Journal of Applied Ecology

British Ecological Society

Journal of Applied Ecology 2016, **53,** 25–33 doi: 10.1111/1365-2664.12560

Efficacy of lecture-based environmental education for biodiversity conservation: a robust controlled field experiment with recreational anglers engaged in self-organized fish stocking

Marie L. Fujitani[1]*, Andrew McFall[1], Christoph Randler[2] and Robert Arlinghaus[1,3]

[1]*Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany;* [2]*Institute of Science, Geography and Technology, University of Education Heidelberg, Im Neuenheimer Feld 561, Heidelberg 69120, Germany; and* [3]*Division of Integrative Fisheries Management, Faculty of Life Sciences and Integrative Institute for the Transformation of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, Invalidenstrasse 42, 10115 Berlin, Germany*

Summary

1. Fish stocking constitutes a widespread management tool for freshwater fisheries, but depending on configuration can be economically wasteful, ecologically harmful and lead to irreversible biodiversity loss. We conducted a large-scale controlled experiment of a lecture intervention to understand whether communication of neutrally worded scientific information about sustainable fish stocking might alter anglers' ecological knowledge and cognitions (e.g. functional beliefs and attitudes) about the benefits and potential costs of fish stocking.

2. Seventeen angler clubs from Germany who engage in self-organized fish stocking were randomly assigned to receive either a stocking lecture or a control lecture (on general fish management). From each club, self-selected anglers including water-body managers ($N = 201$) completed a questionnaire on ecological knowledge and cognitions about stocking before the lecture, immediately after the lecture and 10 months later to assess long-term retention. Data were analysed using Before-After-Control-Impact analysis with club-level random effects.

3. Compared to the control group ($n = 86$), anglers in the treatment ($n = 115$) showed a significant post-lecture increase in knowledge in all six topics taught about the biological nuances of stocking and potential risks. However, there were no changes in stocking-related attitudes or personal norms towards future stocking.

4. Only one knowledge domain was retained long-term (10 months): the understanding that stocking does not always have additive fishery effects ($P < 0{\cdot}05$). There were also trends indicating long-term knowledge gains related to the genetic risks of stocking and the advantages of local adaptation, and a decreased functional belief in stocking efficacy ($P < 0{\cdot}08$). These results suggest that participants may engage more cautiously in fish stocking in the future.

5. *Synthesis and applications***.** Lectures will continue to be a dominant mode of environmental education due to convenience and familiarity, particularly for stakeholders participating during leisure time and in contexts where training lectures are legally required. Our results show that lectures can effectively communicate complex ecological topics and lead to knowledge gain. Lectures on natural resource management will be most effective when addressing issues of high relevance to stakeholder's interests and modifying current practices, but changes in basic cognitions may require a more active learning environment.

Key-words: before-after control-impact analysis, cognitive hierarchy, difference in differences, evidence-based conservation, loop learning, natural resource management, recreational fishing, stock enhancement

*Correspondence author. E-mail: fujitani@igb-berlin.de

Introduction

Fish stocking is a widespread tool for freshwater fisheries management (Arlinghaus, Mehner & Cowx 2002) popular with anglers (Arlinghaus & Mehner 2005; von Lindern & Mosler 2014). Objectives of stocking range from conservation-oriented (re-establishing native species) to enhancement-oriented (elevating fisheries yield). Stock enhancement (the release of hatchery-reared or wild-captured fishes into self-reproducing stocks in an attempt to improve fisheries; Lorenzen, Beveridge & Mangel 2012) involves the release of billions of fish annually (Halverson 2008). In Germany alone around 77 million fish were stocked in 2010 by anglers in clubs (Arlinghaus *et al.* 2015). Stocking can generate large benefits in culture-based fisheries (Lorenzen, Beveridge & Mangel 2012). However, stocking can also negatively impact wild fish stocks and lead to local extinctions through hybridization or competitive exclusion (van Poorten *et al.* 2011; Lorenzen, Beveridge & Mangel 2012). Stocking and the illegal transfer of fishes by anglers between water bodies (Johnson, Arlinghaus & Martinez 2009) is ranked among the top threats to freshwater fish biodiversity (Freyhof & Brooks 2011). Freshwater fishes are among the most threatened vertebrates in Europe and the world (Freyhof & Brooks 2011), which motivated us to design an environmental education intervention to address sustainable stocking among fisheries stakeholders.

The aim of environmental education is to foster scientific literacy, awareness of problems and pro-environmental behaviours (Stapp 1969). Education can encourage pro-environmental behaviours (Jacobson, McDuff & Monroe 2006), but not consistently (Kollmuss & Agyeman 2002; Schultz 2011), and while interventions abound rigorous evaluations are comparatively rare (Carleton-Hug & Hug 2010; Clayton, Litchfield & Geller 2013; St John *et al.* 2014). Here, we provide results from a large-controlled field experiment on lecture-based environmental education involving fisheries stakeholders with a direct say in fisheries management. This is due to the private fishing rights systems in Central Europe (e.g. Netherlands, UK, Austria, Germany) where local users (i.e. angling clubs) are legally entitled managers of fisheries and regularly engage in self-organized fish stocking and other activities conducted by public agencies in countries with public fishing rights regimes (e.g. Canada and the U.S.; Daedlow, Beard & Arlinghaus 2011). We used a controlled intervention on principles of sustainable fish stocking and potential caveats for biodiversity conservation to demonstrate the strengths and weaknesses of the lecture method for imparting ecological knowledge and affecting cognition-based antecedents of human behaviour (Ajzen 2005; Vaske & Manfredo 2012). Lectures are the most common means of environmental education due to their familiarity and economy of time and expense (Bligh 1998; Lord 1999). German anglers are accustomed to lecture-based environmental education, as all anglers must complete a 30-h course (e.g. on ecology, legislation, fisheries management) to obtain a fishing license (Von Lukowicz 1998). Given this background, Germany is an appropriate setting to test the effectiveness of lecture-based instruction about sustainable stocking.

