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# Ecological and social constraints are key for voluntary investments into renewable natural resources

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ABSTRACT

Encouraging pro-environmental behavior is an urgent global challenge. An interdisciplinary framework covering governance, economic, social, ecological, and psychological dimensions is required to understand the salient features that encourage pro-environmental outcomes within and across contexts. We apply the Ostrom social-ecological systems framework to model voluntary investments by members of civil society into the aquatic environment. Using a data set of 1,809 angling clubs managing water bodies for fish stocking and habitat management in Germany and France, we show that a small set of factors, most crucially social-ecological and governance context as well as social norms and other bottom-up social pressures, drive environmental investments. These factors appear to override behavioral influences from psychological variables of the decision-maker. By contrast, the contextual setting related to property rights, size of the resource system, and social expectations were found to be strongly related to behavioral decisions, highlighting that the social-ecological context as well as incentives may be more important than knowledge and cognitions in driving certain pro-environmental actions.

## 1. Introduction

A key challenge of our time is to achieve sustainable development, a challenge composed of multi-faceted issues operating across varying geographical and political scales (Kates et al., 2001; Rockström et al., 2009). Encouraging investment into the environment is critical, yet difficult to achieve as people tend to fail to appropriately value natural capital (Fenichel et al., 2016), have disincentivizing ecological mental models (von Lindern, 2010), or simply lack political or financial power due to other higher order constraints (Fischer et al., 2012). Understanding public drivers of investments by civil society into environmental goods and services is of utmost concern because the sustainability challenges of our time ultimately depend on behavior by members of civil society (Ehrlich and Ehrlich, 2013; Fischer et al., 2012).

To learn and share knowledge about sustainability issues both between and across cases, contexts, regions and countries, a common language is required so that science can produce a cross-cutting body of knowledge and provide empirically grounded recommendations for sustainability (Ostrom, 2005, 2009). The Ostrom framework for the sustainability of social-ecological systems (SES) (McGinnis and Ostrom, 2014; Ostrom, 2007, 2009) has emerged as an interdisciplinary lingua franca for the analysis of the sustainability of common pool resources (Hinkel et al., 2014; Leslie et al., 2015; Partelow, 2018). Being structural in orientation, the SES framework helps to disassemble and compartmentalize complex SESs into pieces that can be compared across systems and understood across disciplines (Ostrom, 2009) while explicitly taking into account hierarchies, feedbacks, and connections that are characteristic of coupled SESs (Berkes and Folke, 1998).

The Ostrom SES framework proposes a rich, yet tractable set of hypothesis-driven factors and variables that influence individual and collective behavior (called second-tier variables) characterizing key

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structural domains (called first-tier variables, e.g.: resource system, resource units, governance system, actors) that are believed to exert systematic impacts on sustainability outcomes across cases (SI Fig. 1) (Hinkel et al., 2014; McGinnis and Ostrom, 2014). The central and largely unresolved academic challenge is to apply the list of second-tier factors across large sets of cases and in turn examine whether specific factors or groups of factors exert generic impacts on resource sustainability or components of it across case studies (Hinkel et al., 2014).

While there have been guides for formalization and structural comparison of SESs using the Ostrom SES framework (Basurto et al., 2013; Gutiérrez et al., 2011; Hinkel et al., 2014; Leslie et al., 2015; Schlüter et al., 2014), a large-N quantitative application of the latest version of the framework to understand predictors of environment-directed decision making at the framework's focal unit of analysis, the 'action situation' (Hinkel et al., 2014), is currently lacking (Partelow, 2018). This is of core interest in the sustainability sciences (Hinkel et al., 2014) to rigorously examine whether and how a large set of possible determinants of environmental decisions exert impacts on sustainability outcomes. Our paper is in response to this challenge.

The intended practical value of the SES framework is to help the analyst understand which second-tier variables exert systematic effects across cases on individual and collective behavior on the micro or macro-level (Hinkel et al., 2014) to provide needed information on "microsituational" as well as broad contextual variables and how they affect real-world outcomes (Vollan and Ostrom, 2010). Such understanding can only be achieved through a rigorous application of the same comprehensive set of second-tier variables to a range of social-ecological contexts (Hinkel et al., 2014; Thiel et al., 2015). Our goals are twofold: a) to test the explanatory power of the Ostrom SES framework for a specific resource investment decision in fisheries that involves decisions around stocking and alternative management approaches that enhance habitats, and b) understand whether a specific set of variables has explanatory power for environmental decisions. Our research analyses a wide range of behaviourally relevant social, economic and psychological factors that might affect how decision-makers invest into natural resources. Our work, by using a case from voluntary investments into natural resources, ultimately contributes to a relevant debate on the relative impact of incentives, constraints and psychological disposition of decision-makers on pro-environmental behavior (Basurto et al., 2016; Byerly et al., 2018; Osbaldiston and Schott, 2011). To specify boundaries for analysis the most recent version of the SES framework defines the core unit of investigation as an action situation (derived from the Institutional Analysis and Development framework) (McGinnis and Ostrom, 2014; Ostrom, 2005), where individuals interact with inputs (e.g., resource units) given exogenous variables (e.g., available actions, costs, benefits, deterrents), resulting in micro-level outcomes (e.g. change of a harvest regulation in fisheries) that feed back into the system and ultimately drive system-level sustainability and its indicators (e.g., overharvest, biodiversity loss, equity, resilience; SI Appendix Table S1). A given SES has many simultaneously interacting action situations, thus one strategy is to study the interactions and processes that lead to specific micro-level outcomes that have decisive roles for system sustainability. For example in fisheries, fish stocking constitutes an important micro-level managerial outcome that is prevalent in many fisheries-management contexts (Lorenzen et al., 2012). Stocking of fish desired by fisheries stakeholders is pervasive and global in nature, and could contribute both to the maintenance of threatened populations and enhance catches, while at the same time potentially affecting wild fishes or other organisms through undesired processes such as competition, predation or genetic hybridization (Eby et al., 2006; Laikre et al., 2010; van Poorten et al., 2011). Thus, understanding the factors that determine whether and with which intensity decision makers engage in fish stocking or alternative investments into natural resources is of high relevance for sustainability in fisheries.

