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LETTER

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Poor understanding of evolutionary theory is a barrier to effective conservation management

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Abstract
Despite increasing recognition that integrating evolutionary theory into conservation decisions can achieve better long-term outcomes, there has been little progress adapting management strategies. A commonly hypothesized barrier to better integration is poor understanding of evolutionary biology among conservation practitioners. To assess this claim, we surveyed conservation practitioners to determine their understanding of evolutionary concepts. We found that most practitioners had a good understanding of general concepts (evolution and genetic diversity), but a much poorer understanding of other relevant concepts. These findings suggest that knowledge is limiting the ability of conservation practitioners to effectively manage evolutionary processes. Encouragingly, practitioners educated in evolutionary biology and population genetics had a better understanding, suggesting focused training is important. However, better integration of evolutionary theory will require that evolutionary biologists develop a culture of knowledge exchange, actively engaging practitioners to improve management. Otherwise, our findings suggest it is unlikely practitioners will be able to adapt their practices.

KEYWORDS
evidence-base conservation, evolutionarily enlightened management, gene flow, genetic management, inbreeding depression, life history strategy, mating systems, outbreeding depression

1 | INTRODUCTION

Conservation science and practice tend to be more focused on ecological than evolutionary principles and processes. Yet, as anthropogenic pressures reduce population sizes, increase fragmentation, and accelerate the rates of environmental change, conservation management must increasingly support populations to adapt to these changes (Sgrò, Lowe, & Hoffmann, 2011; Weeks et al., 2011). To this end, there have been growing calls to ensure lessons from evolutionary theory are being considered alongside important ecological considerations in conservation management (Carroll, Jorgensen, & Kinnison, 2014; Hendry, Kinnison, & Heino, 2011; Weeks et al., 2011) — termed evolutionarily enlightened management (Ashley et al., 2003; Smith, Kinnison, Strauss, Fuller, & Carroll, 2014). In response, there has been huge growth in applied evolutionary research, particularly in the rapidly expanding fields of conservation genetics and genomics (Carroll et al., 2014; Shafer, Wolf, & Alves, 2015). Importantly, several risk assessments (e.g., Byrne, Stone, & Millar, 2011; Frankham et al., 2011) and decision support frameworks (e.g., Sgrò et al., 2011) have also been developed to support the application of this growing body of evidence to conservation management (see Cook & Sgrò, 2017).

The importance of managing genetic diversity is increasingly recognized within relevant conservation policies at international, national, and regional scales (Cook & Sgrò, 2017; Santamaria & Mendez, 2012). However, evolutionary concepts such as gene flow, inbreeding depression, and outbreeding depression are rarely discussed, despite their relevance to a wide range of conservation issues (reviewed in Cook & Sgrò, 2017). Conservation practitioners (policy makers and on-ground managers) recognize the importance of evolutionary principles and processes (hereafter evolutionary concepts) to conservation outcomes, but report that they rarely influence management practices (Cook & Sgrò, 2018; Hoban, Hauffe, & Perez-Espona, 2013; Taylor, Dussex, & van Heezik, 2017).

Commentary about why evolutionary concepts are so poorly integrated into conservation practice has focused on a lack of practical tools to help managers make the necessary changes (Carroll et al., 2014; Frankham, 2010), although this situation is improving (Cook & Sgrò, 2017). Other hypothesized barriers include practitioners being uncertain about the benefits of changing management practices and concerned about the associated risks (Byrne et al., 2011; Frankham, Ballou, & Eldridge, 2011; Shafer et al., 2015). However, the most commonly discussed reason for the low uptake of evolutionary concepts in conservation practice is a poor understanding of evolutionary theory among practitioners (e.g., Ashley et al., 2003; Frankham, 2010; Kinnison, Hendry, & Stockwell, 2007; Taylor et al., 2017). If this is the case, supporting conservation practitioners to develop a working knowledge of important evolutionary concepts could help facilitate evolutionarily enlightened management (Carroll et al., 2014).

Despite many suggestions that practitioners' comprehension of evolutionary theory is a major barrier to better adoption of evolutionarily enlightened management, we are not aware of any studies that have assessed practitioners' understanding of evolutionary biology. Surveys of practitioners have revealed that they believe their knowledge to be a barrier to better integration of evolutionary theory (Cook & Sgrò, 2018) and genetic data (Taylor et al., 2017) into their management. However, it is unclear what knowledge practitioners have of relevant evolutionary concepts.