Despite the potential benefits from sustainable fish stocking for population management and species conservation (Lorenzen 2005; FAO 2012), many stocking programs fail (Hilborn 1999) or have negative consequences for biodiversity conservation (Laikre *et al.* 2010; van Poorten *et al.* 2011). Economic waste is likely when releasing fry or juveniles into self-reproducing stocks where density-dependent population regulation is strong in the juvenile phase (Lorenzen 2005; Hühn *et al.* 2014). Differences in genetics between source and supplemented wild fish populations, as well as artificial selection in the hatchery environment can lead to deleterious hybridization and ultimately contribute to the loss of locally adapted stocks through introgression of foreign genes (Laikre *et al.* 2010; van Poorten *et al.* 2011). Moreover, an increasing fraction of hatchery-reared fish among spawners can be associated with reduced stock productivity in salmonids (Chilcote, Goodson & Falcy 2011). Stocked fish also directly compete with wild fish for food and shelter, and may in other ways affect food webs and the structure of the ecosystem (Eby *et al.* 2006; Lewin, McPhee & Arlinghaus 2008; Lorenzen, Beveridge & Mangel 2012). Furthermore, each fish stocking event carries risks to the ecosystem of introducing invasive species, parasites or pathogens (Hewlett, Snow & Britton 2009; Johnson, Arlinghaus & Martinez 2009). Despite these caveats, stocking is standard practice in many recreational fisheries and is often done indiscriminately based on a belief that stocking can compensate for environmental degradation of spawning and rearing habitats (von Lindern & Mosler 2014). There remains a widespread belief among anglers that stocking is usually successful and elevates stock sizes (Arlinghaus & Mehner 2005; von Lindern 2010). A positive attitude towards stocking is reinforced by the lack of monitored outcomes and inadequate communication of potential negative consequences (Arlinghaus 2006). Furthermore, in Germany, stocking is a tradition with high socio-cultural significance among angling clubs (Klein 1996), and normative pressure from anglers contributes to its routinized use (van Poorten *et al.* 2011). In this context, effective environmental education on sustainable stocking could reap considerable economic and conservation benefits.

Most environmental education programs administered by governmental and non-governmental organizations (Sturgis & Allum 2004) operate under the information-deficit model that knowledge leads directly to behaviour (Fig. 1; Jacobson, McDuff & Monroe 2006). It is now accepted that the path from learning to behaviour is more complex, and to foster behavioural change environmental education must alter cognitive behavioural antecedents such as beliefs, attitudes or personal norms (Fig. 1; Stur-

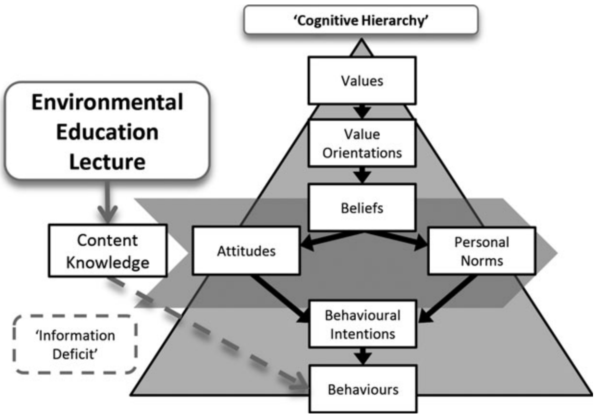

Fig. 1. Diagram illustrating the information-deficit model and the cognitive hierarchy model (adapted from Manfredo 2008). We hypothesized the lecture-based intervention would affect content knowledge and the cognitive portions of attitudes and beliefs.

gis & Allum 2004; Ajzen 2005). Hence, to alter behaviour education on sustainable stocking must impart not only ecological knowledge, but also alter functional beliefs (expectations arising from information and experience, e.g. that stocking works), attitudes (favourable or unfavourable evaluations of objects, i.e. stocking) and personal norms (what ought to be done in a given context; Hungerford & Volk 1990). Few environmental education programs have assessed their effectiveness using a fully elaborated human behavioural model (Carleton-Hug & Hug 2010; Clayton, Litchfield & Geller 2013). We took a cognitive approach because psychological research has repeatedly demonstrated the validity of the cognitive hierarchy model of human thought and action in natural resource applications (e.g. Dressel, Sandström & Ericsson 2015; Estevez *et al.* 2014; Riepe & Arlinghaus 2014). The behavioural model hierarchically structures human cognitions from general (e.g. values held by cultures) to behaviour-specific (e.g. attitudes towards stocking) that guide very specific behavioural intentions and behaviours (Fig. 1; Manfredo 2008; Vaske & Manfredo 2012). It is important to measure both knowledge and cognitions to understand the effect of an intervention because the effect of environmental education on behaviour is mediated through cognitions. Our study is novel because our evaluation was structured around a cognitive behavioural model in addition to assessing changes in ecological knowledge.

We evaluated a lecture-based intervention in the framework of 'loop learning' (Fig. 2; Argyris 1976; Fazey, Fazey & Fazey 2005), which is increasingly used in natural resource management (Pahl-Wostl 2009; Petersen, Montambault & Koopman 2014). Single-loop learners obtain an understanding of the consequences of actions to make current practices more effective; this can be measured by assessing content knowledge gained. We hypothesized that lecture-based instruction would successfully impart information to the involved and ecologically

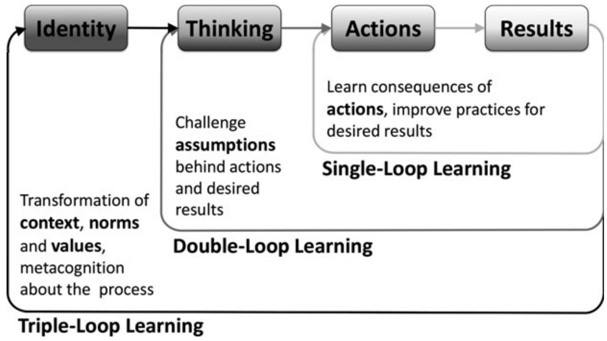

Fig. 2. Illustration of single-, double- and triple-loop learning (inspired by Pahl-Wostl 2009).

