Reorganisation following disturbance: multi trait-based methods in R

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Teaching Issues and Experiments in Ecology

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1. Data set homepage

Title: Reorganisation following disturbance: multi trait-based methods in R

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The Ecological Question:

What effect did a severe coral bleaching event have on the multi-trait structure of coral reef fish assemblages?

Ecological Content: community ecology, traits, trait-based diversity, functional diversity, coral reef ecology, climate impacts, mass coral bleaching event, recovery following disturbance.

Four-Dimensional Ecology Education (4DEE) Framework

- **Core Ecological Concepts**:
  - Community - Habitat types – Marine – Coral reefs
  - Community - Species diversity – Biodiversity – Reef fish
  - Community - Species diversity – Abundance
  - Community - Stability – Disturbance
  - Community - Ecological traits
  - Biosphere - Global climate change
  - Biosphere - Extreme climate events – Coral bleaching

- **Ecology Practices:**
  - Quantitative reasoning and computation thinking - Statistics - Univariate
  - Quantitative reasoning and computation thinking - Statistics - Multivariate
  - Quantitative reasoning and computation thinking - Data skills – Inputting and data-mining / meta-analysis/ data visualization
  - Quantitative reasoning and computational thinking - Computer skills - R
  - Quantitative reasoning and computational thinking - Data analysis and interpretation
  - Designing and critiquing investigations - Study design, familiarity with basic modes of ecological inquiry (description, comparison, experimentation, modelling)
  - Designing and critiquing investigations - Argument from evidence
  - Working collaboratively
  - Communicating and applying ecology
  - Peer review

- **Human-Environment Interactions:**
  - Human accelerated environmental change – there is no pristine ecosystem nor total equilibrium - Anthropogenic impacts, intentional and unintentional
  - Human accelerated environmental change – there is no pristine ecosystem nor total equilibrium - Global climate change
  - Human accelerated environmental change – there is no pristine ecosystem nor total equilibrium - Extreme climate events – Bleaching
  - How humans shape and manage resources/ecosystems/the environment - Conservation biology

- **Cross-cutting Themes:**
  - Structure and function
  - Spatial and temporal - Stability and change

What Students Do:

Students use the statistical programming tool R to examine how fish communities are impacted by a disturbance event. Students receive an existing dataset on the abundance of coral reef fish from underwater visual census of belt transects before and after widespread coral bleaching. The dataset contains the counts of fishes from multiple transects surveyed across different habitat types. Students use R, the free software environment for computing statistical analyses and graphics, to subset and pool the data and plot trends in the data at the fish species level. Students select two specific species, research their ecological traits, and relate these to their abundance before and after bleaching. Students then hypothesize how the fish assemblage as a whole in different habitat types might have been impacted by the disturbance event. The students interpret the 'functional' trait ordination space after learning about multivariate statistical methods and use univariate statistics to compare trait-based 'functional' richness before and after mass coral bleaching. Students relate their findings to the wider literature and summarize their work in a scientific poster that they present to their peers at a student symposium.

Student-active approaches:

Guided enquiry, problem-based learning, critical thinking, 'authentic' assessment (student poster presentation), marking rubric.

Skills:

Data manipulation, analysis, and visualization in R
Knowledge of multi trait-based methods for ecology
Writing testable hypotheses
Synthesizing knowledge
Researching the literature
Communicating science (making and oral presentation of poster)

Student Assessments:

Student skills are assessed based on their production and presentation of a scientific poster. The poster summarizes the analyses they perform on the dataset in R. The students' ability to interpret and present a scientific evidence-based argument, with reference to the existing literature is assessed in oral and written skills.

The assessment associated with the practical session described herein carries 50% of the module marks and is centred on the creation and presentation of the scientific poster, concerning the results of each individual student's data analysis. The assessment mark is split into two parts: 15% for the oral presentation of the poster and 35% for the quality and content of the poster.