Determining which concepts practitioners do or do not understand can provide critical insight into practical strategies to improve the integration of evolutionary theory into conservation management. In particular, it could help uncover why practitioners appear to resist alternative management strategies, such as mixed provenance in revegetation (Broadhurst, Lowe, & Coates, 2008; Sgrò et al., 2011) and genetic rescue of inbred populations (Weeks, Heinze, & Perrin, 2017; Weeks, Sgrò, & Young, 2011), despite demonstrated benefits. Likewise, it could reveal whether a poor understanding manifests as misconceptions about particular concepts (e.g., Kinnison et al., 2007), or whether practitioners have simply not been exposed to relevant knowledge. To address this gap, we surveyed conservation practitioners in Australia, along with conservation scientists, to assess their understanding of a range of important evolutionary concepts and to identify strategies to improve the integration of evolutionary theory into conservation decisions.

2 | METHODS

Our study focused on Australia because it represents a large and diverse continent, with relatively complex environmental governance arrangements, and has a vibrant applied evolutionary research community. The level of integration of evolutionary theory into policy documents in Australia has been assessed (Cook & Sgrò, 2017; Pierson, Coates, & Oostermeijer, 2016), as have practitioners' views on barriers to better integration of evolutionary biology into management practice (Cook & Sgrò, 2018). Therefore, Australia provides an excellent opportunity to explore practitioners' understanding of evolutionary theory and whether this may be contributing to the poor implementation of evolutionarily enlightened management.

To assess the level of understanding of evolutionary theory, we developed a questionnaire (see Supporting Information S1) targeting two groups of respondents:

1) conservation practitioners in policy or on-ground management roles; and
2) conservation scientists whose research programs focus on management-relevant science.

We sought the views of conservation practitioners involved in site-level (protected areas) and landscape-scale (catchment management) conservation management organizations. In Australia, public-protected areas are managed by government agencies within state ($n = 7$) and federal ($n = 1$) jurisdictions. While cross-tenure, landscape-scale environmental management is the responsibility of 56 natural resource management organizations across the country. We were interested in the views of practitioners who work at these different scales, given evolutionary processes can act at multiple scales. Within these organizations, we targeted individuals whose decisions can impact the management of multiple sites (i.e., policy and strategy roles), and those undertaking site-level actions (i.e., on-ground management roles). By targeting both groups, we hoped to gain a broad understanding of the foundational knowledge of practitioners, and determine whether knowledge varies according to the scale at which decisions are focused. Senior managers within the relevant organization across all jurisdictions in Australia were asked to distribute a link to the online questionnaire to all relevant staff members.

We also sought to understand the views of scientists whose research is focused on questions relevant to conservation

TABLE 1 Key concepts relevant to integrating evolutionary theory into conservation practice

Evolutionary concept	Definition
General concepts	
Genetic diversity	Genetic differences between individuals of the same species.
Evolution	The process by which populations or species change over successive generations to become better adapted to their environment.
Specific concepts	
Gene flow	Movement of alleles between populations through mating between individuals from different populations.
Inbreeding depression	Mating between closely related individuals that leads to a loss of genetic diversity and corresponding reduction in reproductive fitness.
Outbreeding depression	Mating between genetically distinct individuals that introduces new alleles that disrupt local adaptation and lead to reduced reproductive fitness.
Mating system	The reproductive strategy of a population based on patterns of mating or fertilization.
Life history strategy	The way in which individuals invest in growth, reproduction, and survivorship.

TABLE 2 Coding of responses for level of understanding

Level of understanding	Description	Score
Strong	All important points were correctly covered described and no misconceptions were apparent.	3
Basic	Correctly described what the principle was and to some degree how it occurs. No understanding or some minor misconceptions about the consequences for populations.	2
Unsure	Directly stated they did not know.[a]	1
Wrong	Clearly demonstrated lack of understanding.	0

[a]Respondents were coded as unsure for concepts they left blank when they did attempt definitions for several other concepts.

policy and practice. These individuals generate research and decision-support tools that may inform management practices, and often engage directly with practitioners about best practice management. Therefore, we wanted to understand the degree to which these scientists understand evolutionary theory and can assist practitioners integrate evolutionary considerations into their management practices. To identify conservation scientists, we searched the online staff profiles from all universities and government research institutes (n = 23) across Australia. Relevant individuals were identified from the description of their research interests and active research projects (n = 78). These individuals were contacted via email, invited to participate in the study, and asked to distribute the survey to relevant members of their research groups, using a snowball sampling method (Patton, 2002).