empowered stakeholder group of anglers (Hungerford & Volk 1990). Double-loop learning is a change in the way of thinking about an issue, challenging assumptions, altering functional beliefs and reducing uncritically positive attitudes about a topic. Changes in knowledge can affect cognitions because the explicit component of attitudes comes from deliberate thought processes, and beliefs are formed from information and experience (Vaske & Manfredo 2012). Thus, we hypothesized stocking lectures would also foster double-loop learning by influencing stocking beliefs and attitudes. In contrast, we did not expect triple-loop learning to occur, where fundamental change in conceptual understanding and perspective of the learner is achieved. Triple-loop learning would for example be identified by a decrease in pro-stocking personal norms and be associated with a radical change in how fisheries management is perceived, but we did not expect our "one-shot" lectures to alter personal norms, which stem from an individual's long-term experience modified by active interaction (Vaske & Manfredo 2012). We instead hypothesized the lecture would foster single and possibly double-loop learning.

Materials and methods

EXPERIMENTAL DESIGN

Evaluation of the lecture intervention took place within a larger survey project of anglers in 17 clubs in Lower Saxony, Germany. Clubs were randomly assigned to either a stocking lecture (11 clubs) or a control lecture (six clubs). The purpose of the control lecture was as a placebo for the effects a lecture may have outside of content (e.g. the Hawthorne effect) as well as controlling for the retest effect of reusing the same scales (Randler 2012). The same individual gave all lectures to control for instructor effects. A pre-test was mailed to all club members to assess pre-lecture baselines. After those responses were received, an open invitation to a lecture was announced to each club. There were no incentives given to attend the lectures.

Control clubs received a 90 min lecture about introductory freshwater fish ecology (concepts such as carrying capacity, density-dependence and stock-recruitment) and focused on the effects of harvest regulations (particularly harvest slots) for fisheries management. The 4·5 h stocking lecture was broken into three parts with breaks in between. The first part was largely the same freshwater fish ecology material from the control lecture. The second part focused on sustainable stocking, and attendees were given many species-specific examples of successful and unsuccessful stocking events, as well as content on potential ecological and genetic risks of stocking. Complex genetic topics were discussed, specifically the benefits of locally adapted stocks and the risks of genetic biodiversity loss due to stocking non-local genetic material. The final portion of the lecture emphasized planning, evaluation, communication and adaptive management and the use of alternatives to stocking (e.g. habitat enhancement; FAO 2012). Slides in the original German and translated into English are available in the supporting material (Appendix S2) and recordings of the lectures can be found online (in German; www.besatzfisch.de).

Immediately after the lecture, a post-test questionnaire was administered with identical scales to those in the pre-test. The vast majority of attendees completed the questionnaire on site. 86 anglers from the 6 control clubs and 115 anglers from the 11 stocking lecture clubs completed both pre- and post-test questionnaires. Ten months later, a retention test was mailed to respondents to assess whether the post-lecture changes were stable over time. Lecture retention questionnaires between the six control clubs and six of the 11 stocking lecture clubs were compared in our analysis, as five other clubs received a different treatment after the stocking lecture and were not included in the retention analysis. Eighty-one anglers/managers from the control clubs and 55 anglers/managers from the stocking lecture clubs completed the pre-test, post-test and retention tests, and thus form the empirical basis for analysis of long-term retention effects.

QUESTIONNAIRE

Multi-item Likert scales were constructed to operationalize the domains in our study (e.g. ecological knowledge, attitudes and personal norms towards stocking, Table 1; for full text of the questionnaire see Appendix S1 in Supporting Information). Questionnaires were discussed and developed with experts in the field of fisheries management to verify the knowledge content reflected current state of the art. The questionnaire was co-developed by experts in fisheries biology, education and psychology, to ensure equal rigor in the ecological content and social psychological measurement (St John *et al.* 2014). Post hoc reliability metrics were assessed for the latent constructs and knowledge domains to assure consistency.

Cognitive behavioural antecedents assessed in the questionnaire were 'personal norms regarding stocking' (anglers feel a personal responsibility to stock) and 'attitude towards stocking' (positive or negative evaluation of stocking as a management tool), along with 'belief in the functionality of stocking' (that stocking works to increase catch) and the related belief 'consideration of alternate management options to stocking', as anglers who believe less in the efficacy of stocking could consider alternative options to a greater extent (e.g. habitat enhancement).

Informational topics assessed included ecological knowledge that there may be no additive effects of stocking into self-reproducing populations ('additive effects'; Lorenzen 2005), potential negative impacts of stocking including intraspecific competition and risk of invasive species introduction ('potential negative impacts'; Eby *et al.* 2006; van Poorten *et al.* 2011), 'advantages of locally adapted stocks' (vs. hatchery stock of different genetic origin with adaptations to different conditions; Fraser *et al.* 2011) and 'genetic risks of stocking' including introgression and

Table 1. Domains measured, coefficients, standard errors and *P*-values for immediate lecture learning (interaction) effects†; significant coefficients indicated learning

Domain measured		Description	Loop learning	β	SE	*P*-value
Latent constructs	Personal norms	Do you personally feel obligated to stock?	Triple	−0·221	0·151	0·142
	Attitude	Do you have a favourable opinion of stocking?	Double	−0·227	0·164	0·168
	Belief (Functionality)	Does stocking work to increase catch?	Double	−0·205	0·116	0·077
	Belief (Consideration of alternatives)	Do other methods work as well or better than stocking?	Double	0·199	0·125	0·112
Ecological knowledge	Additive effects	Knowledge that sometimes there are no additive effects of stocking	Single	0·534	0·123	<0·001***
	Potential negative impacts	Knowledge of potential negative ecological impacts of stocking	Single	0·568	0·113	0·005**
	Advantages of local adaptation	Knowledge that locally adapted fish do better than non-local ones	Single	0·609	0·113	<0·001***
	Genetic risks of stocking	Knowledge of risks to locally adapted populations from stocking individuals with foreign genes	Single	0·716	0·119	<0·001***
Adaptive management knowledge	Adaptive management	Understanding of the process of continuously learning from management interventions	Triple	0·430	0·106	<0·001***
	Monitoring success of stocking	Understanding effective ways to measure the success of fish stocking	Triple	0·364	0·102	<0·001***

