in the Introduction *versus* the Discussion and what analyses to include. So for new topics/systems, I prefer detailed outlines where I write out the topic sentence for each paragraph and a couple bullet points on what the sentences in each paragraph will say (and in what order). With a detailed outline, reorganizing is a matter of moving bullet points, and once you feel ready, writing out the full text becomes a matter of sentence structure and explaining ideas.

**Streamlining.** Minimize details not central to the story (moving supplemental ones to Appendix) and standardize terms/definitions. This focuses attention on the important components and makes readers and reviewers happy. Almost all criticism in reviews arises because the motivation or approach to the study are insufficiently clear. So: many rejections are a reflection on the writing rather than the science.

**Show rather than tell.** This is critical to motivating and illustrating ideas within papers. But also: papers with a simple theory/concept grounded in a system or active biological conundrum fare better (in reviews+citations) than papers with a complex model and no easy connection to data. Of course, both papers are needed and can be fun to write.

# Paper organization

## 2.1 Introduction, aka your core question

A 5-paragraph Introduction often works well for distilling your core question:

- Paragraph 1: First sentence here states the overall topic, while the last sentence here resolves **a question in the field that your work substantially addresses (E1)**. This paragraph can be short and watch the length of the first sentence in particular. My favorite opening sentence is "Herbivores eat leaves that a plant needs for photosynthesis" (Low et al 2013, *Cold War Dynamics between Plant and Herbivore*).

- Paragraph 2: Resolve a **result/trend in existing research (E2)** studying the broad question.

- Paragraph 3: Describe a **mechanism/reason why this result/trend might break down/reverse (E3)** that your paper will ultimately resolve/inform.

Resolving how broad/specific the 3 elements bolded above are is a matter of story-telling, refining, and how much research there is on the topic - with more existing research your paper and these 3 elements will be more specific. For example, if there isn't much these elements might be (E1) *How do we quantify difficult-to-measure ecosystem services?*, (E2) *One approach is predicting ecosystem services from functional traits*, and (E3) *BUT strong trait-service links found in some taxa fall apart in other taxa, possibly for reasons A and B*. On the other hand for a well-studied topic you may have (E1) *When do functional traits reliably predict ecosystem services?*, (E2) *In a range of systems easy-to-measure plant functional traits, combined with overall plant biomass, have predicted services*, and (E3) *BUT link between plant traits and services can disappear when the provisioning of services by plant traits is contingent on the presence of secondary species / system features*.

From here the rest of the Intro can be:

- Paragraph 4: This is where you emphasize the ways in which your approach (broad parameters of literature review, broad form of model, or broad study system features) are ideal to resolving the contradiction between P2 and P3. For empirical studies this is where you first introduce the system.

- Paragraph 5: The "Here, we..." paragraph over-viewing what you'll be doing. This needs to include the specific question you investigate - which is: "when does mechanism/contradicting pattern in P3 break down the broad pattern (P2)?", and also a sentence on the overall method you use. Beyond that you can spend more time on the question (ie spelling out several hypotheses for how things will play out) or on road-mapping your methods+results (ie one sentence on each main analysis/figure).

**A thing to avoid.** If your overarching question (E1) or your specific research question in Paragraph 5 are "this hasn't been studied before", that is a bad motivation for fundamental research. In theoretical biology this sometimes leads to models that are both too complex to build intuition across systems and make too many assumptions to inform any specific system. This also means that exploring a compelling conundrum raised by data in a specific system can be a great start to good theory.

## 2.2 Abstract: [Wonderful advice from Brian McGill here.](#)

## 2.3 Discussion

**"Results and Discussion" as a single section?** This mostly depends on how complex the results are. With much luck and preparation, your overarching question may boil down to just a couple simple models or simple statistical tests that directly examine the overarching question from P5 of intro. Then a single section can work well. Notice that Nature/Science papers have no sections - usually they have strong and direct tests of the question (or at least frame them as such). On the other hand, if results are more nuanced or models are complex, having a separate Results section is good to guide interested readers through the patterns more closely before discussing their implications.

**Discussion intro/opener.** Sometimes you have a very comprehensive or descriptive study that closely matches the broad questions you set out to address. If so, congrats! But in theoretical models or controlled experiments, there can be quite a distance between your results and the main question of what actually happens in the field (a gap you have already begun to bridge in the Introduction). In these cases, it is really great to begin the Discussion with an opener that has one paragraph for each of the study's 1-3 main results. In each paragraph, briefly summarize your theoretical/experimental result and then say how it compares and builds on prior theory/experiments. After you have done this, you can go on to the different subsections, each of which now details how the model/experiment results apply to / inform patterns or management questions in real systems.

**Use sub-sections to organize and guide readers.** It is important to organize the Discussion (and the Results) by the multiple subquestions or take-homes you have. To highlight the thoroughness of your approach, a good idea is to include a separate subsection evaluating the caveats/assumptions in your analysis. There are usually many; focus on assumptions that could qualitatively change your result. One 2-paragraph organization is by assumptions that make your analysis (1) over-predict or (2) under-predict a phenomenon.

Throughout, you can focus readers on your findings by starting discussion paragraphs with a quick reference to a result can work well, eg: "Our result that X can drive Y builds on previous findings showing z."

A good concluding paragraph should spell out how your work answers/informs the broad question from P1 of intro. And/or lay out 2-3 key priorities / specific objectives for next research on this question.

## 2.4 Big journals and grants

Papers with the above layout will be appreciated by most in your field, and all the elements above are required for any basic research. What changes in really broad (big) journals and grant proposals (and any decent newspaper article, by the way) is you need to really quickly grab attention. This means increasingly "front-loading" your paper: giving your central question and its significance very early on, and then back-tracking to give context/motivation based off previous research.