2.1 | Questionnaire development

We developed a set of key concepts, covering both broad and specific evolutionary principles and processes (Table 1) suggested to be important for practitioners when designing management actions (see Cook & Sgrò, 2017). For each key concept, we asked respondents to describe in their own words what they understood the concept to mean.

Respondents were asked for a range of demographic information, including role, age, years of experience, gender, level of education, and exposure to evolutionary theory during their formal education. In addition, scientists were asked if they spent time engaging with practitioners.

Before distributing the questionnaire, it was piloted with seven experts who provided feedback on the face validity of the survey tool (Wainer & Braun, 1988).

2.2 | Data analyses

To assess the respondents' understanding of the key concepts, we developed a scoring rubric for whether respondents could accurately describe the concept (Supporting Information Table S1). We judged responses in relation to whether they demonstrated an understanding of what the principle or process was, deemed a basic understanding. Where respondents also understood the consequences (positive or negative) for populations, and why these consequences arise, this was deemed a strong understanding. Any misconceptions apparent in the definitions provided were also captured.

We coded responses on an ordinal scale (Table 2) and used Kruskal–Wallis nonparametric tests to determine if the level of understanding of respondents varied among the different concepts. Mann–Whitney U nonparametric tests were used to determine whether there were differences in the level of understanding of the concepts between practitioners and scientists, or between practitioners with different roles (i.e., policy or on-ground management). Kruskal–Wallis tests were used to assess the influence of respondent's level of education, or their training in evolution and genetics, on their understanding of evolutionary concepts.

3 | RESULTS

In total, we received 140 responses to the questionnaire (101 practitioners; 39 scientists). Slightly more practitioners were on-ground managers ($n = 58$), than in policy or strategy roles ($n = 43$). Practitioners represented all jurisdictions, ranged in experience from 6 months to 29 years ($\mu = 8.6 \pm 0.3$) and were 59% males. The scientists filled research only ($n = 18$) or teaching and research roles ($n = 21$), and were more likely to be female (62%). Our sample of scientists was drawn from all states and territories, and ranged in experience from 1 to 43 years ($\mu = 9.3 \pm 0.7$).

3.1 | Understanding of evolutionary concepts

Across the whole sample, the level of understanding varied among the concepts ($\chi^2 = 65.86$; df = 6; $P < 0.001$; Figure 1; Table 3). The difference in understanding across the concepts tended to be driven by variability in the knowledge of practitioners ($\chi^2 = 71.07$; df = 6; $P < 0.001$; Table 3), rather than variability in the understanding of scientists ($\chi^2 = 5.98$; df = 6; $P = 0.426$; Table 3). Scientists had a higher level of understanding of the concepts than practitioners ($U = 72{,}125.5$; $P < 0.001$; Figure 1; Table 3; Supporting Information Table S2). Overall practitioners in policy and strategy roles had a slightly better understanding of evolutionary concepts than those in on-ground management roles ($U = 46{,}404.0$; $P = 0.010$; Table 3), but not for any one concept (Supporting Information Table S3). There was no significant difference between the understanding of those involved in site-level versus landscape-scale management ($U = 17{,}554.0$; $P = 0.762$; Table 3).

The general evolutionary concepts (i.e., genetic diversity and evolution; Table 1) were the most well understood across the sample (Figure 1), although there was a common perception that evolution requires very long time scales (e.g., millennia), failing to recognize the role of rapid evolutionary responses. The level of understanding of more specific concepts tended to be lower, with gene flow, life history strategy, and outbreeding depression being least well understood (Figure 1).

Few practitioners demonstrated a strong understanding of the specific concepts (maximum 32% for inbreeding depression; Figure 1b). The proportion of practitioners unsure or incorrect about the specific concepts was relatively high, reaching 63% for life history strategy and 73% for outbreeding depression (Figure 1b). Life history strategy was most commonly confused with the life cycle of an organism, while outbreeding depression was often confused with gene flow or described as a barrier to the transfer of genes (Table 4), suggesting a lack of understanding about how these concepts relate to fitness.

Despite scientists having a higher level of understanding of more specific evolutionary concepts than practitioners, many were still unsure or incorrect in their understanding of concepts such as outbreeding depression (49%) and gene flow (39%; Figure 1c). The proportion of scientists with a strong understanding of the specific concepts ranged from 44% for outbreeding depression to 59% for gene flow and life history strategy (Figure 1c).