## 2. The case of fisheries management by angler communities

We apply the SES framework to a specific provisioning focal action situation (i.e., fish stock enhancement through the choice of various methods) over replicated SESs using a freshwater fisheries example. There are still relatively few large-N quantitative comparative studies designed to understand environmental decision making and outcomes following ideas of the SES framework (Cinner et al., 2012; Gutiérrez et al., 2011; Meinzen-Dick, 2007; Oberlack et al., 2016; Rahimi et al., 2016), and the size and detail of our dataset allowed us to parameterize all relevant second-tier SES variables from the most current version of the SES framework (McGinnis and Ostrom, 2014). Unlike most comparative studies with a high number of observations in the SES literature, our dataset has the advantage of being primary data, with hypothesis-driven collection and methodological consistency. We analyzed the importance of governance, environmental, social and psychological variables to explain the outcome metric "investment into natural resources" by members of civil society. In our case, these members include hundreds of angling clubs engaged in voluntary decisions to invest into natural resources (fish stocks) through the actions of fish stocking and habitat enhancement.

We present a case application of environmental investment performed by members of the public. In Germany and France, as in much of central Europe, many rivers and lakes are directly managed by thousands of small angling communities organized in clubs as non-governmental organizations (NGOs). These clubs hold fisheries and management rights for their waters (Arlinghaus, 2006; Daedlow et al., 2011). The civilian club resource managers are locally elected from the club members and are directly responsible for selecting managerial actions to meet legal obligations and club priorities, with limited or no input from fisheries agencies and public experts (Arlinghaus et al., 2015; Daedlow et al., 2011). Depending on the region, each angling club faces different property rights, institutions (state-level fisheries legislation) and environmental conditions, and are subject to different national and regional de jure and de facto regulations (Arlinghaus et al., 2015). Common tools that angling clubs choose are investments into the fishery by releasing cultured or wild captured fishes (i.e., fish stocking) or by altering the environment (e.g., creating spawning habitats to improve reproduction or create refuges for juvenile fish to enhance survival) (Arlinghaus et al., 2016). We take advantage of the large existing natural variation among the socio-economic conditions of clubs and ecological heterogeneity to quantitatively assess correlates of natural resource investment using the SES framework in Germany and France, where more than 10,000 angling clubs and associated decision makers largely independently govern local fisheries resources. The Ostrom SES framework facilitated selection of explanatory factors from a vast number of potential predictors to a tractable number of variables. Our large sample of replicated environmental decision-making contexts allowed us to include one or more indicators for each of the relevant second-tier variables (Table 1) and to explore the relationship between the second-tier variables and outcomes in focal provisioning action situations (investment into natural resources).

In our analysis, the resource systems (RS) are the still and running bodies of freshwater managed by each club, which are additionally governed by the regional and state-level governance systems (GS) and a cocktail of national, regional, local, and even water-body-specific rules that the club resource managers are subject to. The resource units (RU) are the fish available to be caught by the anglers, who together with the club resource managers are the relevant actors (A). Within each first-tier variable are nested second-tier variables (McGinnis and Ostrom, 2014), for which we generated indicators relevant to these SESs (Table 1; SI Appendix Table S1). As in other studies (Basurto et al., 2013; Delgado Serrano and Ramos, 2015; Partelow and Boda, 2015; Vogt et al., 2015) we found that some second-tier variables in the original framework needed to be expanded to measure different aspects relevant to our case (Table 1). We followed the version proposed by

**Table 1**
Factors in the action situation inland fisheries provisioning resource units (fish) to actors (anglers) hypothesized to affect the outcome metrics, which themselves directly measure or mediate outcome criteria. Table adapted from Table 1 in Ostrom (2007) and drawing content from (Arlinghaus et al., 2017; Hinkel et al., 2014; McGinnis and Ostrom, 2014). Perceived abbreviated as 'perc.'

| | |
|---|---|
| **Social, Economic, and Political Settings (S)** | |
| S1 – Economic development S2 – Demographic trends S3 – Political stability | |
| S4 – Other governance systems S5 – Markets S6 – Media organizations S7 – Technology | |
| **Resource systems (RS)** | **Governance systems (GS)** |
| RS1 – Sector: *inland fisheries* | GS1 – Government organizations: de facto *approval* |
| RS2 – Clarity of system boundaries: *lake* vs *river* | *GS2* – Nongovernment organizations: *angling clubs* |
| RS3 – Size of resource system: *managed waters* | GS3 – Network structure: *network complexity* |
| RS4 – Human-constructed facilities: *hatcheries* | GS4 – Property-rights systems: *property rights type* |
| RS5 – Productivity of system: *perc. spawning stock* | GS5 – Operational-choice: *constraints and club influence* |
| RS6 – Equilibrium prop.: *perc. threats to equilibrium* | GS6 – Collective-choice: *constraints* |
| RS7 – Predictability of system dynamics: *artificial* vs *natural* | GS7 – Constitutional-choice rules: *by country* |
| RS8 – Storage characteristics: *overlaps RS2 and RS7* | GS8 – Monitoring and sanctioning: *legal sanctions* |
| RS9 – Location: *Cat 1 or 2 in France* | **Actors (A)** |
| **Resource units (RU)** | A1 – Number of relevant actors: *active anglers, managers* |
| RU1 – Resource unit mobility: *overlaps RS2 and RS7* | A2 – Socioeconomic attributes: *overlap with RU4* |
| RU2 – Growth or replacement rate: *culture stocking* | A3 – History or past experiences: *age of club, past practices* |
| RU3 – Interaction among resource units: *understanding of interactions* | A4 – Location: *Geographic variables* |
| RU4 – Economic value: *club funds / membership fee* | A5 – Leadership/entrepreneurship: *Leader experience* |
| RU5 – Number of units: *perc. stock abundance* | A6 – Norms (trust-reciprocity)/social capital: *variables from environmental psychology* |
| RU6 – Distinctive characteristics: *overlaps RU2* | A7 – Knowledge of SES/mental models: *Knowledge and knowledge-seeking behavior* |
| RU7 – Spatial and temporal distribution: *overlap with RS1-3* | A8 – Importance of resource (dependence): *social pressure towards resource* |
| | A9 – Technologies available: *overlaps RS4* |
| **Action Situation – *investment into inland fishery while provisioning RU to A*** | |
| **Interaction (I5) → Outcomes (O)** | |
| **Activities and Processes:** | **Micro-level Outcomes (fast feedbacks)** |
| I1 – Harvesting | O1 – Stocking density |
| I2 – Information sharing | O2 – Monetary investment into stocking |
| I3 – Deliberation processes | O3 – Monetary investment into habitat enhancement |
| I4 – Conflicts with other users | |
| I5 – Investment activities | **Macro-level Outcomes (slow feedbacks, systemic)** |
| I6 – Lobbying activities | O4 – Socio-economic performance measures |
| I7 – Self-organizing activities | O5 – Ecological performance measures |
| I8 – Networking activities | O6 – Externalities to other SESs |
| I9 – Monitoring activities | |
| I10 – Evaluative activities | |
| **Related ecosystems (ECO)** | |
| ECO1 – Climate patterns ECO2 – Pollution patterns ECO3 – Flows into and out of focal SES | |