***$P < 0.001$.
**$P < 0.01$.
†The difference in differences in the pre-test to post-test change between the control (n = 86) and stocking lecture treatment (n = 115) participants.

outbreeding depression (Laikre *et al.* 2010). Two final knowledge domains addressed a new way of flexibly thinking about management as an active process of adaptation as environmental, economic and social conditions change (Walters 1986; FAO 2012). The 'adaptive management' domains assessed understanding that stocking operations should be flexible under changing conditions and 'monitoring success of stocking' evaluated knowledge of effective monitoring methodology to inform adaptive management of stocking programs.

STATISTICAL ANALYSIS

Constructs of each assessment domain were obtained from mean Likert scales (Carifio & Perla 2007) and analysed with parametric methods (Glass, Peckham & Sanders 1972). Data were analysed using Before-After-Control-Impact assessment (Green 1979; also known as a difference in differences approach). In this context, the absolute differences between control and treatment groups were irrelevant, as there may be systematic differences between these groups unrelated to their assignment. Instead, the differences in the changes between tests were compared between control and treatment groups. Assumptions underlying this methodology are that there are no perturbations to the control group concurrent with the intervention that would bias results, and that the control and treatment groups did not influence each other (Stewart-Oaten, Murdoch & Parker 1986). To the best of our knowledge both assumptions were met in the present work.

A generalized linear mixed model approach was used to partition variance in club-level random effects from the fixed effects of interest that characterize all individuals in the model (Gelman & Hill 2007). Linear mixed models were fit by maximum likelihood in the statistical software R (http://cran.r-project.org) using the package *nlme* (Pinheiro *et al.* 2015), as:

$$y_{ij} = X_i\boldsymbol{\beta} + b_j + \boldsymbol{\varepsilon}_{ij} \; b_j \sim N_j(0, \Psi) \; \varepsilon_{ij} \sim N_{ni}(0, \; \sigma^2),$$

where $\boldsymbol{y}_{ij}$ is the response vector for the *i*th respondent in the *j*th club for each model, $\boldsymbol{X}_i$ is the design matrix, and $\boldsymbol{\beta}$ is the vector of coefficients for fixed effects for the pre-test vs. post-test (or pre-test vs. retention test), control vs. stocking lecture treatments and the interaction between the two (the treatment effect). $\boldsymbol{b}_j$ is the vector of random-effect coefficients for club j, with Ψ as the covariance matrix for club-level random effects, parsed from global variance. ε_{ij} is the vector of residual variance terms. Missing values were replaced with the neutral response category "not sure" or "neither agree nor disagree". The structure of the data supported the decision to recode missing values as neutral/unsure, as missing values clustered on particular items instead of occurring uniformly, and more missing values were found in the pre-test compared to the post-test. This suggested that a missing value indicated a lack of understanding or confidence. For robustness, we also analysed cases where all respondents missing an item for a construct were dropped from analysis of that construct, and where all missing values were replaced with a respondent's average response for a given construct. Results were similar in all analyses and for brevity only the neutral replacement case is presented.

Results

Immediately post-lecture, stocking lecture attendees demonstrated improvement in knowledge scores from their baseline level relative to the control group for all six ecological and fisheries management topics (Table 1). Specifically, anglers learned that there can be no additive effects of stocking in some circumstances, that stocking can have negative ecological consequences, that the genetic makeup of stocked fish matters for stocking outcomes, and that locally adapted genes are to be preferred because such fish often show higher survival and have less biodiversity risks. Anglers also learned that stocking is ideally an adaptive process that must be constantly evaluated, and demonstrated knowledge gain about the best methods to evaluate stocking events. In contrast, there were no significant changes for any of the latent hierarchical cognitive constructs (Fig. 1), i.e. personal norms, attitudes and beliefs related to stocking (Table 1).

When assessing long-term (10 months) retention of concepts by comparing pre-test to retention test changes relative to the control, the lecture had a lasting learning effect on the lack of additive effects of stocking into self-reproducing populations (Table 2). There was also a strong trend towards a decrease in the functional belief in stocking ($P = 0{\cdot}071$), an increase in the knowledge that there are advantages to stocking local genetics ($P = 0{\cdot}073$) and the genetic risks of stocking to native populations ($P = 0{\cdot}060$). The signs of the coefficients aligned with expectations so we feel confident to interpret the low P values as indicative of strong supported trends, particularly given the lower sample size in the retention test. There were no changes in attitudes or personal norms related to stocking, nor increased consideration of alternatives to stocking in the retention test (Table 2). Though the knowledge domains 'potential negative impacts of stocking,' 'adaptive management' and 'monitoring success of stocking' were significantly elevated immediately post-lecture, they did not show significant retention effects compared to the control, indicating these knowledge areas were forgotten long-term (Table 2).

The lecture effects are most easily observed graphically (Fig. 3). Recall that the absolute difference between

Table 2. Coefficients, standard errors and *P*-values for long-term retention learning (interaction) effects†

	β	SE	*P*-value
Personal norms	−0·256	0·197	0·194
Attitude	−0·260	0·199	0·193
Belief (Functionality)	−0·264	0·146	0·071
Belief (Consideration of alternatives)	−0·014	0·150	0·928
Additive effects	0·351	0·161	0·030*
Potential negative impacts	0·165	0·142	0·245
Advantages of local adaptation	0·262	0·146	0·073
Genetic risks of stocking	0·276	0·146	0·060
Adaptive management	0·077	0·131	0·557
Monitoring success of stocking	0·084	0·123	0·496

*$P < 0.05$.