3.2 | Level of education in evolutionary concepts

Most respondents were highly educated, with 56% of practitioners having a Bachelor's degree and 30% having a Masters or PhD. Those with higher levels of education had a better understanding of the concepts ($\chi^2 = 11.005$; df = 3; $P = 0.012$; Figure 2a; Table 3). Most respondents had some exposure to evolutionary biology or genetics during their education, although 35% of practitioners and 10% of scientists had not. Subjects relating to both evolution and genetics was more common (33% of practitioners; 59% of scientists), than evolutionary biology (23% of practitioners; 21% of scientists), or genetics (7% of practitioners; 10% of scientists) alone. Some training in genetics, or both evolution and genetics, was associated with higher levels of understanding compared to those who had only taken evolutionary biology or no relevant subjects ($\chi^2 = 10.00$; df = 3; $P = 0.019$; Figure 2b; Table 3).

4 | DISCUSSION

Consistent with previous studies that have highlighted poor integration of evolutionary concepts into conservation policies (Cook & Sgrò, 2017; Lankau, Jorgensen, Harris, & Sih, 2011) and management practices (Cook & Sgrò, 2018), our results support the view that many practitioners do not have a strong understanding of important evolutionary principles and processes (Frankham, 2010; Hoban et al., 2013; Figure 1). Encouragingly, most practitioners do have a good understanding of evolution and genetic diversity (Figure 1) and are convinced that managing genetic diversity is important to conservation outcomes (Cook & Sgrò, 2018; Hoban et al., 2013; Taylor et al., 2017). However, moving beyond broad acceptance to active management requires an