Arlinghaus et al. (2017) specifically tailored towards recreational fisheries. For example, because substantial diversity exists in the motivations of the individual club resource managers, and it is ultimately their behavior that we are modeling, the aggregate second-tier variable A6 "Norms (trust-reciprocity) / social capital" (McGinnis and Ostrom, 2014) was expanded into several individual-level sociopsychological variables (i.e., value orientations, social and personal norms, perceived individual control, beliefs about the functioning of the fishery ecosystem, attitudes towards management tools) based on sociopsychological theory (Ajzen, 2005; Stern, 2000; Stern et al., 1999; Vaske and Manfredo, 2012). In fact, Hinkel et al. (2014) previously outlined that the Ostrom framework falls short in acknowledging the importance of individual-level psychological variables for driving actor behavior. As others have demonstrated, the psychology of actors is of high importance in conservation and management contexts (Stern et al., 1999; Vaske and Manfredo, 2012). Therefore, we paid particular attention to operationalizing both higher order contextual variables (e.g., social-ecological context, property rights) in which the decision maker is embedded as well as individual-level psychological disposition. There is a large tradition of sociopsychological studies examining the beliefs, attitudes, and norms of resource users (e.g., anglers, hunters) in fish and wildlife contexts (Decker et al., 2012; Vaske and Manfredo, 2012), but there is almost no quantitative work available on the relative importance of psychology versus social and economic context for environmental decision makers.

The focal action situation modeled is the chosen means of recreational fisheries management, that is, the provisioning of fish (resource units) either for the anglers (actors) to harvest or for population and species conservation. The SES framework designates investment activity as one of many interactions occurring at the level of an action situation, the interplay of which leads to overall system outcomes when aggregated across all interactions in a given SES (e.g., social and ecological sustainability) (McGinnis and Ostrom, 2014). We conceptually treat investment quantities as micro-level outcome metrics (e.g., how many fishes are released each year), which will in turn affect system-level outcomes (which we do not explicitly measure and model).

Two separate but related types of investments to increase the number of resource units available to actors were quantified for this study. The first was direct increase of resource units through fish stocking. Fish stocking, the release of wild captured or hatchery reared fishes to support fisheries, is a common freshwater fisheries management tool (Arlinghaus, 2006), and under some circumstances can deliver substantial fisheries benefits (Lorenzen et al., 2012). Even if fish stocking fails to provide additive effects (Hühn et al., 2014), the fact that local level resource managers stock can be seen as a voluntary decision to invest money to support the fishery and the fish population (Riepe et al., 2017). Fish stocking investment was measured through actual monetary investment (Euros paid toward stocking per angling club member per year) and the ecological intensity of investment (stocking density in kg per ha).

The second type of investment we modelled was indirect increase of resource units through investment in habitat enhancement (Euros paid towards habitat enhancement per angling club member and year). Habitat enhancement, that is, improving habitat quality for fish, or constructing spawning grounds, has shown to be effective to increase natural recruitment in some popular fish species (Nilsson et al., 2013; Roni et al., 2008) and can be employed as an alternative to stocking (Arlinghaus et al., 2016). Habitat enhancement activities to increase fish abundance can also have positive environmental effects, such as increasing the richness of other species (Cowx and Van Zyll de Jong, 2004). Despite stated support from anglers (Arlinghaus and Mehner, 2005) habitat enhancement is today far less regularly employed than stocking (e.g., SI Appendix Table S4), potentially due to political and social constraints (e.g., rules in use, social pressure to stock) or habitat (Arlinghaus et al., 2016; Sass et al., 2017). The reliance on stocking as opposed to habitat management is the source of an ongoing debate among fisheries groups and conservationists because the latter believe inappropriate stocking can harm biodiversity through the release of non-native species or genotypes (Arlinghaus, 2006).

The three measures of resource investment outlined above served as dependent variables in our analysis. The institutional and environmental context differs greatly between Germany and France with respect to angler resource investment in water bodies (SI Appendix Tables S2 and S4). Thus, they were modeled separately. For example, a key difference is that in France habitat enhancement is partially a substitute for stocking-related investment, while habitat enhancement complements stocking density and investment in Germany (SI Appendix Table S2). Other important differences are in the composition of water bodies managed by clubs in each country. French clubs manage proportionately more running waters (SI Appendix Table S4). As still waters are stocked at higher density (consistent with theory predicting higher investment given defined physical boundaries; Ostrom, 2009) and as German clubs manage more still waters, German clubs on average stock at higher densities than French clubs (SI Appendix Table S4). However, average stocking densities into still and running waters were the same, suggesting that clubs in both countries stock with some implicit idea of carrying capacity, lending credence to the consistency and quality of the data from both countries (SI Appendix Table S4).

## 3. Materials and methods

Detailed self-completion questionnaires (Phellas et al., 2011) were designed to measure stocking and habitat investment, and collect information on key angling club characteristics and the characteristics of the club resource manager who filled out the survey in both France and Germany (the full text in English can be found in the supplementary materials). Data were collected from two nationwide representative surveys of angling clubs using the tailored design method (Dillman et al., 2014; details on survey methods and item construction can be found in the supplementary materials). We obtained n = 1222 completed questionnaires from Germany (61.3% response rate) and n = 536 from France (66.4% response rate) from the individual predominantly responsible for decision making and stocking activities in a given club (e.g., the club head or water body manager). Non-response checks showed the data were unbiased (Riepe et al., 2017). Concepts and constructs addressed in this study were operationalized using the SES framework outlined in McGinnis and Ostrom (2014) and questions and items of the administered questionnaire were constructed following standard procedures (Ajzen, 2016; Dillman et al., 2014; Oppenheim, 1992) on an ad-hoc basis or as adaptations from prior related work (Anderson et al., 2007; Arlinghaus and Mehner, 2005). Item and construct relationships were verified with confirmatory factor analysis prior to modeling, as well as checked and transformed to meet normality assumptions and address collinearity in the full models.