The oral presentation marking criteria include the following categories: 4-minute verbal presentation, demonstrated understanding, structuring, and timekeeping. The structure is expected to include an introduction to the study, aims and hypotheses, methods (data, design, analyses), results, and discussion (see 'Marking_criteria_oral_presentation.pdf'). The poster quality assessment is based on the poster content (including the background, aims and hypotheses, methods of data design and analysis, results, discussion, references) and poster visuals (including layout design, graphics, and writing style (see 'Poster_quality_rubric.pdf').

Class Time: Total recommended class time for this practical is 16 hours (hr). We split this into six sessions (1 x introductory lecture; 1 x 6-hr practical; 3 x 2-hr practicals; 1 x 3-hr student symposium). The practical sessions can be split as required to enable working through the practical materials. Where instructors do not have enough space in their courses to allocate this time to complete all parts, they might choose to adapt the materials to end the computer-based practicals after Part 2, where they will have computed functional diversity and created the main results figures for their poster (PCoA and boxplot graphs showing fish assemblage trends before and after bleaching). By excluding Part 3, students would miss testing whether observed differences are statistically significant. Similarly, instructors could have students write up their findings (in poster or report format), without extending this to the in-person poster symposium.

Course Context: This practical is designed for third-year undergraduate students, as part of a wider module on 'marine ecosystems and processes' in the UK. This equates to junior level on a bachelor degree in the United States. Students will need to have done an 'Introduction to R' course ahead of this practical. For example, at Bangor University, all students taking this practical course would have completed module ONS-1001 'Environmental Data and Analysis' in year 1, where they receive training in basic R coding, data wrangling, graphing, common statistical tests and simple linear models, and an introduction to mapping in R. These students then use R to analyse data in several other modules during their first and second year, so would approach this practical with prior experience of some required tasks in R (e.g., creating boxplot graphs, implementing a t-test). If instructors wish to implement this practical with students who do not have any prior background using R, we suggest running two 3-hour workshops where students are introduced to R, covering basic data wrangling, graphing, and statistical tests.

Source: Richardson et al. (2018). Mass coral bleaching causes biotic homogenization of reef fish assemblages. *Global change biology* 24.7: 3117-3129.

https://doi.org/10.1111/gcb.14119. Available free of charge and without subscription here: https://doi.org/10.25903/5b57c26b0beb7 (Chapter 4).

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Relevant Cover Image: Bleached anemone image (see attached).

Keywords: R, ecology, traits, trait-based diversity, coral reef ecosystems, reef fish, data exploration, statistical programming.

2. Overview

Individual species, or groups of species, play a unique role in the function of their ecosystem. Species can be, and often are, classified into ‘functional’ groups based on their morphological and/or ecological characteristics or ‘traits’ (Magneville et al. 2021; Parravicini et al. 2021). For example, a coral reef ecologist might group herbivorous reef fishes based on the physical impact their feeding has on reef substrata or benthic reef communities (Bellwood et al. 2004; Hughes et al. 2007; McClure et al. 2019). A disadvantage of considering individual species or functional groups in isolation is that it can overlook patterns within the broader community (Mouillot et al. 2013; Richardson et al. 2018). Moreover, many species contribute to multiple ecological functions.

In a biological community or ecosystem, measuring multi trait-based ‘functional’ diversity can overcome a narrower single species or group perspective by offering complementary additional indices to elucidate disturbance dynamics (Mouillot et al. 2013). Functional diversity measures the diversity of species characteristics (Petchey and Gaston 2006; Naeem et al. 2012) which define how species fulfil different ecological roles in the community (Mouillot et al. 2013; Magneville et al. 2021). This community-level measure of function differs from species diversity (i.e., species richness – how many species there are) and instead focusses on the number or diversity of ecological or ‘functional’ roles (what species are doing). Morphological or ecological traits are often used as proxies for the roles that species play in contributing to ecosystem function (Bellwood et al. 2019). For example, diet informs community trophic dynamics and can influence energy flow as well as providing information on ecosystem processes like herbivory which can impact ecosystem resilience (Bellwood et al. 2004). Body size can provide information on animal movement, home range, and energetic needs of an individual (Bellwood et al. 2004; Heenan et al. 2020; Parravicini et al. 2021). In turn, a trait-based approach can be used to understand species in terms of their ecological roles and interaction with the environment and other species (Mouillot et al. 2013; Villéger et al. 2017).

