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Subconscious Biases in Coral Reef Fish Studies

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Abstract

In complex, diverse ecosystems, one is faced with an exceptionally challenging decision: which species to examine first, and why? This raises the question: is there evidence of subconscious biases in study species selection? Likewise, in selecting methods, locations and times? We addressed these questions by surveying the literature on the most diverse group of vertebrates (fishes) in an iconic high-diversity ecosystem (coral reefs). The evidence suggests that we select study species that are predominantly yellow. Reef fish studies also selectively examine fishes that are behaviourally bold, and in warm, calm, attractive locations. Our findings call for a re-evaluation of study species selection, and methodological approaches, recognising the potential for subconscious biases to drive selection for species that are attractive rather than important, and methods that give only a partial view of ecosystems. Given the challenges faced by high diversity ecosystems, we may need to question our decision-making processes.

Keywords

Biodiversity; Coral reef; Fish; Function; Subconscious bias

Overview of the issue

Coral reefs are one of the world's most iconic high-diversity ecosystems. Such diversity offers a plethora of potential study species, leaving one faced with an exceptionally challenging decision: which species do we examine first? And where, when and how should we conduct our study? Logically, it is in such high-diversity systems that the potential for subconscious biases are likely to be greatest, given the range of study options available (Bonnet et al. 2002; Clark and May 2002). This issue is particularly pressing as many high-diversity ecosystems are rapidly reconfiguring in response to climate-induced environmental disruption (Barlow et al. 2018; França et al. 2020). As a result, there have been urgent calls to understand and maintain the ecosystem functions that sustain high-diversity ecosystems, such as coral reefs, and the services they provide to humanity (Hughes et al. 2017; Brandl et al. 2019b). However, our understanding of ecosystem functions depends on the species we examine and how we study them (Bellwood et al. 2019). Such selection processes may involve subconscious biases.

There is a burgeoning literature on the extent, nature and impacts of subconscious biases (also termed unconscious and, perhaps most accurately, implicit biases) (e.g. McNutt 2016; Knezek 2017; Asplund and Welle 2018; Baum and Martin 2018). These biases have been repeatedly shown to influence the nature of academia, especially in terms of selecting researchers for funding, promotion and publication (Wenneras and Wold 1997; Bornmann et al. 2007; Moss-Racusin et al. 2012). However, there have been few critical evaluations of our decisions when undertaking scientific research, especially in terms of what species we study (but see Bonnet et al. 2002; Clark and May 2002), or how we conduct our research. To address this knowledge gap we asked two key questions: 1) is there evidence of biases in our selection of study species and, 2) are there biases in our approaches when undertaking research in high-diversity systems? Ultimately, this raises the question: to what extent may these biases shape our understanding of ecosystem processes?

To address these questions, we surveyed the published literature on the most diverse group of vertebrates (fishes) in an iconic high-diversity ecosystem (coral reefs) (Fig. 1). Coral reef fishes represented a particularly amenable study group because of their ease of identification to a species level, taxonomic stability, pantropical distribution, and exceptional taxonomic and morphological diversity (Fig. 1). Our focal literature source was the international journal *Coral Reefs*; the world's primary journal for coral reef studies. This journal was specifically selected for its research breadth, while offering the highest concentration of papers on coral reefs. The sole restriction for papers in this journal, apart from scientific merit, is that they pertain to coral reefs; there is no restriction on geographic location or approach (i.e. field or experimental). Limiting our study to this one broad journal therefore minimizes the potential for other biases, associated with journal selection, to confound our results. For each article related to reef fishes published between 1982 and 2018 that involved a field-based component (e.g. fish collection, observation or quantification) (n = 377 articles) we recorded details pertaining to: a) selected study species, b) the month/s when the field-component of the study occurred, c) fish abundance quantification methods and d) the habitat where and fish quantification methods were performed (studies may involve only some or all of the above; see the supporting information for a full overview of the literature survey and associated methods). It is important to note that our interest is in the selection of study species, locations, methods and times by researchers, i.e. decisions that will fundamentally shape our understanding of these systems. The focus is solely on the decisions made by the scientist(s), not the subsequent popularity or perceived importance of the study based on metrics such as citations or journal impact factor.

Species biases

Although biases were recorded in all four study criteria, it was in the selection of focal species that the most striking patterns were revealed. Of an estimated 6000+ reef fish species, less than 7% (396 species) were selected for study, with just 0.1% (6 species) examined 10% of the time (Fig. S2). Most research is restricted to a small range of quintessential coral reef butterflyfishes and damselfishes. The selection of these specific species may be influenced by a range of factors, however, it is particularly interesting to consider the colouration of these species; almost all focal study species had bright colours, especially yellow (Fig. 2a).