Due to the inherent complexity of SESs we expected there may be non-linear relationships, feedback effects, and interactions between second-tier variables and resource investment decisions (Berkes and Folke, 1998; Liu et al., 2007). Recent advances in computing allow for machine learning techniques suited to these situations. Boosted regression trees (BRT) is a non-parametric method relatively new to social science applications, combining decision trees and boosting (Elith et al., 2008; Friedman, 2001; Hastie et al., 2008). BRT analysis is robust to missing data and outliers, and for the most part tends to ignore non-informative variables making model reduction unnecessary (Friedman, 2001).

We implemented our BRT analysis in R (R Development Core Team, 2018) using the package 'gbm' (Elith and Leathwick, 2017; Elith et al., 2008). BRT is a method that combines many simple decision tree models into an ensemble model to improve accuracy that operates in a forward, stage-wise procedure. A new tree is added at each step that reduces deviance, in a stochastic process where a random subset of data are used to fit each new tree (Friedman, 2001). This makes BRTs more robust against overfitting, for example as compared to random forests (Friedman, 2002). To avoid overfitting, using BRTs involves jointly optimizing the number of trees in the model, the learning rate (or shrinkage parameter, the contribution of each subsequent tree to the growing model), and the tree complexity (levels of interactions fitted). The optimal number of iterations was calculated by maximizing the model log likelihood with a 10-fold cross-validation (Elith et al., 2008). As the true interaction structure of the data is unknown, we fit models for each dependent variable for three tree sizes, 1 (i.e., decision stump), 2 (i.e., 2-way interactions), and 5, checked that the cross-validated residual deviance was comparable, and averaged the outputs of these models. The contribution of each variable in each model was calculated using the gbm library and measured by the number of times a variable was selected as a splitting criterion, weighted by the improvement of the model and averaged across trees (Friedman and Meulman, 2003) to indicate the relative importance of particular variables (Elith et al., 2008).

In all models, Federal State (Bundesland in Germany) or Département (in France) was by far the most important explanatory variable (SI Appendix Table S6), though this had little interpretive value as it indicates the trivial result that categorizing by States/ Départements provides the best predictor of differences, without having contextual detail into the drivers of these differences (Müller et al., 2013). Models without Federal State or Département relied on independent variables that provided specifics on what may drive differences, and this also improved the model fit diagnostics of predictive performance either slightly or considerably. Therefore, models without Federal State or Département are presented in the analysis. Only variables with model importance greater than would be expected due to chance given the number of variables in the model were retained. Marginal effects plots over the parameter space of independent variables were reviewed for directionality of relationships, and select plots are included in the SI Appendix.

We also employed linear mixed-effects models (Gelman and Hill, 2007) to supplement the findings of the BRT models, but under the restrictive assumption of linear relationships between independent and dependent variables, with no interactions between independent variables. The linear mixed effects models allowed a hierarchical nesting of clubs within relevant administrative units (i.e., State or Département), as well as a more streamlined summary of directional effects (compared to the marginal effects plots of a BRT analysis). Linear mixed models (LMM) were run for each of the three dependent variables in each country separately. Pairwise correlation plots for all variables were carefully inspected, and where necessary variables were constructed from the residuals of correlated variables. All models were tested for collinear variables using generalized variance inflation factor (GVIF) scores, and for all models all variable scorings were below the cutoff of 3 (SI Appendix Table S14), indicating collinearity was not an issue (Zuur et al., 2009).

There were a number of questionnaires with missing values, and while the number of complete case questionnaires still yielded a larger sample size of independent management arrangements in replicated natural resource management systems than currently exist in the literature, we wished to take advantage of the full range of available data. The incomplete questionnaires had only a few items without responses, so we imputed missing values as item mean imputation for independent variables – a method that has been shown to perform as well as more complex imputation methods especially with a low number of missing values (Shrive et al., 2006; van der Heijden et al., 2006), and has as a potential drawback biasing coefficients towards zero and non-significance (Donders et al., 2006). Thus, we selected it as a conservative choice. We discuss only those variables that are significantly related to the dependent variable at the $p < 0.05$ level on both models, or at the $p < 0.05$ level on one modeled dataset and $p < 0.1$ on the other.

To assess goodness of fit, LMMs were fit by maximum likelihood in the statistical environment R (http://cran.r-project.org) using the package *nlme* (Pinheiro et al., 2016) to construct McFadden's Pseudo $R^2$ values (McFadden, 1978), as restricted maximum likelihood (REML) cannot be used to compare models with differing fixed effect structures (Zuur et al., 2009). McFadden $R^2$ values from 0.2 to 0.4 are considered "excellent" (McFadden, 1978). McFadden's Pseudo $R^2$ values for the complete-case German data were very high (between 0.58 and 0.62 for all three models) and was still excellent though lower as is expected with the inclusion of imputed means (0.33–0.43); French data were similar with models fitting complete case data having $R^2$ values from 0.58 to 0.69 and imputed data from 0.21 to 0.30 (SI Appendix Table S7). Plots of residuals versus fitted values were visually inspected for deviations from homoscedasticity; none were found. Linear models with Federal State (German) or Département (France)-level fixed effects were also fit to check normality assumptions. Final models were fit using REML using *lmerTest* (Kuznetsova et al., 2016) in R. Residual versus fitted plots were checked for heteroscedasticity and Satterthwaite approximations to degrees of freedom were used to conduct t-tests on model fixed effects with an $\alpha$ cutoff of $p < 0.05$ for rejection of the null hypothesis (Tables S8–S13).

## 4. Results and discussion

We demonstrate that operationalizing the Ostrom SES framework to the specific action situation of natural resource investment in freshwater fisheries has immense practical applicability to understand natural resource management decisions by members of civil society. As highlighted by BRT analysis (Fig. 1), a key finding is that the environmental and social context, rather than the psychological disposition of the decision maker, contained the most relevant variables associated with resource investment decisions by angling clubs in both France and Germany. The relative influence of variables from the BRT analysis indicates the strength of the effect (Fig. 1; size of circles). The direction of the effect can be discerned from marginal effect plots for individual variables from the analysis (SI Appendix Fig. S2, S4). More concise indications of the direction of effect can be viewed from the LMM analysis, though this analysis is not equivalent to the BRT and relies on more restrictive assumptions (Fig. 2; SI Appendix Fig. S3). We present these two analyses together to show the overall robustness of the results to model specification.