The goal of this practical is to investigate what effect a mass coral bleaching event had on the trait-based diversity of coral reef fish communities at Lizard Island, in the northern Great Barrier Reef, Australia. The disturbance event was the prolonged marine heat wave and extreme temperatures experienced in 2016 that triggered mass coral bleaching across the Great Barrier Reef (Hughes et al. 2017).

Students will conduct analyses at the individual species level and research the ecological traits of these species from published sources such as FishBase and a peer-reviewed fish trait database (Froese and Pauly 2021; Parravicini et al. 2021). They interpret the functional trait space, a principal coordinates ordination analysis (PCoA), generated for the fish assemblage based on their assigned traits, and hypothesize how their selected species and the fish assemblages found in different habitat types, may have been influenced by the heatwave and resulting mass coral bleaching event.

This multi-part practical teaches quantitative ecology and functional multi trait-based methods through computational coding of a pre-existing dataset (Richardson et al.

2018) and use of the R package, mFD (Magneville et al. 2021). Students will gain experience in data wrangling ('manipulation') and exploration, hypothesis testing, data visualization, statistical analysis, and critical evaluation of their results. Students present their work via a scientific poster to their peers at a student symposium. Students will advance their understanding of community ecology and how community level responses following disturbance can be assessed using both univariate and multivariate statistics.

Key reading

Background on the disturbance event and ecosystem of focus:

Hughes et al. (2017) Global warming and recurrent mass bleaching of corals. *Nature* 543.7645: 373. https://doi.org/10.1038/nature21707

Paper on which the practical is based, and dataset is sourced:

Richardson et al. (2018) Mass coral bleaching causes biotic homogenization of reef fish assemblages. *Global change biology* 24.7: 3117-3129. https://doi.org/10.1111/gcb.14119. Available free of charge and without subscription here: https://doi.org/10.25903/5b57c26b0beb7 (Chapter 4).

Papers outlining methods employed to build a functional space. Just read to understand general concepts, pay particular attention to mentions of functional richness:

Magneville et al. (2021) mFD: an R package to compute and illustrate the multiple facets of functional diversity. *Ecography* 1. https://doi.org/10.1111/ecog.05904

Mouillot et al. (2013) A functional approach reveals community responses to disturbances. *Trends in ecology & evolution* 28,3: 167-177. https://doi.org/10.1016/j.tree.2012.10.004

Learning Objectives (LOs): At the end of this practical session, students should be able to:

LO.1: Describe the key environmental and biological drivers that affect marine processes and ecosystem functioning, and the relevant temporal and spatial scale at which these operate.

LO.2: Relate the organisation of ecosystems (i.e. coral reef fish assemblages) to environmental or ecological processes (i.e. thermal stress, habitat provisioning)

LO.3: Process, analyse, and present a large dataset.

LO.4: Explain how biodiversity contributes to the resilience and regime shifts of marine systems, and appreciate the importance of organism trait diversity on ecosystem structure.

LO.5: Prepare and present a conference poster that conveys, simply and clearly, the results of a piece of research.

3. The data sets

Student version

Richardson gave permission for these data to be included on the TIEE website. Data collection was funded, collected, and published by Richardson et al. (2018). Note, all student handouts are created from the .Rmd instructor versions, as described below.