At the broadest scale, looking at all species examined, our results strongly suggest that selected study species are not random with regards to colour (Fig. 2a). Naturally, there is a range of other potential explanations. Yellow fishes may be more territorial and thus easier to observe, see or catch. Most importantly, yellow fish species may be more common or abundant than fishes with other colours. To directly test whether species selection does favor predominantly yellow species, rather than other traits (e.g. territoriality), we looked in detail at the family Pomacentridae. This family was selected as it is, by far, the most frequently studied, making up more than a third of all records. It also contains numerous species, with a wide variety of colour patterns, thus permitting robust analyses. Focusing on the GBR, almost all species had appropriate photographs available. Most importantly, the family is composed of species with very similar traits (other than colour); all have relatively small body sizes, are strongly site attached, show minimal diver avoidance, live in relatively shallow waters, are easily collected and are omnivorous, herbivorous, or planktivorous.

We can therefore ask: compared to the Pomacentridae on the GBR, are study species selected randomly with regards to their colour patterns? The answer is no (Fig. 2b) (see ESM for statistical values). We cannot say species are selected because they are yellow, inferring causation, but we can say with confidence that yellow species are studied most often (and equally, that dark fishes appear to be strongly avoided). Furthermore, if we focus specifically on the abundance of species (around one of the peak research locations in the GBR - Lizard Island); asking if damselfish species are selected randomly with regards to their estimated local abundance, we get the same pattern. Yellow species were preferred, dark ones avoided (Fig. 2c). Taken together, these patterns raise questions about the possibility of a colour-based bias. Interestingly, a recent study using simulated reefscapes provides strong supporting evidence, documenting human preferences for attractive reefs organisms based on colour; with a clear indication that yellow fishes are by far the most attractive (Tribot et al. 2019). Thus, the possibility of yellow fish being both overrepresented and positively selected for based on their colour, represents a distinct possibility.

Methodological biases

We also found evidence of preference or bias in the three methodological approaches. The relationship between sampling period and time of year was strongly selective, with almost twice the research effort in the summer months (Fig. 3a) (offset in northern and southern hemisphere locations Fig. S1). Likewise, habitats were unevenly studied, with 50% of all fish censuses undertaken on the reef slope or crest where fish densities and coral cover are often highest (Russ 1984; Wismer et al. 2009); they are therefore, arguably, the most attractive habitats. When examined as a proportion of the available reef area, across four standard reef habitats, this selectivity is striking (Fig. 3b), with 64% of the censuses looking at just 35% of the reef area. Fish census methods were also revealing (Fig. 3c), with most studies using methods which are likely to have strong diver-effects (potentially missing up to 70% of fishes) (Dickens et al. 2011; Emslie et al. 2018). Counts from these approaches, therefore, focus on bold, non-diver-averse fishes.

Overall, it appears reef fish studies focus on fishes with bright predominantly yellow hues, using field approaches that focus on relatively warm-water seasons, in attractive locations (that do not represent the majority of reef area), using methods that favor bold fishes. Furthermore, it should be noted that although we looked at four separate aspects, there is a possibility that these factors may be operating synergistically. For example, we may choose locations because they support more bold, yellow fishes or select survey methods that are particularly good at censusing bold (territorial) brightly coloured fishes (cf. Emslie et al. 2018).

Biases and our approach to research

Biases, be they conscious or sub-conscious may be logical: in summer, reefs are usually warm and calm with high fish recruitment (Meekan et al. 1993; Booth and Beretta 1994). The crest and slope often support the highest densities of fish and corals (Russ 1984; Wismer et al. 2009), and standard fish censuses are quick and easy to conduct. Colour-based biases, however, appear to have a stronger influence from subconscious biases; yellow fishes are undeniably attractive to humans (as reflected by their frequent occurrence on marketing images in magazines) (cf. Tribot et al. 2019), and in reef environments they stand out clearly (Marshall 2000). Unfortunately, whether conscious or subconcious, such selectivity may lead to a biased or partial understanding of coral reef fish ecology.

Why does this matter?

The problem with subconscious or implicit biases are many fold, with the potential for missed opportunities, partial understanding and misleading interpretations. Indeed, they may lead to an over- or under-estimation of the impacts of climate change or a redirection of research resources to functionally irrelevant species. We provide four examples where biases may change our understanding of reef ecosystems.