Overall, results matched expectations arising from economic theory and empirical knowledge of stocked fisheries systems (Welcomme, 2001). Resource system size in terms of area managed by each club (RS3) was negatively associated with stocking density and investment (SI Appendix Fig. S3). By contrast, and also consistent with theory, the availability of club funds (RU4; proxy for economic status of a club) were associated with increased stocking density and investment (SI Appendix Fig. S3 and S4). Individual clubs managed a mix of enclosed water bodies (i.e., lakes and ponds) as well as sections of running water (i.e., streams and rivers). Clubs stocked higher biomass densities into enclosed water bodies (i.e., systems with clearly defined ecological boundaries) in both Germany and France, despite French clubs managing a much higher proportion of running waters and having a club culture more focused on stocking salmonids into riverine ecosystems (Table S4). Salmonids are more expensive than other stocked species, and because of this, French clubs managing a higher proportion of enclosed vs running waters had a lower monetary investment into stocking as French clubs stock proportionally more salmonids into running waters (Fig. S3). Importantly, habitat investment in France was higher in clubs that managed a larger proportion of water bodies with well-defined ecological boundaries, i.e., enclosed stillwater fisheries (Fig. S3). Therefore, the overall investment into local fisheries, independent of the prices of stocking material, were generally more intensive the more clearly the ecological boundaries were in both France and Germany. Similarly, for all types of investments, we saw more investment into water bodies with more exclusive property rights; that is, with decreasing access for non-club members to free-ride off the investments made by clubs (SI Appendix Fig. S3 and S4).

The number of relevant angling actors (A1 number of actively fishing club members per ha), which can be related to the intensity of resource use as well as social interactions (Casari and Tagliapietra, 2018), was positively associated with fish stocking density and habitat investment in Germany, and negatively associated with monetary stocking investment in both Germany and France (Fig. 2, SI Appendix Fig. S3). This indicated that with increasing intensity of resource use clubs boosted stocking density possibly to increase club member satisfaction, though an alternate explanation is that higher stocking densities attract more members to a club (Dabrowska et al., 2014). At the same time, the managers decreased the monetary investment per angler, thereby suggesting the clubs engaged in stocking less expensive species.

Together, these findings on resource system and economic characteristics are consistent with previous empirical work that found lower fish stocking investments given larger resource system areas (Welcomme, 2000), reported lower likelihood of resource investments in systems with less clearly defined boundaries and higher transaction costs (Cox et al., 2010; Ostrom, 2009), and demonstrated economically rational behavior of maximizing returns given budget constraints (McFadden, 1980).

In terms of social and governance variables, increased club influence on decision making, as opposed to decisions being strongly influenced by external governance bodies (e.g., fisheries agencies) (GS3), was associated with increased stocking density and investment in both countries (SI Appendix Fig. S2), consistent with expectations of increased investment given increased operational choice by resource users (Ostrom, 2009; van Poorten et al., 2011). Overall, we find support for the general and theoretically consistent pattern of increased resource investment into predictable systems with clear boundaries and increased ownership (Table 2; SI Appendix Fig. S2).

As discussed earlier, stocking could be viewed as a positive investment into natural resource sustainability by an avid group of people in civil society. The decision of whether and how much to stock is a micro-level outcome, a fast feedback that connects to slower and systemic macro-level outcomes such as social, economic, and ecological sustainability (Table 1) (Arlinghaus et al., 2017). While social sustainability and cohesion in a club may be supported by intensive stocking, the continued reliance on stocking by angling clubs may in fact have negative impacts on economic and ecological sustainability in club social-ecological systems. For example, indiscriminate stocking and reliance on non-local populations can pose a relevant ecological and genetic risk (Arlinghaus et al., 2015; Lorenzen, 2014), which can even threaten wild fish with extinction (Laikre et al., 2010; van Poorten et al., 2011). Further, stocking in many conditions fails to provide additive effects to increase the population of fish above natural recruitment (Arlinghaus et al., 2015; Hühn et al., 2014; Johnston et al., 2018), which can be both economically wasteful and create risks for genetic diversity. By contrast, increased investment into habitat enhancement