File names:

1. **Practical 'Part 1': Getting to know the dataset and the ecosystem**

   LI_fish_abundance_pre_post_bleaching.csv ## Richardson et al. (2018) subset datafile

2. **Practical 'Part 2': Building the multi-trait space to measure trait-based diversity**

   tiny_trait_matrix.csv ## to illustrate how dissimilarity matrix calculation works

   tr_cat_1.csv ## to illustrate how traits can be categorized into distinct types

   tr_cat_2.csv ## to categorize traits as distinct types

   traits.csv ## dataset of species traits from Richardson et al. 2018 supplementary material

3. **Practical 'Part 3': Analysing the trait-based diversity indices and presenting your data**

   No additional data files required. Datafiles required for practical 'Part 3' are generated during practical 'Part 2'.

Instructor version

- Introductory overview slides (editable optional PowerPoint file)

- Practical '*preparation'* document (.docx; or .Rmd):

  This should be updated and shared with students prior to practical to reflect institutional access to RStudio. Currently contains instructions to create an account and use RStudio Cloud.

- RMarkdown files (*part1.Rmd*, *part2.Rmd* and *part3.Rmd*) and images used to create student handouts for practical 'Part 1', 'Part 2', and 'Part 3'.

Rmd files include commented-out code that address student questions and has code answers (these do not appear in the student versions).

- Poster preparation guide (editable optional PowerPoint file):
  Should be updated with example posters that the instructor considers “good” and “not so good”, and to reflect how the instructor wants to run the scientific poster session and receive assignment files.

- Marking schemes / rubrics for assessment via the scientific symposium:

  Two schemes, one for oral presentation of the poster (‘Marking_criteria_oral_presentation.pdf’); one for poster content quality (‘Poster_quality_rubric.pdf’).

4. Student instructions

Attached as MS PowerPoint (lecture slides and poster guide) and Word files (student handouts rendered from Markdown files in RStudio). Accompanying Rmd files contain answers for instructors.

I. Introductory overview lecture (ppt slides)
II. Practical introduction (‘Practical_introduction_for_students.docx’)
III. Prepare to work in R (‘preparation.docx’)
IV. Practical ‘Part 1’: Getting to know the dataset (‘part1. docx’)
V. Practical ‘Part 2’: Building and interpreting a functional trait space and measuring multi-trait-based diversity (‘part2. docx’)
VI. Practical ‘Part 3’: Analysing the multi-trait-based diversity indices and presenting your data (‘part3. docx’)
VII. Poster preparation guide (ppt slides)

5. Faculty notes:

Overview

The objective of this teaching material is for students to practice quantitative ecology and computational coding in R, whilst learning about ‘trait-based’ ecology using coral reefs as a model system. Undergraduate students and other trainee scientists require training in computation skills if they are to work with data (Braun and Huwer 2022). The teaching approach here embeds data, programming, and statistical literacy within subject-specific and course-relevant theory (trait-based approaches for functional ecology). This has been identified as a priority action to address the data science gap within higher education curriculum (Blake 2019; Braun and Huwer 2022).

Instructional design

This teaching resource was created for the undergraduate course “Marine Ecosystems and Processes” in the School of Ocean Sciences at Bangor University, North Wales, UK. The content addresses the module learning objectives listed above, towards the following broad learning outcomes:

- Students will demonstrate an in-depth understanding of how biodiversity contributes to the resilience and regime shifts of marine systems, and appreciate the importance of trait diversity to ecosystem functioning.

- Students will have the ability to process, analyse and present a dataset.

- Students will have the ability to make and present a conference poster that conveys, simply and clearly, the results of a piece of research

The content is designed to be a blended combination of traditional learning (knowledge acquisition through instruction), flipped classroom-based computer practicals and opportunity for peer-peer learning. Specifically, it forms a multi-part practical, with resources designed to foster the six different learning types: i) acquisition, ii) inquiry, iii) practice, iv) production, v) discussion, and vi) collaboration (Laurillard 2012). We used Laurillard's (2012) conversational framework, an educational design tool, to create material that includes a mix of these different learning types and to facilitate learning through instruction, practice, and learner communication back to the teacher and between students.