†The difference in differences in the pre-test to retention test change between the control ($n = 81$) and stocking lecture treatment ($n = 55$) participants.

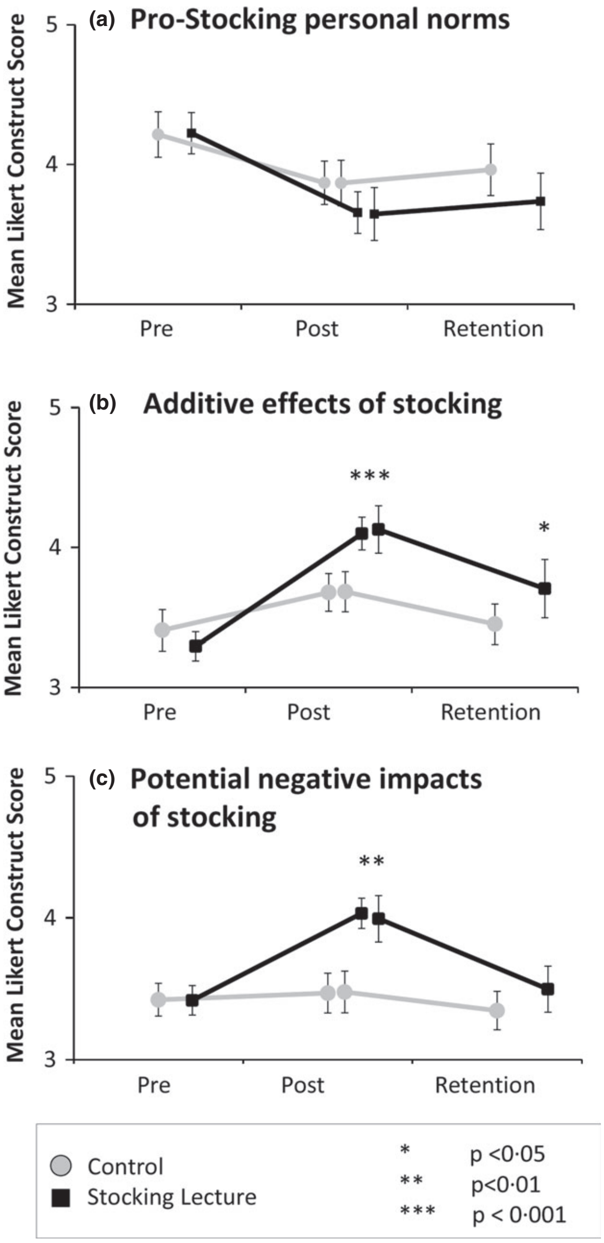

Fig. 3. Illustration of lecture and retention effects where (a) there were no lecture or retention effects, (b) there was a positive lecture effect and concept retention 10 months later, and (c) there was a positive lecture effect but no retention 10 months later. Significance levels indicate significant treatment effects comparing the pre-lecture Likert construct score and the post-lecture or retention test score. Pre- to post-lecture questionnaire and pre-lecture to retention questionnaire sample sizes differed and are plotted separately.

control and lecture scores is irrelevant; what matters is how the changes in the control and lecture groups differed. Figure 3a illustrates a case with no significant treatment effects – changes in the normative obligation to stock in the control group did not differ from the treatment group. Figure 3b shows an immediate learning effect, where content knowledge on additive fishery effects of stocking increased significantly post-test compared to the change in the control. Furthermore, the change from pre-lecture questionnaire to retention questionnaire is significantly different from the control, indicating that knowledge learned was retained over a period of 10 months. Finally, Figure 3c shows significant initial learning that there can be negative ecological impacts of stocking (e.g. introduction of pathogens and parasites). However, from pre-test to retention test 10 months post-lecture, knowledge of this topic was not significantly different from the control, indicating knowledge acquired from the lecture was forgotten.

Discussion

Our study supported expectations that a lecture on complex fisheries management topics would result in knowledge gain among fisheries stakeholders. The long-term result of the lecture was starkly single-loop learning (Tables 1 and 2), where anglers acquired knowledge to refine current practices – to continue to do what they were already doing (i.e. to stock), with improvements, rather than questioning whether stocking should remain the favoured management tool. In contrast to our hypothesis, double-loop learning was not fully achieved. Despite presenting anglers with evidence that many stocking programs fail to deliver intended benefits (Lorenzen, Beveridge & Mangel 2012) a detailed lecture was insufficient to strongly alter pro-stocking beliefs, though there was a promising trend indicating the functional belief in stocking was reduced (Table 2). Though lecture-based instruction is not necessarily expected to change attitudes and other deeply held cognitions (Heberlein 2012) it can occur, particularly with motivated learners (Bligh 1998) like our sample. However, double-loop learning did not emerge. Moreover, there was no evidence of triple-loop learning, revolutionizing the process of fisheries management as measured by altered personal norms and adaptive management domains (Table 2).

The stocking lectures were immediately effective at conveying complex ecological content, but only a single topic was retained long-term at $P < 0{\cdot}05$. The knowledge domain remembered 10 months post-lecture – that additive effects of stocking cannot be generally expected – has a core ‘rule of thumb’ that could be operationalized to make current stocking practices more effective – the hallmark of single-loop learning. This knowledge domain could be distilled into a rule not to stock into self-reproducing populations, as additive effects are unlikely to emerge (Lorenzen 2005; Arlinghaus *et al.* 2015). This concept was repeatedly emphasized within the stocking lecture as a “fundamental principle of sustainable stocking.”