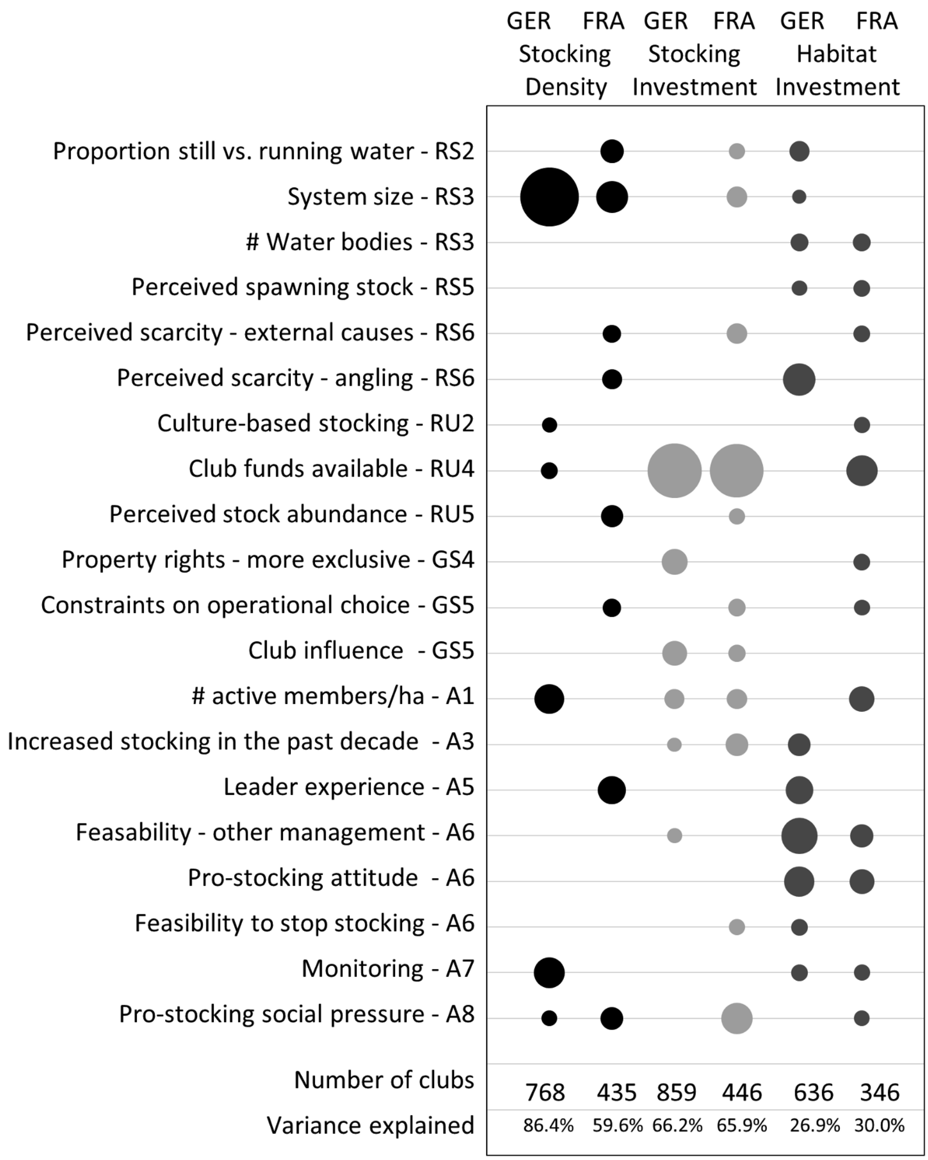


**Fig. 1.** Most important second-tier variables by relative contribution at predicting natural resource investment from boosted regression tree models. The size of the circle indicates the relative importance of the variable for the given model as compared to all other variables in the model. Variables influential in more than two models are illustrated here. The number of discrete management arrangements and the variance explained by each model are shown at bottom.

can have both fishery (e.g., through increased recruitment) and environmental benefits, contributing to ecological and economic sustainability (Cowx and Van Zyll de Jong, 2004; Nilsson et al., 2013; Sass et al., 2017). Thus, though stocking can be an intensive environmental investment, increased stocking density is not necessarily desirable for macro-level sustainability outcomes.

Within each country separate but related stories emerged about resource investment into stocking, with a theme of internal path-dependence of club behavior in Germany, and of externally constrained managerial control in France coupled with strong internal club social pressure towards stocking; both processes perpetuate intensive stocking investment. In Germany a few largely economic variables dominated in importance, and the BRT models indicated that the size of the managed system (RS3 negative relationship) and funds available to the club (RU4 positive relationship, in Germany equivalent to the amount anglers pay to be club members, related to economic value of the resource) were central to all resource investment decision making (Fig. 1, Fig. 2). German clubs also stocked at high densities and invested more money into stocking if they had a history of increasing their stocking amount in the last decade (A3 history or past experiences), and if they stocked more culture-based species (i.e., species that do not naturally recruit) (RU2) (Fig. 1, Fig. 2). These relationships indicate that both legacy and path-dependence with positive feedbacks (if one engages in stocking, one tends to continue the practice) were key drivers of stocking behavior in Germany.

In France, the BRT results for relative explanatory contributions of second-tier variables initially showed the only important explanatory variable as Département (SI Appendix Table S4). This, as discussed earlier, indicates that strong differences exist between Départements, without providing explanatory power on the reason for these differences. Départements (through the Fédérations Départementales) are also fishery management units in France composed of many clubs, that differ broadly and consistently in their practices. In some Départements, management strategies are de jure and de facto defined at the Département level and applied by all clubs within the Département, while in other Départements collective strategies are not clearly applied and club decision making is more independent. When Département was removed from the models, model fit improved, indicating that the second-tier variables included in the model were informative and had greater predictive power than Département alone. Instead of few