The practical is introduced during a 1-hour lecture (*acquisition*), in which the ecological theory, the quantitative tools, the dataset, and the ecological study question are introduced (‘Introductory_overview_lecture.ppt’). This lecture also provides a refresher on the statistical programming environment in R. Emphasis is made on why it is important for students to learn how to program, and the growing demand amongst employers for programming skills (Braun and Huwer 2022).

The handouts which accompany the computer-based practicals (2 x 3-hr; ‘part1’, ‘part2’, ‘part3’) are designed to be question based (*inquiry*, *practice*). This is to stop students racing through and copy-pasting the code without critically thinking about each step. Students are also provided with the option for self-directed, inquiry-based learning. In Part 1, students are assigned by the instructor to different habitat groups (i.e., ‘branching Porites’, ‘low coral cover’, ‘mixed coral’, ‘soft coral’), and students investigate their habitat specific recommended species of interest. If they follow the handouts and answer questions as they go, they should have all the required information for the results section of the scientific poster that they each independently produce (*production*). Students then participate in an in-person mock scientific symposium, each giving an oral presentation of their poster (4-minutes), displayed digitally on a large monitor, with the opportunity to learn from their peers who will have focused on different subsets of the data (specific species and habitat types) (*discussion*, *collaboration*). Specifically, students are split into groups (~ 20 students per group) and required to observe each other’s poster presentations. Following each student presentation, the student observers are instructed to ask content-related questions (1-minute for questions). At the end of the presentations, all participants engage in a short discussion based on their shared findings, highlighting examples of good presentation practice, and offering suggestions for improvement informed by the poster presentations they have reviewed.

Prior to participating in the mock scientific symposium and during the computer practical session, anonymised exemplars of previous students’ posters can be shared (‘Poster_preparation_guide.ppt’). These exemplars should comprise both “good” and “not so good’ scientific posters intended to enhance student understanding of the assessment task and standards, and their evaluative judgement. By working with exemplars and engaging in assessment tasks that comprise components of peer feedback, such as the question and discussion sessions participants experience during the mock scientific symposium, students participate in making academic judgements for themselves, thereby developing learner agency (Panadero et al. 2016; Nicol 2022). Furthermore, assessment approaches like these that engage students in the overall assessment process have the potential to improve their levels of assessment literacy (Evans et al. 2019; Evans 2021).

Lessons learned

Getting off to a strong positive start will be important for acquiring confidence in computational literacy. A common issue of teaching and learning in R for students and lecturers is in the start-up, installation, and set-up. If students struggle at this point, you can lose students already hesitant to program in R, even before the class material has started. Different operating systems on personal machines and different versions of R can all make getting going in a class a real challenge and can take up an extraordinary amount of class and teacher time. We took the following steps to minimize these issues:

1) Students were provided with detailed installation instructions, to be done prior to the practical (‘preparation.pdf’), to allow for any issues to be resolved prior to the scheduled class time. Using a cloud-based version of RStudio may circumvent issues in relation to start up, installation, back compatibility, and

version control. Depending on institutional access, students may need to also set up a free RStudio Cloud account. Ensuring a consistent R environment facilitates this material being delivered remotely and reduces the risk of compatibility issues taking up scheduled class time.

2) A high instructor to student ratio (suggest 1:10), especially for the first computer session. Initially, students tend to have a lot of questions, especially if they have not used R recently. Responding to and facilitating their progress at this early stage is important for maintaining momentum, so instructors (i.e., session lead plus teaching assistants) should ensure they move around the room and check that all individuals are up and running in R early on.

3) The .Rmd files generate MS Word document handouts for the students that do not include the outputs from the code. A teaching assistant version of the handouts could be created that includes the code outputs for reference.

Evaluating the efficacy of teaching

We learned from the module evaluation (response rate ~ 22 students) that students overall found the new material developed to be a positive addition to the course. In particular the opportunity to further develop their computer literacy with statistical programming skills in R as well as practice presenting using the alternative format of a scientific poster:

"I particularly enjoyed the opportunity to present a scientific poster. I definitely think it provides students with a great way to practice a "real-life" scenario as a marine biologist."