# Basics of better paragraphs and sentences

## 3.1 Paragraph structure

**Pauses provide natural emphasis** The beginning and end of a paragraph provides stress points which are nice places to put key ideas. This also means that for the same space and writing quality, two moderate-length paragraphs are often more effective than one long one. This is also true for sentences. In the middle of a paragraph, a diversity of sentence lengths can help: a point you spend several sentences building up to is best made by a short sentence tying everything together. Likewise, colons and semicolons provide additional pauses - and secondary stress points - within a sentence.

**Topic sentences.** Paragraphs should begin with a sentence summarizing or identifying the direction in which the following sentences are going. These can be tricky to write but they benefit readers by telling them where you're headed before getting into the weeds and help those skimming the paper. And they benefit you in streamlining the section into a clear logical progression and help you focus on connecting everything to the main story.

**Sentence logic flow.** This is really easy to do and becomes obvious once after you see it once. If one sentence says A affects B, you don't want the next sentence to say C follows from B; much better to say B links to C. So across sentences you want to have subjects flow like A→B, B→C, C→D.

**Transitions.** First, transitions such as "However" or "In contrast" interrupt the logic flow to emphasize ideas but, for the same reason, should be used only when highlighting truly divergent things. Eg if your whole paragraph is highlighting one theme across many studies, "However" is a good way to point out one paper/concept that breaks the pattern. Second, if you have many transitions ("In addition, ...", "Similarly, ...", or "Vice versa"), that is an indication that your paragraph could use a better organization of ideas to improve logic flow or highlight the common theme across these sentences (or the studies you're examining). Maybe all the "Likewise" transition sentences group into one theme, the "However" transition sentences group into a second, and the topic of the paragraph should be the feature that distinguishes between the two types?

## 3.2 Sentences

**Minimize sentence subject-verb separation.** This helps engage readers and remove ambiguity. *We found that X, as shown by Strunk et al and in conjunction with Y and Z, can result in an increase in A.* Is much less engaging than *We show that X can increase Y. The increase in Y with X depends on Y and Z, a result that expands previous findings of Strunk et al.* Note that stronger verbs make the action easier to find.

**Active voice and present tense.** Take work but make reading much more engaging and easier to follow. Spellcheckers can highlight passive voice.

**Getting excited together.** This is a personal style choice, but I find papers with direct questions (*How could X cause Y?*) and a bit of emotion (*Surprisingly / Counter-intuitively, we found X follows Y*) interspersed throughout the text to be engaging in much the same way as active voice: readers get involved in your story. Every plant ecologist I know (there are many) made their career choice because of a captivating teacher.

# Appendix

## 4.1 A theoretical ecology paper people will cite

Insights from Steve Ellner et al ([more here](#)): First, don't maintain suspense:

- Present the topic clearly at the very beginning.
- Explain the relevance of the paper at the very beginning.
- Quickly telegraph where the entire paper will be going. Give away all your punchlines in the abstract, and do it again in the Introduction.

Second, make the paper easy to skim:

- Make sure that the "meat" – the core that everyone should read – is well labeled and easy to find.
- Explain your main results using graphs.
- Remove from the main text any technical details that aren't needed for the flow of ideas. Readers shouldn't have to stop and think about whether or not they have to think about an equation.
- Use signposting to help people "peel the onion" – get as deep into the paper as they want, but no deeper. Technical sections should be prefaced by an explanation of what and who it's for, so it's easy for a reader to tell if they should read it, skim it, or skip it for now

## 4.2 Tips on NSF Graduate Research Fellowship proposal

It is important to have a bit of theory incorporated, which is a big part of addressing the intellectual merit criteria. I started with a broad theoretical topic in ecology (types of disturbance), and related it to a big question in lake ecosystems, such as the ones I'm proposing to study. You'll most likely do this in the first paragraph, with subsequent paragraphs transitioning into what you plan to do.

I think it's equally important to also describe some of the experiments/studies that you will do to demonstrate that you're fully competent to carry out the project. The key here is to I think describe a few of the main approaches and techniques to show that you are well acquainted with both the latest techniques as well as designing a sound study. However, it's also important to describe these (perhaps complex) techniques in a concise, intuitive way that would be accessible to any person in the field (which is who your reviewers will be). For example, I proposed using stable isotope analysis to study food webs in lakes, but my reviewer could have been an ornithologist studying tropical birds.

Finally, the key in the research proposal is synthesizing what you're proposing to do (the empirical component) with the theory you discuss. Don't be too afraid of proposing an ambitious study - your thesis needn't be even related to your proposal - the point of this is to demonstrate an ability to think about basic/theoretical aspects of your field, and address these big questions with a relevant, well-designed study.

Two more small notes here. 1: don't neglect broader impacts by writing 1-2 generic sentences. Try to make them original to your study, and it is great if you can support the things you say you plan to do (working with youth or community) with personal experiences in the personal statement. 2: use formatting effectively - bullets, boxes, bold/italics, subsections/hypotheses, etc are great ways to emphasize the key bits of your statement and what you plan to do. This makes it much easier to tell what your main question is and how you plan to go about addressing it. If you clearly emphasize these few bits, your proposal as a whole will stand out more. Also, if you're getting ready to submit and find you have some empty lines at the end, use that space to add some more space between the paragraphs in your main text to make the whole thing more readable.

Throughout the process, find out what works and what doesn't by getting your peers and professors to give feedback on your proposal. Good luck, and remember that what you gain from this experience is just as important as having a good shot at the fellowship.