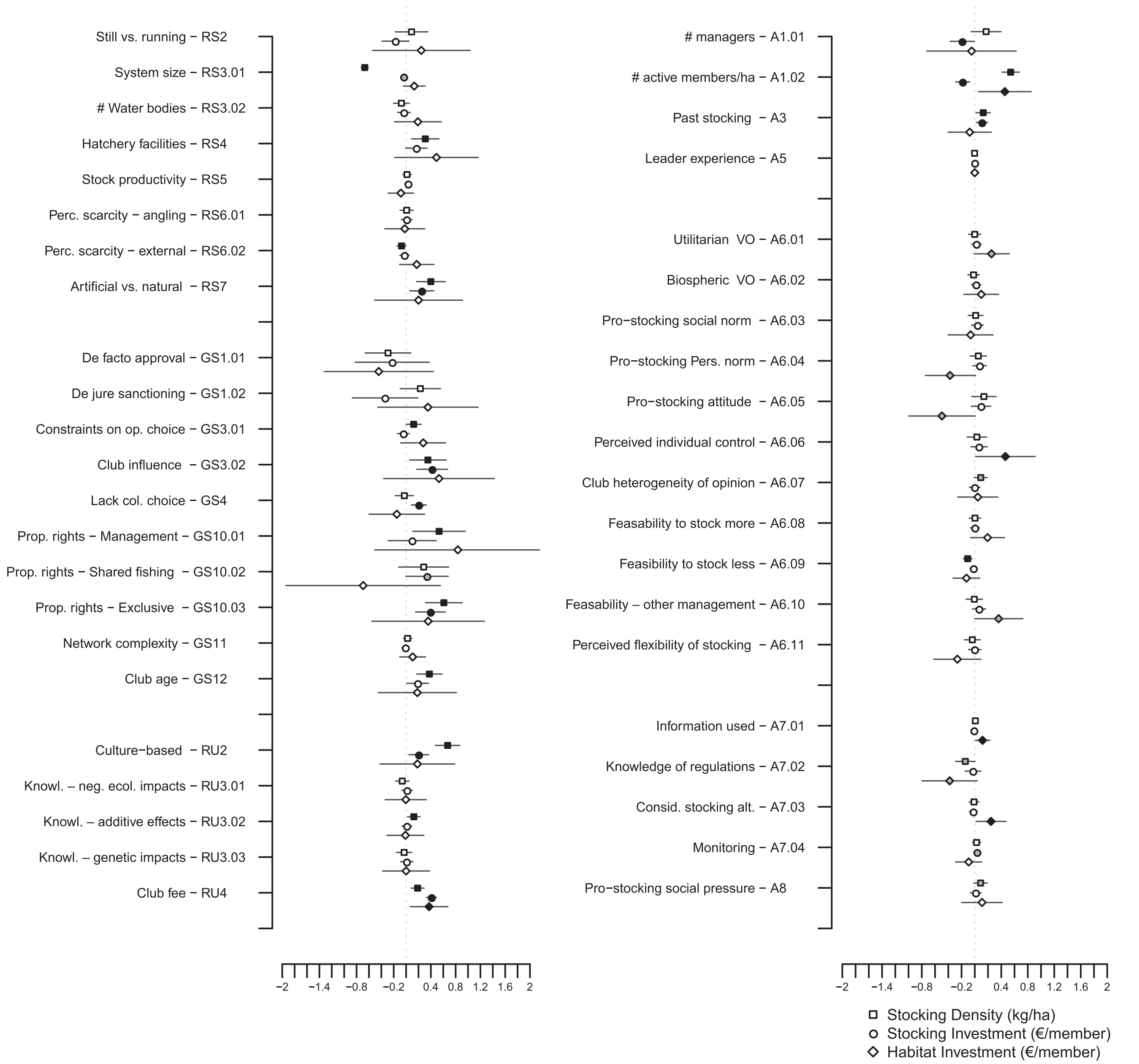


**Fig. 2.** Plots of hierarchical mixed model coefficients 95% confidence intervals for the influence of second-tier variables on stocking density (kg/ha; squares), stocking investment (euros/member/year; circles), and habitat investment (euros/member/year; diamonds) in Germany. Results from both Germany and France can be found in the supplementary material (Fig. S3). Coefficients significantly different from zero at the $p < 0.05$ level are colored black; $p < 0.1$ are colored light grey.

variables with high explanatory power as in the German case, we see many variables with small to moderate importance, indicating a strong impact of "country" or more generally culture on our study findings (Fig. 1). The exception was the relevance of club-available funds, which in the French case, unlike the German case, are controlled by the Départemennt. In Germany, club membership fees are dictated by the clubs, while in France they are the same for all adults. Fees are paid to each Département, which in turn gives back some percent to the club after taking a portion for tax and the Département agency; the amount given back to the club is highly variable between Départements. Interestingly, perceived behavioral control (A6) by club resource managers was ranked of lower importance to guide stocking in France than in Germany (SI Appendix Table S3), which does not reflect the de jure reality. German clubs face numerous stocking regulations (though there is little actual enforcement; Arlinghaus et al., 2015) and can be obligated by management contracts to stock. By contrast, in France there are fewer regulations governing stocking and clubs likely have more flexibility in their decisions in France than in Germany. However, in practice many follow the strategies established at the Département level. All of these factors account for the strength of the Département in influencing investment behavior in France.

Beyond the overarching governance and economic contextual variables that dominate stocking decision making across the two countries (i.e., funds available, system size, and active anglers per hectare of managed system), the next three most important variables across the different contexts and different measurements of investment (as ranked by their influence across multiple BRT models, as well as importance within individual models) show the importance of the social environment of the clubs in both France and Germany. The presence of pro-stocking social pressure (A8), whether the respondent feels

**Table 2**
Descriptive summary of variables associated with different investment outcomes drawn from examples from both countries.

| | Socio-economic and governance variables | Club context and actions | Decision maker perception of social atmosphere | Decision maker knowledge and psychological disposition |
|---|---|---|---|---|
| **Increased stocking density** | Smaller system size, club has strongest influence on decision making, higher density of active anglers | Past history of increased stocking, stock a species that depends on stocking (cannot recruit naturally) | Pro-stocking social pressure, decision maker does not feel they have the leeway to employ other methods than stocking | Knowledge that stocking may not result in additive effects above carrying capacity, lower leadership experience |
| **Increased stocking monetary investment per angler** | Smaller system size, club has strongest influence on decision making, Lower density of active anglers | Past history of increased stocking | Pro-stocking social pressure, decision maker does not feel they have the leeway to employ other methods than stocking | |
| **Increased investment into habitat enhancement** | Higher density of active anglers | No past history of increased stocking, more rigorous monitoring | Lack of pro-stocking social pressure, decision maker feels they have the leeway to employ other methods than stocking | More leadership experience, less favorable attitude towards stocking |
| **All investments** | More exclusive property rights, more available club funds, well-defined physical boundaries, have a hatchery | | | |

it is feasible to apply other management measures than stocking (A6), and whether the club has a history of increasing stocking in the recent past (10 years; A3) were all highly important in the decision to stock at higher densities and invest more funds into stocking (Fig. 1). Social pressure in a club to engage in stocking (A8) was an influential determinant of stocking in both countries, but particularly in France (Fig. 1, SI Table S3), corroborating previous qualitative (van Poorten et al., 2011) and quantitative findings (Riepe et al., 2017) and correlating positively with increased stocking density and monetary investment in stocking (SI Appendix Fig. S2).

As with stocking density and investment in Germany, club funds, system size, and number of active members were also important predictors for habitat investment (Fig. 1, Fig. 2). By contrast, in the French case there were many variables with a lesser degree of influence on habitat investment. What was consistent between countries, however, is that when social pressure towards stocking was lower, when it was believed to be more feasible to manage in other ways than stocking, and when there had been less of a history of stocking in the past decade, clubs invested more in habitat enhancement. This can be seen in SI Appendix Fig. S2c: when respondents felt they have the flexibility to stop stocking (A6) they invested more heavily in habitat enhancement, but where they felt they lacked the flexibility they stocked at higher densities and invested more into stocking (SI Appendix Fig. S2).

Leadership experience of the respondent (A5) was one of the variables of importance on the level of the decision maker completing the questionnaire. Leadership has been identified as an important variable in previous SES framework studies of management arrangements of common pool resources, including small-scale fisheries (Gutiérrez et al., 2011; Meinzen-Dick, 2007; but see Brooks et al., 2012; Cinner et al., 2012). We found leadership experience to have a less prominent influence on stocking, compared to the other economic, governance and social contextual factors mentioned above (Fig. 1, SI Appendix Fig. S4). However, the BRT analysis indicated that in France decision makers with less experience were associated with stocking at higher densities, and in Germany and especially France more experience was associated with higher investment into habitat enhancement (SI Appendix Fig. S4).