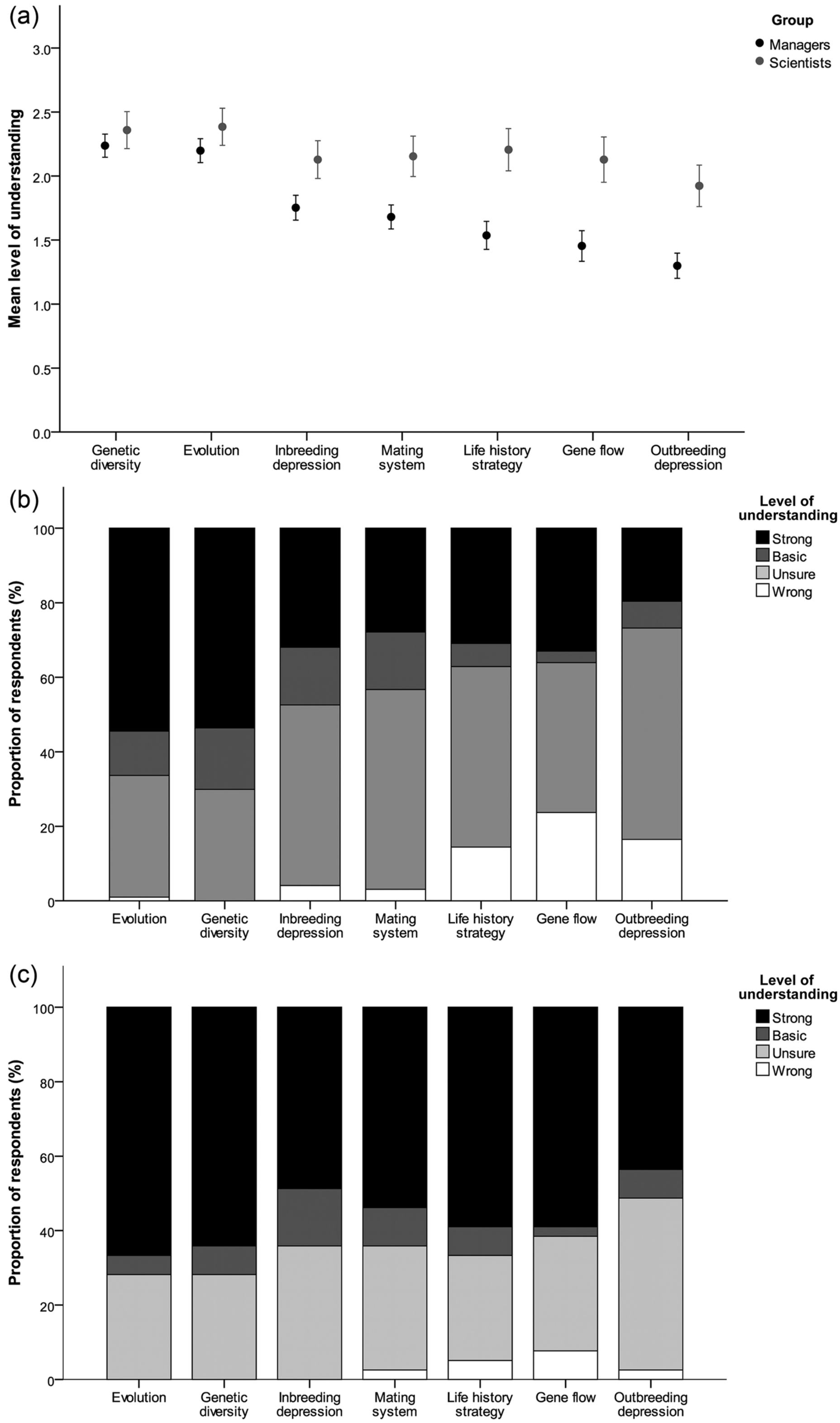

FIGURE 1 The difference in level of understanding of the evolutionary concepts: (a) between practitioners and scientist (mean ± *SE*); (b) among practitioners; and (c) among scientists

TABLE 3 The 95% confidence intervals for all comparisons associated with all statistical tests. Results are presented in the order tests appear in the text

Individual concepts[a]							
	Genetic diversity	**Evolution**	**Inbreeding depression**	**Mating system**	**Life history strategy**	**Gene flow**	**Outbreeding depression**
All respondents	2.12–2.42	2.10–2.41	1.70–2.02	1.65–1.98	1.54–1.92	1.44–1.85	1.31–1.65
Practitioners	2.06–2.42	2.01–2.38	1.56–1.95	1.50–1.87	1.32–1.75	1.22–1.69	1.10–1.49
Scientists	2.07–2.65	2.09–2.68	1.83–2.43	1.83–2.47	1.83–2.54	1.77–2.49	1.60–2.25
		All concepts[b]					
Practitioners		1.66–1.82					
Scientists		2.07–2.30					
Practitioner roles							
Policy and strategy roles		1.75–2.00					
On-ground management role		1.55–1.74					
Practitioner management scale							
Site level management		0.96–2.04					
Landscape scale management		1.60–1.94					

Level of education[a]				
	Postgraduate degree	**Bachelor's degree**	**Certificate**	**Diploma**
Practitioners	1.74–2.04	1.65–1.87	1.13–1.87	1.21–1.69
Scientists	2.20–2.46	1.52–2.00	n/a	n/a

Relevant subjects studied[a]				
	Evolutionary biology and genetics	**Genetic**	**Evolutionary biology**	**None**
Practitioners	1.68–1.98	1.72–2.32	1.42–1.77	1.51–1.76
Scientists	2.27–2.55	2.07–2.79	1.48–2.02	1.14–1.86

[a]Kruskal–Wallis tests.

[b]Mann–Whitney *U*-test.

TABLE 4 Common misconceptions associated with conservation practitioners and scientists understanding of relevant evolutionary concepts

Concept	Most common misconceptions
Evolution	Described as future change.
Genetic diversity	Considered to be phenotypic rather than genotypic variation.
Gene flow	Confused with inheritance of genes.
Inbreeding depression	Described as the process of inbreeding, rather than impact of inbreeding on fitness.
Outbreeding depression	Considered to be a form of restricted gene flow or a consequence of too much genetic diversity.
Mating systems	Confused with reproduction or with a mode of inheritance.
Life history strategy	Confused with the life cycle of a species, described as the consequences of natural selection, confused with pedigree.

understanding of the evolutionary processes that influence genetic diversity, which is currently lacking for most practitioners (Figure 1). With fewer than half of practitioners having at least a basic understanding of relevant evolutionary concepts, it is not surprising that opportunities to improve conservation outcomes through evolutionarily enlightened management are being missed (Ralls, Ballou, & Dudash, 2018). We did find that practitioners exposed to evolutionary biology and genetics demonstrated a greater understanding of relevant concepts (Figure 2), suggesting there is value to investing in greater training for practitioners. However, it will be important that training be specifically focused on how evolutionary processes can be harnessed to improve conservation management outcomes in order to create knowledge that can be operationalized.