Firstly, for example, many of the highly-studied, yellow-hued species have extremely tight associations with live branching coral and may be severely impacted if corals are lost. Indeed, yellow damselfishes (e.g. *Pomacentrus moluccensis*) and brightly-coloured yellow and white butterflyfishes show some of the strongest declines following coral loss (Pratchett et al. 2006, 2008; Wismer et al. 2019). However, losses in these species may not be representative of other species or families. For example, many dark-coloured damselfishes often show significant increases following bleaching events (Pratchett et al. 2008; Wismer et al. 2019). Our favourite fishes may just be exceptionally sensitive.

Secondly, and by contrast, is the case of the gobies and their allies, collectively termed cryptobenthic reef fishes; one of the most overlooked fish groups on coral reefs (Brandl et al. 2018). Frequently overlooked because of their small size and cryptic behavior, recent work has identified cryptobenthics as a major driver of trophodynamics on coral reefs (Brandl et al. 2019c), supplying up to 70% of consumed fish flesh (Brandl et al. 2019a).Yet, these fishes are strongly selected against in surveys, remaining largely invisible in visual censuses (Ackerman and Bellwood 2000) due to their predominantly drab or cryptic colours (Fig. 1c), and their low densities on the upper reef slope and crest (Depczynski and Bellwood 2005). A similar situation is seen in some off-reef plankton-feeding species, e.g. the fusiliers (Caesionidae), which are often overlooked on visual censuses because they occur high off the reef (Hamner et al. 1988; Russ et al. 2017). Despite being missed, they represent one of the most important conduits for supplying energy to coral reefs via pelagic subsidies (Morais and Bellwood 2019).

Third, is the example of herbivorous reef fishes, a group widely regarded as critically important on coral reefs (Hughes et al. 2010; Bellwood et al. 2019; Brandl et al. 2019b). Even in this group, biases have potentially shaped and/or hindered progress in this field. For example, it was not until detailed video-based assessments of herbivory were conducted that we were able to identify the potential importance of three drab reef fishes *Platax pinnatus* (Bellwood et al. 2006), *Melichthys niger* (Tebbett et al. 2020) and *Siganus canaliculatus* (Fox and Bellwood 2008) in macroalgae removal on coral reefs. Until these video-based studies were performed, the former two species were not recognized as significant reef herbivores in the study areas, while the later had not been recorded from the study location despite the widespread use of traditional census techniques. Thus, highlighting the potential for 'how' we conduct our studies to provide only a partial understanding of specific processes.

Finally, the impacts of biases associated with selective seasonal and location sampling might have a particularly pronounced effect on our understanding of the process of herbivory. This process can be strongly related to seasonally-variable factors such as temperature (Longo et al. 2019). Indeed, evidence suggests that macroalgae removal on GBR reefs can decrease by over 60% in the winter relative to summer months (Lefèvre and Bellwood 2011), while algal turf consumption by herbivorous fishes in the Caribbean can decrease by over 20% in the winter (Van Rooij et al. 1998). In addition, while herbivorous fish densities are higher per unit area on the crest and slope (Russ 1984; Wismer et al. 2009), where studies generally count fishes (Fig. 3b), the reef flat is the most substantive reef habitat by total area (Bellwood et al. 2018). Consequently, reef flat habitats support nearly 80% of the herbivorous fish populations on reefs and account for approximately 75% of the herbivorous fish biomass production on reefs (Bellwood et al. 2018). Despite this, to-date, we have focused our research on a small subset of the available reef area, providing only a partial view of reef-wide processes. As such, there is a clear potential to underestimate or overestimate the rates of specific functions depending on 'when' and 'where' we perform our studies.

Many of the examples above stand in marked contrast to the overwhelming attention paid to damselfishes and butterflyfishes, with >35% and >11% of all studies that selected species involving these families, respectively (compared to <7% and <2% of studies involving the cryptobenthic gobies or blennies, respectively, and <1% involving the off-reef fusiliers). Arguably, damselfishes and butterflyfishes are among the most intensely studied reef fish families. However, their sensitivity to coral loss (Pratchett et al. 2006, 2008) offers a stark contrast to the patterns seen in the examples where herbivores, cryptobenthics and off-reef planktivores show an unexpected degree of resilience, especially in supporting ecosystem processes, even in the face of coral loss (Morais and Bellwood 2019; Robinson et al. 2019; Taylor et al. 2019). Unfortunately, it is fishes such as damselfishes and butterflyfishes that are often used to examine the impacts of future climate change scenarios, habitat degradation and predator-prey interactions; potentially biasing our view towards one of high-sensitivity (cf. Clark et al. 2020). Much of the research to-date appears to be looking at the ‘passengers’ rather than the ‘drivers’ of ecosystems (sensu Walker 1992); many of which are evolutionary baubles on the tree of life (sensu Bellwood et al. 2017). This results in a partial understanding of reef ecosystems. Previous results, therefore, are not wrong, just incomplete. The most valuable step is in recognizing the potential for such oversights. Thus, the selection of study species, as well as when, where and how we conduct our research, has the potential to profoundly change our perception of coral reef ecosystems and associated critical processes.