Genetic issues inherent in stocking were the focus of most of part two of the stocking lecture, and were highlighted at the end of the lecture as a rule of thumb to ‘stock local genetics’ to improve additive effects and minimize genetic risks. Although the genetic concepts were probably the most novel for anglers, making uptake more challenging with the increased cognitive load (Sweller &

Chandler 1994), the lecture targeted a general audience, for example explaining 'advantages of local adaptation' with an amusing sports metaphor ("home court advantage"). However, "substance uncertainty" is particularly strong in relation to the genetics of fish stocking (Sandström 2010) as genetic issues related to stocking are controversial even among the scientific community. Sandström (2010) and Sevä (2013) reported that uncertainty, even among scientists, about the presence and relevance of local genetic biodiversity was a major reason for the lack of adaptive stocking policies in some Scandinavian countries. Furthermore, we found many anglers held pre-conceived notions about genetics, due to a prevalent idea in the clubs that 'adding new blood to the population' (i.e. stocking material of non-local origin) is a good management practice (R. Arlinghaus, personal observations). This belief was directly discredited in the lectures, but established knowledge, even if incorrect, will persist if not fully overcome (Confrey 1990). Thus, it is promising that we found a strong trend towards long-term concept retention given these barriers to knowledge uptake. As genetic biodiversity is thought to be under greatest threat by contemporary stocking practices (Laikre *et al.* 2010), these findings are particularly encouraging.

In contrast to the genetics topics discussed above, the 'potential negative impacts of stocking' domain, which covered several potential ecosystem threats from stocking, was not presented as a single 'rule of thumb' recommendation. The lecture covered the complex range of ecological outcomes from no impacts to severe ecological effects as is consistent with the literature (Arlinghaus *et al.* 2015). This ambiguity may have contributed to the lack of retention, despite concepts of density-dependence and carrying capacity being covered twice (in different lecture sections). Furthermore, mitigation of degraded ecosystems using stocking is a rationale for stocking among anglers (von Lindern & Mosler 2014). Psychological processes of cognitive dissonance may have rationalized away the potential for negative impacts given adherence to best practices. Stronger effects seen in the genetics domains is consistent with the idea that strong challenges to existing ecological mental models (in this case, a lack of or incorrect information in anglers' mental models on stocking genetics) can lead to stronger knowledge uptake than small challenges to angler mental models where impacts of stocking were likely already present and connected by anglers (von Lindern 2010).

Given that single-loop learning occurred, the pertinent management question is how future stocking behaviour could be affected by the lecture. Von Lindern (2010) found that Swiss anglers who internalized knowledge of no "additive effects" (as did anglers in this study) reduced preferences for stocking. While those results are promising, our behavioural model indicated that double-loop learning (changing beliefs and attitudes) did not fully occur, despite the promising trend ($P = 0{\cdot}071$) towards a reduction in the functional belief in stocking. Our results suggest anglers will continue to support stocking, and will likely not radically alter their practices and engage in alternatives to stocking. However, anglers' support for stocking will now be tempered with new knowledge of best practices. Indeed, single-loop learning alone can have utility. Economic waste can be avoided by not stocking into self-reproducing populations, as is now standard practice. Anglers also show trends towards awareness of the importance of the genetic composition of stocked fish. If anglers make a point to select local genetic material to stock they can avoid environmental harm and economic inefficiency in the future. Therefore, our message is not that lectures are ineffective; however, they cannot be expected to revolutionize thinking about natural resource management and biodiversity conservation.

The latter aspect is demonstrated by the lack of adaptive management knowledge retention long-term, despite section three of the stocking lecture focusing solely on adaptive management and the necessity of monitoring stocking outcomes (FAO 2012). Adaptive management teaches anglers there are no easy answers to the question of whether or how to stock, that stocking outcomes are highly contextual and that management needs to be a process to constantly learn as circumstances change over time (Walters 1986). Successful understanding of adaptive management imparts a new way of thinking and a conceptually new approach indicative of triple-loop learning. The lecture was able to convey ideas about this new way of thinking in the short-term, but the concept was not internalized and retained. This suggests that the information on adaptive management was processed factually (single-loop) but did not transform anglers' perspectives on fisheries management (triple-loop).

A substantial shift in thinking and behaviour is most likely to occur with double- or triple-loop learning (Argyris 1976; Fazey, Fazey & Fazey 2005). In constructivist learning (Brooks & Brooks 1993), learning by doing, learners build their own understanding. As knowledge is experiential and personalized, constructivist learning is more likely to lead to double- or triple-loop learning (Kollmuss & Agyeman 2002; Scholz *et al.* 2006). Yet, lectures still play a key role, as experiential learning requires a foundation on which to base personal experiences (Bransford, Brown & Cocking 2000). Although it may seem that complex topics are best learned through complex, experiential learning methods, instructional methods have an additive cognitive burden (van Merrienboer & Sweller 2005). For inexperienced learners, or learners with insufficient background on the topic, the layered cognitive load can hinder learning (van Merrienboer & Sweller 2005). There is no best teaching method as learning is situationally dependent, with lectures out-performing more involved and resource-intensive methods in different contexts (Bligh 1998; Struyven, Dochy & Janssens 2008). Teaching methods must be adapted to the situation, and here, anglers spending their leisure time might favour a lecture over a hands-on, time-consuming activity.

We conducted a large randomized experiment to assess the effect of lecture-based environmental education on fisheries stakeholders involved in managing fish populations. Our results are transferrable across many European countries where private fishing rights exist, as well as to other contexts where stakeholders may benefit from exposure to ecological knowledge, e.g. in the context of forestry, hunting or agriculture. We distil from our study a few suggestions to optimize the use of lectures for long-term knowledge retention in natural resource management. First, lecture-based environmental education promotes single-loop learning and to a smaller degree double-loop learning, and straightforward recommendations to modify and improve current practices will gain the most long-term traction. Secondly, unambiguous 'rules of thumb' can help highlight concepts for long-term retention. Just as freshwater stocking practices can be tailored to be economically and environmentally responsible, so can lectures. If employed wisely, lectures can be useful tools for management and conservation, but expectations that one-shot lectures change personal norms or attitudes may be unrealistic.

Acknowledgements

We thank C. Riepe, M. E. Beck, A. Türck, F. D. Johnston, M. Morkritzki, E.-M. Cyrus and J. Hilsberg for assisting with data collection and entry, D. Hühn and T. Pagel for assisting with the interventions and B. Chéret for translating the lecture slides. We sincerely thank all 17 angling clubs for their participation, and reviewers for feedback. The study was funded by the Besatzfisch project through the Program on Social-Ecological Research by the German Ministry of Education and Research to R.A. (www.besatz-fisch.de, grant # 01UU0907).