Practitioners do not need to be experts in evolutionary biology to recognize its value for conservation management (Cook & Sgrò, 2018), and may have an intuitive understanding of how to manage for genetic diversity without having explicit knowledge of how it is influenced by evolutionary processes. For example, they may understand that small populations are at risk of losing genetic diversity, without appreciating the factors that influence the rate at which genetic diversity is lost. Therefore, a better understanding of inbreeding depression and outbreeding depression could help practitioners balance the risks of each when deciding how to manage small, isolated populations (e.g., when genetic rescue might be appropriate; Frankham et al., 2011; Weeks et al., 2017). Likewise, changing provenance strategies to prioritize long-term adaptive potential over short-term seedling survival (Prober, Potts, & Bailey, 2016) requires an understanding of processes that promote or reduce genetic diversity within populations. Of course, management decisions will always be multifaceted, and evolutionary considerations are only one of many that practitioners must take into account, but better knowledge of evolutionary processes could help practitioners argue the case for long-term over short-term conservation outcomes (Smith et al., 2014).

Alleviating the concerns of practitioners about changing current practices (e.g., Frankham, 2010; Love Stowell, Pinzone, & Martin, 2017) is likely to require they have a basic knowledge of evolutionary concepts. However, if practitioners are not able to recognize the consequences of evolutionary processes for populations (i.e., have only a basic understanding; Table 2; Supporting Information Table S1), their ability to promote or retard the influence of these processes on populations will be limited. For example, utilizing the presence of environmental gradients when augmenting gene flow can help increase the adaptive potential of populations facing changing environmental conditions (Hoffmann & Sgrò, 2011). Conversely, the mating system of a species can influence the rate at which genetic diversity is lost (e.g., Miller, Nelson, Smith, & Moore, 2009), and therefore should be considered when managing small populations. Given the links among concepts, and their influence on conservation outcomes, an understanding of some concepts is unlikely to compensate for a lack of knowledge (Figure 1) or misconceptions about others (e.g., gene flow; Table 4). This makes the role of management-focused syntheses (e.g., Lankau et al., 2011; Weeks et al., 2011) and risk assessment tools (e.g., Byrne et al., 2011; Frankham et al., 2011) for guiding management decision particularly important in building the capacity of practitioners.

Despite the increasing availability of decision support tools in the literature to help integrate evolutionary theory into management (reviewed in Cook & Sgrò, 2017), practitioners themselves have identified their knowledge to be a key barrier to better integration (Cook & Sgrò, 2018; Taylor et al., 2017). They have also highlighted the role of direct communication with scientists about how to apply evolutionary theory in their decisions as important to build their capacity to change management practices (Cook & Sgrò, 2018; Hoban et al., 2013). Although conservation biologists have a culture of engaging with practitioners, we found they may not always have a sufficient understanding of evolutionary concepts to support practitioners to change their management (Figure 1). Therefore, it is critical that evolutionary biologists and geneticists engage directly with practitioners to strengthen their understanding of evolutionary processes, and of how they can be harnessed to achieve better conservation outcomes (Lankau et al., 2011; Ralls et al., 2018). Practitioners from Europe (Hoban et al.,