Conclusions

As coral reefs reconfigure in response to anthropogenic stressors, it is becoming increasingly clear that we need to understand what keeps reefs functioning if we are to steer them through the challenges they will face in the near future (Hughes et al. 2017; Bellwood et al. 2019). Yet, it appears that other factors, not necessarily functional importance, may have largely influenced our selection of study species, and when, where and how we have studied them. These factors, potentially shaped by human preferences or biases, may have limited our ability to fully understand reef functions.

If we are to understand high-diversity ecosystems, be they coral reefs, alpine grasslands or rainforests, it is imperative to understand ourselves first. There is undoubtedly a place for interest-based science looking at morphologically unique or colourful species. But in a rapidly changing world where the functionality of high-diversity ecosystems is under threat, a new focus on function rather than convenience or appearance may be warranted (Bellwood et al. 2019). Brightly coloured fishes may be interesting, but the future of coral reefs may depend on their drab counterparts that do not make it into advertisements but do keep coral reefs alive.

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Figure 1 Four coral reef fish species; a) *Pomacentrus brachialis*, b) *Pomacentrus moluccensis*, c) *Crossosalarias macrospilus* and d) *Chaetodon rafflesii*. Of these species, two have characteristics that would lead to strong positive selection as study species (b, d), while two (a, c) are rarely studied. (Photos. a, c Victor Huertas, b. Christopher Hemingson, d. Renato Morais).