"The poster practical was an essential piece of experience. It helped develop people's R studio skills, which has become an essential skill for new researchers and data analysis skills which are also in high demand."

That said, some student comments revealed that there was room for improvement in future deliveries. Specifically, we learned that students coming from different degree programs have varying comfort levels with R:

"The data analysis was very confusing and poorly explained. At no point did I feel like I knew what I was doing. Although most of the students in the room had used the software, anyone from the physical ocean science side haven't."

Though these comments are no longer received across subsequent years running the teaching (Skov *pers. comm*.), we suggest offering supplementary catch-up sessions or additional exercises for students to get up to speed with those students more familiar and comfortable with R. In particular, we recommend the user friendly tutorial accompanying the mFD R package publication (Magneville et al. 2021), available here. To help boost students' confidence and literacy in using R, the Teaching and Scholarship team of the School of Ocean Sciences developed an 'R Student Support' facility on '*Blackboard'*, Bangor University's Virtual Learning Environment. This support site contained additional R learning resources, including online tutorials, data analysis guidance, and discussion boards. Students also had the option of booking into weekly R support drop-in sessions for troubleshooting coding issues. We recommend this high-level, School-wide approach to R-support if staff time is available.

Some students found the overarching purpose of the analysis less clear. Additional context and explanation has been added to the handouts as a result. We recommend discussing a clear research 'aims and objectives' framework from the outset, and encourage students to write this out as a statement, as a model for their own individual piece of work.

Staff answers to questions in the handout

Students are asked the following questions in the handout.

Q1. Based on the trait table above, fill out the following table, calculating the average dissimilarity scores for each species pair combination.

Ensure students understand 0 = not dissimilar at all (i.e. all traits match), 1 = different for all traits. If you see students filling out the top half – get them to realize it is exactly the same.

	A	B	C	D
A				
B	0.0			
C	0.5	0.5		
D	1	1	0.5	

Q2. What different trait types are there, and what are the levels within each?

Prompt students to problem solve themselves, with each other, and by referring to the resources listed in the handout. The fish and benthic assemblage paragraph in the methods section of Richardson et al. (2018; see https://doi.org/10.25903/5b57c26b0beb7; Chapter 4) details the trait types, with further information in the supplemental materials. Students should be familiar with the diet categories, but if they want more information (especially for nominal herbivores) point them to the Green and Bellwood (2009) reference listed at the end of the handout, FishBase, or a recently published global reef fish trait database (Parravicini et al. 2021).

Trait	Meaning	Factor levels	Notes on definitions
Size	Mean observed body-size (total length in 10 cm size categories)	1-7	1: 0-10, 2:10-20…7: > 70
Diet		Browser, Corallivore, Excavator, Farmer, Grazer/detritivore, Invertivore, Mixed diet,	Browser: eats macroalgae Corallivore: eats coral Excavator: eats chunks of the reef matrix

		Piscivore, Planktivore, Scraper	Grazer/detritivore: crops diminutive forms of algae and detritus Invertivore: eats invertebrates Mixed diet: omnivorous Piscivore: eats fish Planktivore: eats plankton Scraper: takes scraping bites from reef matrix
Mobility	Mobility within and between reefs	Mobile across reefs, Mobile within reef, Sedentary	Sedentary: site attached
Activity	Time when active	Both, diurnal, nocturnal	Diurnal: during the day, nocturnal: during the night
Schooling	Social grouping behaviour	largeG, medG, pairing, smallG, solitary	G = group
Position	In the water column	Benthic, bentho-pelagic, pelagic	Benthic: associated with the reef substrate Pelagic: up in the water column (note: ensure students realize this is not pelagic in strict sense of open water)

Students should fill out the trait table for these species – prompt them to think about how they might be differently affected by mass coral bleaching. *Lujanus bohar* being a relatively large bodied piscivore is probably less sensitive to coral loss as their prey are still available, also they are less reliant on corals for shelter and hence less at risk of predation, and are typically mobile and so can move off elsewhere. *Chaetodon kleinii* eats coral (a 'corallivore') so is coral dependent and could decrease in abundance due to reduced food availability. Heat stress and mass coral bleaching could also impact their sociality and territory use if competing for live coral food (Keith et al. 2018).