Data accessibility

Questionnaire response data are uploaded as online supporting information.

References

Ajzen, I. (2005) From intentions to actions. *Attitudes, Personality and Behavior*. 2nd edn. Open University Press, Maidenhead, United Kingdom.

Argyris, C. (1976) Single-loop and double-loop models in research on decision making. *Administrative Science Quarterly*, **21**, 363–375.

Arlinghaus, R. (2006) Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environmental Conservation*, **33**, 46–59.

Arlinghaus, R. & Mehner, T. (2005) Determinants of management preferences of recreational anglers in Germany: habitat management versus fish stocking. *Limnologica-Ecology and Management of Inland Waters*, **35**, 2–17.

Arlinghaus, R., Mehner, T. & Cowx, I.G. (2002) Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries*, **3**, 261–316.

Arlinghaus, R., Cyrus, E.-M., Eschbach, E., Fujitani, M., Hühn, D., Johnston, F., Pagel, T. & Riepe, C. (2015) *Hand in Hand für eine nachhaltige Angelfischerei: Ergebnisse und Empfehlungen aus fünf Jahren praxisorientierter Forschung zu Fischbesatz und seinen Alternativen* Berichte des IGB, 28.

Bligh, D.A. (1998) *What's the Use of Lectures?* Intellect Books, Exeter

Bransford, J.D., Brown, A.L. & Cocking, R. (2000) *How People Learn*. National Academy Press, Washington, DC.

Brooks, J.G., Brooks & M.G. (1993) *In Search of Understanding: The Case for Constructivist Classrooms*. Association for Supervision and Curriculum Development, Alexandria, VA, USA.

Carifio, J. & Perla, R.J. (2007) Ten common misunderstandings, misconceptions, persistent myths and urban legends about Likert scales and Likert response formats and their antidotes. *Journal of Social Sciences*, **3**, 106–116.

Carleton-Hug, A. & Hug, J.W. (2010) Challenges and opportunities for evaluating environmental education programs. *Evaluation and Program Planning*, **33**, 159–164.

Chilcote, M.W., Goodson, K.W. & Falcy, M.R. (2011) Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. *Canadian Journal of Fisheries and Aquatic Sciences*, **68**, 511–522.

Clayton, S., Litchfield, C. & Geller, E.S. (2013) Psychological science, conservation, and environmental sustainability. *Frontiers in Ecology and the Environment*, **11**, 377–382.

Confrey, J. (1990) A review of research on student conceptions in mathematics, science programming. *Review of Research in Education*, **16**, 3–55.

Daedlow, K., Beard, T.D. & Arlinghaus, R. (2011) A property rights-based view on management of inland recreational fisheries: contrasting common and public fishing rights regimes in Germany and the United States. *American Fisheries Society Symposium*, **75**, 13–38.

Dressel, S., Sandström, C. & Ericsson, G. (2015) A meta-analysis of studies on attitudes toward bears and wolves across Europe 1976–2012. *Conservation Biology*, **29**, 565–574.

Eby, L.A., Roach, W.J., Crowder, L.B. & Stanford, J.A. (2006) Effects of stocking-up freshwater food webs. *Trends in Ecology & Evolution*, **21**, 576–584.

Estevez, R.A., Anderson, C.B., Pizarro, J.C. & Burgman, M.A. (2014) Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology*, **29**, 19–30.

FAO (2012) Recreational fisheries. *FAO Technical Guidelines for Responsible Fisheries*. No. 13. FAO, Rome.

Fazey, I., Fazey, J.A. & Fazey, D.M.A. (2005) Learning more effectively from experience. *Ecology and Society*, **10**, 4. [online] URL: http://www.ecologyandsociety.org/vol10/iss12/art14/

Fraser, D.J., Weir, L.K., Bernatchez, L., Hansen, M.M. & Taylor, E.B. (2011) Extent and scale of local adaptation in salmonid fishes: review and meta-analysis. *Heredity*, **106**, 404–420.

Freyhof, J. & Brooks, E. (2011) *European Red List of Freshwater Fishes*. International Union for Conservation of Nature and Natural Resources. Publ, Office European Union, Luxembourg.

Gelman, A. & Hill, J. (2007) *Data Analysis: Using Regression and Multi-Level/Hierarchical Models*. Cambridge University Press, New York, NY.

Glass, G.V., Peckham, P.D. & Sanders, J.R. (1972) Consequences of failure to meet assumptions underlying the fixed effects analyses of variance and covariance. *Review of Educational Research*, **42**, 237–288.

Green, R.H. (1979) *Sampling Design and Statistical Methods for Environmental Biologists*. 257 pp. Wiley, Chichester.

Halverson, M.A. (2008) Stocking trends: a quantitative review of governmental fish stocking in the United States, 1931 to 2004. *Fisheries*, **33**, 69–75.

Heberlein, T.A. (2012) *Navigating Environmental Attitudes*. Oxford University Press, Oxford.

Hewlett, N.R., Snow, J. & Britton, J.R. (2009) The role of management practices in fish kills in recreational lake fisheries in England and Wales. *Fisheries Management and Ecology*, **16**, 248–254.

Hilborn, R. (1999) Confessions of a reformed hatchery basher. *Fisheries Management and Ecology*, **24**, 30–31.

Hühn, D., Lübke, K., Skov, C. & Arlinghaus, R. (2014) Natural recruitment, density-dependent juvenile survival, and the potential for additive effects of stock enhancement: an experimental evaluation of stocking northern pike (*Esox lucius L.*) fry. *Canadian Journal of Fisheries and Aquatic Sciences*, **71**, 1–12.

Hungerford, H.R. & Volk, T.L. (1990) Changing learner behavior through environmental education. *The Journal of Environmental Education*, **21**, 8–21.