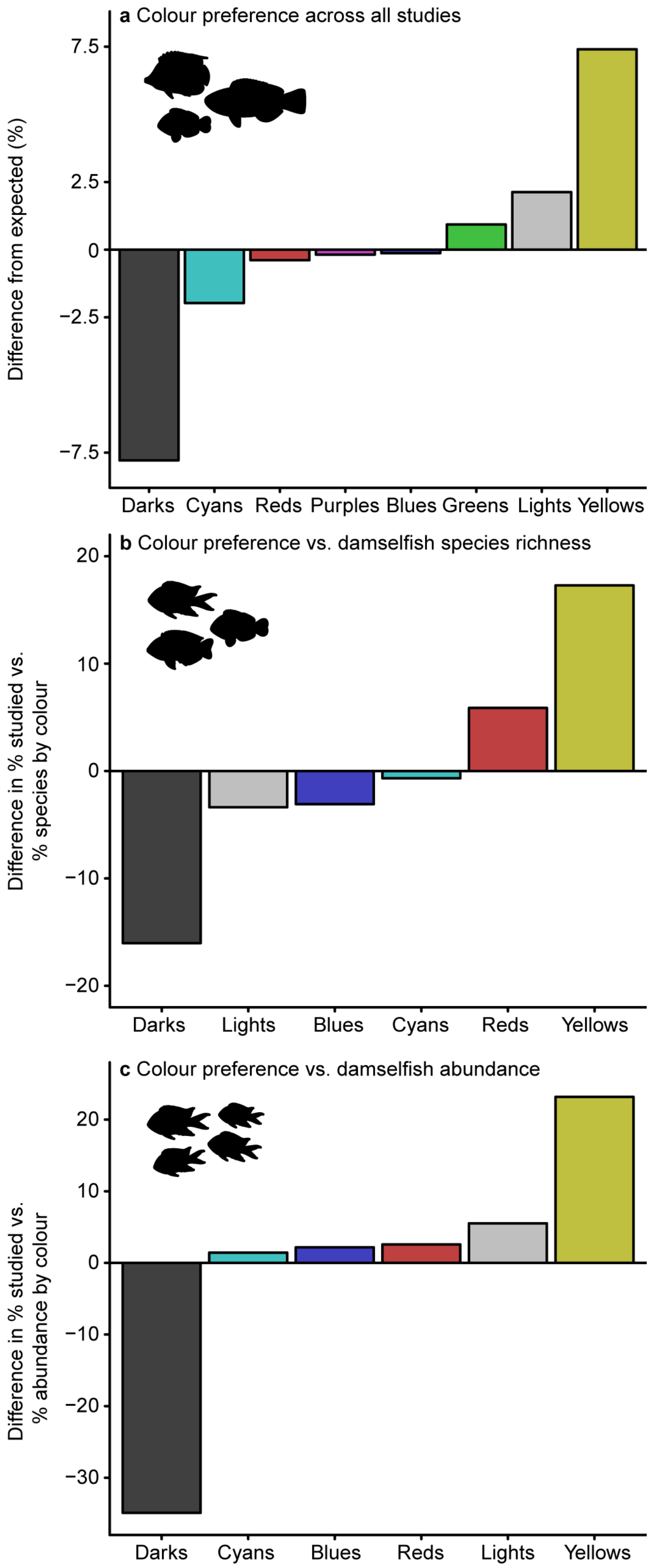

Figure 2 Species selection in coral reef fish research (based on 37 years of research in the journal *Coral Reefs*). Whether examining species colouration relative to a) all species studied, b) all damselfish species on the GBR, or c) damselfish abundances on GBR mid-shelf reefs, the pattern was the same: research was overwhelmingly focused on yellow fishes with a strong negative selection for dark-coloured fishes.

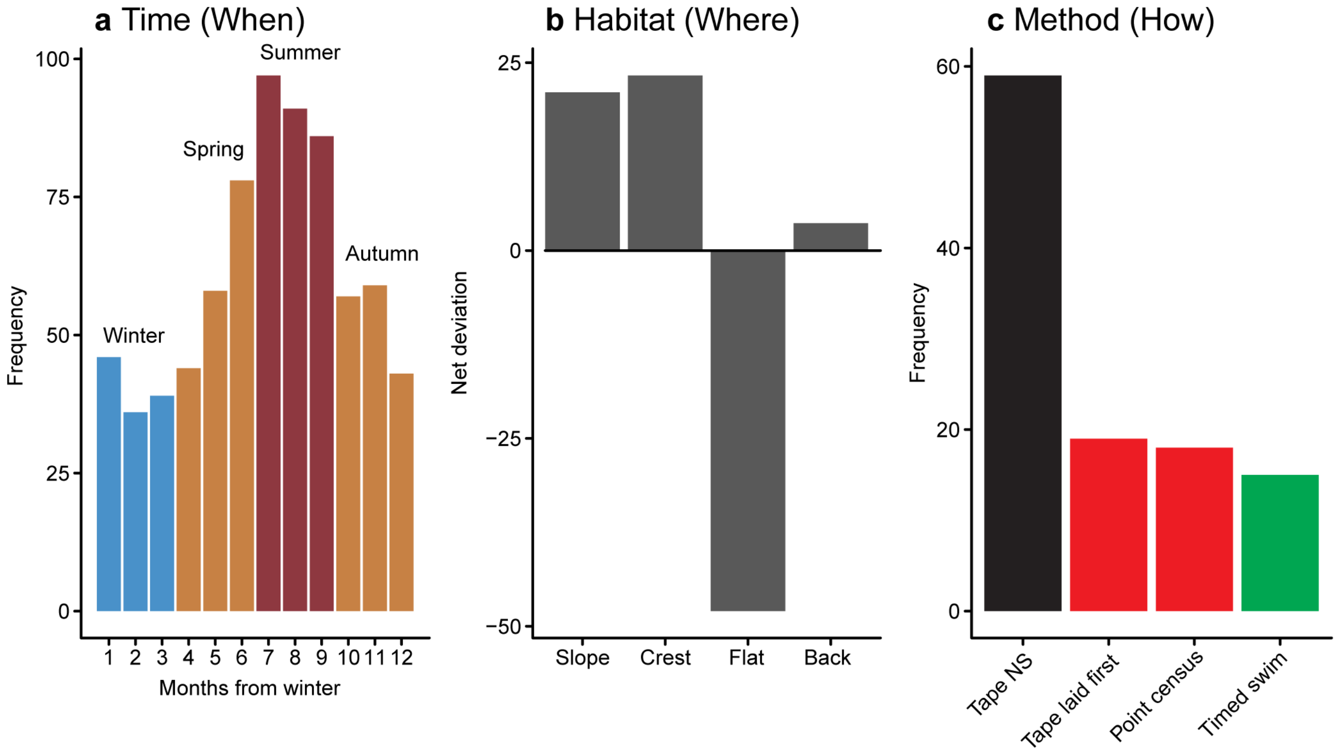

Figure 3 The when, where and how of coral reef fish research. a) Frequency distribution of sampling months during field-based studies (standardized for the northern and southern hemisphere as months since first winter month). b) The selectivity of four major reef habitats as fish census locations (deviation from expected if habitats were selected based on their area covered). c) The frequency distribution of the four most common fish census methods (NS = not specified). For more details please see the supporting information.