Species	**Size**	**Diet**	**Mobility**	**Activity**	**Schooling**	**Position**
Lutjanus bohar	21 -30	Piscivore	Mobile within reef	Nocturnal	MedG	Bentho - pelagic
Chaetodon kleinii	11 -20	Corallivore	Sedentary	Diurnal	Pairing	Bentho - pelagic
[Your selected species 1]						
[Your selected species 2]						

Note on the code to visualize the functional trait space: The point here is that students see the Principal Coordinates Analysis (PCoA) code. The aim is not for students to have an in-depth understanding of the underlying math, more to grasp the concept of what is happening.

It can be helpful to point out that this is a data reduction technique. All the variation in the original dataset (the pair-by-pair species comparisons) is reduced down into a derived set of variables – synthetic axes. If all original linear combinations were included, then 100% of the variation would be explained. However, this would result in the same 189 species pairwise comparisons, therefore the ability to look at patterns wider than species-by-species comparisons is lost. Instead, here we create four synthetic axes (lines) through the data that capture as much as the variability as possible.

We also recommend explaining that this trait space represents all observed fish species surveyed in all habitats across both time periods, clustered according to their shared trait characteristics (see Q3 below). The students will not recreate a habitat- or time period- specific PCoA.

Q3. How many pairwise combinations do you have with this dataset?

17766.

This is calculated with the formula: n (n-1) / 2 (i.e., 189 species * 188 / 2).

Q4. Write a short (3-4 sentence) summary to describe how the fish species have clustered in this trait space, i.e. how do some of these fish traits vary across the trait space?

Trait vectors are overlaid and can then be used to see how these fishes vary across multiple traits at once. We suggest that they look for any patterns across the PCoA where, for example, body-size increases/decreases, or social grouping changes across one of the axes (or diagonally). Also, we suggest students look for specific clusters – i.e. are specific trophic levels clustered together (e.g. omnivores 'mixed diet' and piscivores are together, scraping, and excavating herbivores are clustered).

From the Richardson et al. (2018) paper: "Generally, fish body-size and mobility increased along PCoA 1 and 2, with diet groupings positioned along those gradients, ranging from small-bodied site-attached farming species through to larger, more mobile, piscivorous fish species (Figure 2). Nocturnally active, schooling planktivores occupied the left of PCoA 1, and browsers were positioned in the centre of PCoA 1 and 2…"

Some things the students could pick out from their PCoA:

1. Generally, fish body-size increases from the top middle of trait space to the middle right hand-side.
2. Social grouping decreases from left to right of PCoA 1, from fish species that associate in medium and large schools, pairing species in the centre of PCoA 1, to typically solitary species on the right.
3. Medium and large schools of planktivores are positioned on the left of trait space (left of PCoA1).
4. Larger-bodied fish that eat other fish (mixed diet and piscivores), hunt day and night, and are mobile across reefs, are clustered broadly together in the middle of trait space.

Q5. Create boxplot graphs showing the estimates of functional richness, species richness, and total abundance of fishes before and after bleaching, and export these for your poster.

Note: some students might like to consider using something other than a boxplot – the ggplot2 cheat-sheet has base code for barplots and error bars etc. Encourage them to explore. Ensure they export the figures at the end for their poster.

Assessment preparation

During the computer practical session, students are presented with a series of slides with instructions on creating an effective scientific poster ('Poster_preparation_guide.ppt') with blank slides for the instructor to add exemplars of both "good" and "not so good' scientific posters. The marking rubric should also be shared and discussed ('Poster_quality_rubric.pdf').

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