Jacobson, S.K., McDuff, M.D. & Monroe, M.C. (2006) *Conservation Education and Outreach Techniques*. Oxford University Press, New York.

Johnson, B.M., Arlinghaus, R. & Martinez, P. (2009) Are we doing all we can to stem the tide of illegal fish stocking? *Fisheries*, **34**, 389–394.

Klein, M. (1996) Fischbesatz: Gewohnheitsübung, Hegemaßnahme oder Garant zur Ertragssteigerung? *Fischer and Teichwirt*, **47**, 152–156.
Kollmuss, A. & Agyeman, J. (2002) Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, **8**, 239–260.
Laikre, L., Schwartz, M.K., Waples, R.S. & Ryman, N. (2010) Compromising genetic diversity in the wild: unmonitored large-scale release of plants and animals. *Trends in Ecology & Evolution*, **25**, 520–529.
Lewin, W.-C., McPhee, D. & Arlinghaus, R. (2008) Biological impacts of recreational fishing resulting from exploitation, stocking and introduction. *Global Challenges in Recreational Fisheries* (eds Ø. Aas, R. Arlinghaus, R.B. Ditton, D. Policansky & H.L. Schramm Jr), pp. 75–92. Blackwell Science, Oxford.
von Lindern, E. (2010) *Changing Mental Models to Promote Pro-Environmental Ecosystem Management: Recreational Fishermen and their Fish Stocking Practices in Swiss Running Waters*. Doctor of Philosophy, University of Zürich.
von Lindern, E. & Mosler, H.J. (2014) Insights into fisheries management practices: using the theory of planned behavior to explain fish stocking among a sample of Swiss anglers. *PLoS One*, **9**, e115360.
Lord, T.R. (1999) A comparison between traditional and constructivist teaching in environmental science. *The Journal of Environmental Education*, **30**, 22–27.
Lorenzen, K. (2005) Population dynamics and potential of fisheries stock enhancement: practical theory for assessment and policy analysis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **360**, 171–189.
Lorenzen, K., Beveridge, M. & Mangel, M. (2012) Cultured fish: integrative biology and management of domestication and interactions with wild fish. *Biological Reviews*, **87**, 639–660.
Manfredo, M.J. (2008) *Who Cares About Wildlife?*. Springer, New York, New York, USA.
van Merrienboer, J.J. & Sweller, J. (2005) Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review*, **17**, 147–177.
Pahl-Wostl, C. (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, **19**, 354–365.
Petersen, B., Montambault, J. & Koopman, M. (2014) The potential for double-loop learning to enable landscape conservation efforts. *Environmental Management*, **54**, 782–794.
Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & R Core Team (2015) *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-122, http://CRAN.R-project.org/package=nlme.
van Poorten, B.T., Arlinghaus, R., Daedlow, K. & Haertel-Borer, S.S. (2011) Social-ecological interactions, management panaceas, and the future of wild fish populations. *Proceedings of the National Academy of Sciences*, **108**, 12554–12559.
Randler, C.I.E. (2012) Field experiments in learning research. *Encyclopedia of the Sciences of Learning, Part F* (ed. N.M. Seel), pp. 1293–1297. Springer, New York.
Riepe, C. & Arlinghaus, R. (2014) Explaining anti-angling sentiments in the general population of Germany: an application of the cognitive hierarchy model. *Human Dimensions of Wildlife*, **19**, 371–390.
Sandström, A. (2010) Institutional and substantial uncertainty—Explaining the lack of adaptability in fish stocking policy. *Marine Policy*, **34**, 1357–1365.
Scholz, R.W., Lang, D.J., Wiek, A., Walter, A.I. & Stauffacher, M. (2006) Transdisciplinary case studies as a means of sustainability learning: historical framework and theory. *International Journal of Sustainability in Higher Education*, **7**, 226–251.
Schultz, P. (2011) Conservation means behavior. *Conservation Biology*, **25**, 1080–1083.
Sevä, M. (2013) A comparative case study of fish stocking between Sweden and Finland: explaining differences in decision making at the street level. *Marine Policy*, **38**, 287–292.
St John, F.A., Keane, A.M., Jones, J.P. & Milner-Gulland, E.J. (2014) Robust study design is as important on the social as it is on the ecological side of applied ecological research. *Journal of Applied Ecology*, **51**, 1479–1485.
Stapp, W.B. (1969) The concept of environmental education. *Environmental Education*, **1**, 30–31.
Stewart-Oaten, A., Murdoch, W.W. & Parker, K.R. (1986) Environmental impact assessment: "pseudoreplication" in time? *Ecology*, **67**, 929–940.
Struyven, K., Dochy, F. & Janssens, S. (2008) Students' likes and dislikes regarding student-activating and lecture-based educational settings: Consequences for students' perceptions of the learning environment, student learning and performance. *European Journal of Psychology of Education*, **23**, 295–317.
Sturgis, P. & Allum, N. (2004) Science in society: re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, **13**, 55–74.
Sweller, J. & Chandler, P. (1994) Why some material is difficult to learn. *Cognition and Instruction*, **12**, 185–233.
Vaske, J.J. & Manfredo, M.J. (2012) Social psychological considerations in wildlife management. *Human Dimensions of Wildlife Management* (eds D.J. Decker, S.J. Riley & W.F. Siemer), pp. 43–57. The Johns Hopkins University Press, Baltimore, Maryland.
Von Lukowicz, M. (1998) Education and training in recreational fisheries in Germany. *Recreational Fisheries: Social, Economic and Management Aspects* (eds P. Hickley & H. Tompkins), pp. 287–293. Fishing News Books, Blackwell Science, Oxford.
Walters, C.J. (1986) *Adaptive Management of Renewable Resources*. Macmillan, New York, New York, USA.

Received 13 January 2015; accepted 19 October 2015
Handling Editor: Marc Cadotte

Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Complete list of questions in the original German with English translations for each Likert scale construct.

Appendix S2. Slides of the stocking and control lecture content, in the original German and translated into English.

Appendix S3. Questionnaire response data.