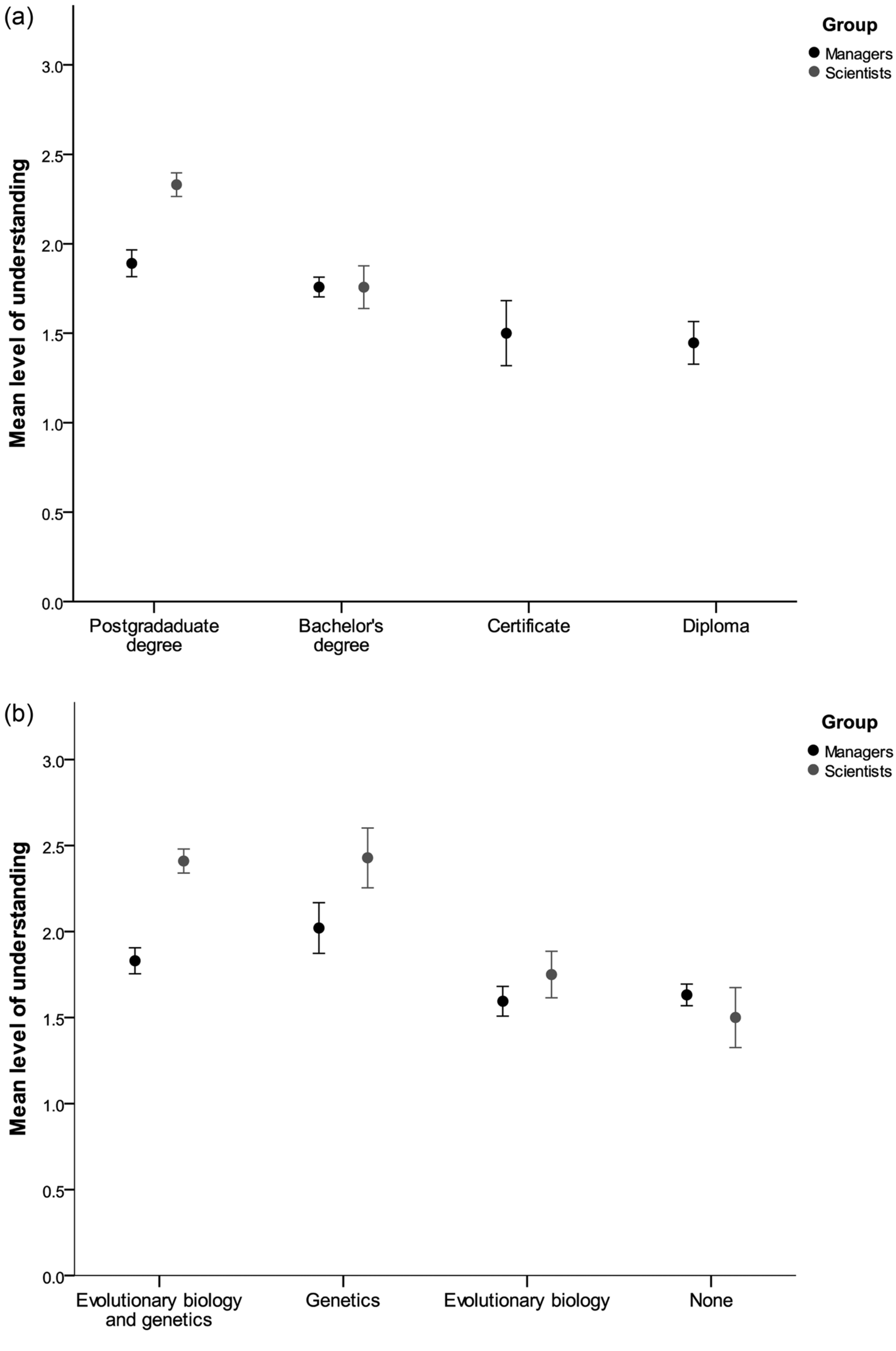

FIGURE 2 The mean (±*SE*) level of understanding of evolutionary concepts of respondents based on their: (a) level of education and (b) exposure to relevant subjects during their education

2013) to New Zealand (Taylor et al., 2017) have expressed concerns about their capacity to integrate evolutionary considerations into management. We encourage future research to consider practitioners' understanding across other regions of the world in order to better target strategies to improve integration.

Problems bridging the science–policy interface are not unique to evolutionary biology, and many strategies have been developed to facilitate improved evidence-based decision-making (Cook, Mascia, Schwartz, Possingham, & Fuller, 2013). Effective knowledge exchange requires active engagement between researchers and practitioners (Cvitanovic et al., 2015). To achieve this, we encourage more evolutionary biologists and geneticists to become involved in the policy process, play an active role in recovery teams and advisory panels, and engage practitioners in research that demonstrates the benefits of changing management practices (Cook & Sgrò, 2018; Hendry, Lohmann, & Conti, 2010). By involving practitioners in producing management-relevant science, evolutionary biologists can increase the capacity of practitioners to implement these strategies more broadly in their management (Cvitanovic et al., 2015). Other effective strategies evolutionary biologists could employ are to lobby governments to fund knowledge brokers (Cvitanovic et al., 2015) or boundary organizations (Guston, 2001), which are devoted to facilitating communication between scientists and practitioners to support evidence-based management. Our findings suggest that without management-relevant training, and increased efforts by evolutionary biologists to engage directly with practitioners to improve their understanding, the poor integration of evolutionary theory in conservation practice is unlikely to improve, to the detriment of long-term conservation outcomes.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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