As highlighted earlier, stocking fish is the default management action in Germany and France and thus is under strong control by social norms. When club resource managers believed they had agency to be flexible with management, they chose to do so and stocked less. This is corroborated by focus group discussions with club managers in both countries, who have expressed knowledge of some of the ecological and genetic risks of stocking, and the lack of additive effects of stocking into naturally recruiting populations (Fig. 2; Table 2) (Araki et al., 2007; Hühn et al., 2014; Lorenzen et al., 2012). However, they continue to stock because they feel that their club members expect them to stock (von Lindern and Mosler, 2014). This is further supported by our results concerning the number of types of ecological monitoring activities (A7) performed by a club to track effects of management measures on fish stocks. Monitoring has a strong influence on stocking density in Germany (Fig. 1), yet the marginal effects are weak and directionally unclear (SI Appendix Fig. S4). This is likely due to the mixed success of stocking for stock enhancement. There is nearly no explanatory power of monitoring on stocking in France (SI Appendix Fig. S4). In contrast, monitoring activities are influential and are positively correlated with habitat enhancement in both Germany and France (Fig. 1, SI Appendix Fig. S4). This indicates that even when club members are tracking the success of stocking measures, they do not have the flexibility to adjust stocking. Thus, across the two countries, managerial choices were shaped most strongly by the broad characteristics of the resource system and its socio-economic and governance attributes, while agency and flexibility were key to changing the managerial status quo, in this case from stocking to habitat enhancement. These results suggest that once top-down and bottom-up pressures encouraging stocking are alleviated, decision makers can invest more into habitat investment.

There is a broad literature on the importance of psychology

(Saunders et al., 2006; Stern, 2000; Swim et al., 2009) and environmental education (Hungerford and Volk, 1990; Jacobson et al., 2006; Stapp, 1969) to influence pro-environmental behavior. Yet surprisingly, we find that psychological constructs and environmental knowledge metrics of the club resource managers had relatively weaker importance regarding actual resource investment behavior, particularly when it comes to stocking (Fig. 1). Economic, social and governance context appears to exert a stronger influence than knowledge and sociopsychological disposition when it comes to decisions on resource investments. The strongest psychological or ecological knowledge variables with substantial explanatory power in our study related to social norms and pressure, that is, what the decision maker believed club members thought their behavior should be as resource manager. By contrast, individual perception of ecological or genetic risks of fish stocking and ecological understanding about the success probability of stocking appeared to have no influence on the actual stocking decisions. The only sociopsychological variable that showed influence on management decision making was a pro-stocking attitude, which was positively related to stocking investment in France, and negatively related to habitat investment in Germany (i.e., an unfavorable attitude towards stocking was associated with elevated habitat investment). In both cases, however, there were limited respondents with unfavorable stocking attitudes (SI Appendix Table S3). With this exception, clubs that stocked heavily did not appear to consistently have decision makers with pro-stocking orientations or specific beliefs in the functionality or ecological risks of stocking; instead their behavior was largely driven by ecological and economic context, social pressure, and governance structures, e.g., the type of fishing right in place that governs the management sovereignty of the local angling community. This lack of explanatory power of individual psychological variables, as well as the influence of social norms may indicate that respondents are following organizational values, irrespective of their personal preferences. Organizations have values, and these values shape and constrain the decision makers who are at the helm of these organizations (Manfredo et al., 2017a, 2017b). If the individuals comprising an organization, and the organization itself is pro-stocking, this would devalue the explanatory power of psychological variables measured at the level of the decision-makers themselves, on stocking-related behavior.

Our results highlight how the social-ecological and governance environment determines what behavioral options are available, while the social environment determines which of those options are most attractive (stocking vs habitat management), with psychological beliefs and ecological understanding of the decision maker being surprisingly of smaller influence on what environmental decision makers in angling clubs do. Instead, the social-ecological context strongly shapes operational decision making in ways that appear unaffected in a systematic way by individual preferences and dispositions at the level of the decision maker. This is relevant given the importance accorded to educational interventions targeting enhanced ecological understanding and psychological constructs in the conservation psychology literature (Byerly et al., 2018; Kollmuss and Agyeman, 2002), which according to our research will not strongly affect the intensity of stocking shown by environmental decision makers in voluntary angling clubs. This is not to say that interventions have no value; in fact participatory learning processes can have striking effects on pro-environmental behavioral intentions and reduce the intention to engage in stocking (Fujitani et al., 2017) and may alter mental models about aquatic ecosystem functioning (von Lindern, 2010). If conducted broadly with club members, this could contribute to changing the culture of the clubs and alleviating the pressure to stock. However, current practice is to provide regular trainings and environmental education only to the decision makers. Thus, higher order economic and governance constraints may still mean that despite increased learning (e.g., about the ecological risks of stocking) or altered psychological cognitions (e.g., norms related to stocking), decision makers are limited in what actions they can freely chose.

Ostrom (2005, 2009) noted that with hierarchical governance structures in common-pool resource management, higher-level governance can support or destabilize SESs depending on which contextual conditions are developed. Against this background, we provide an example of how higher order structures can substantially guide the resource investment behavior of environmental decision makers in two countries, with room to perpetuate the system onto either sustainable or unsustainable trajectories. For example, our study shows that angler communities with funds and sovereignty to decide about fish stocking are associated with intensive investments into stocking, and real-world examples show that in the presence of such a favorable context, stocking behavior can emerge (e.g., Rosenberger et al., 2004). Our models of the factors associated with stocking and habitat enhancement can be of use to policy makers to either develop situations amenable to such behavior, or to identify regions where intensive stocking can be expected, to design other institutions to channel activities in sustainable directions. This can be non-trivial to resolve, as those in power are frequently reluctant to permit a change in the status quo (Ribot et al., 2006). Thus, increased policy focus is required on the contextual factors that may be the strongest impediments to sustainable behavior.

To conclude, our work demonstrates the immense value of the Ostrom SES framework to provide insights from outcome metrics for specific action situations. Our operationalization of the SES framework allows us to understand drivers of both stocking and habitat investment, which can help shape policy levers that can differentially influence each, to lead systems towards ecologically, economically, and socially sustainable trajectories. Our results provide insights into natural resource investment that are broadly applicable across Germany and France, as well as specifically germane to each individual country given the distinct ecological, social, cultural, and economic characteristics of each. We find that incentives set by environmental, governance and economic contexts are behaviorally more relevant than pro-environmental psychological disposition and environmental knowledge in driving resource investment decisions, but that the type of action (fish stocking or habitat management) and the culture of a country or type of fishery (e.g., whether a fish stock is culture based or naturally recruiting) moderates this effect. Specifically, the psychology of the decision maker in relation to functional beliefs, attitudes and personal norms appeared more powerful when deciding about habitat management than it was when deciding about releasing fish to support fisheries. Therefore, we can conclude that both context and psychology drive resource investment decisions, but contextual conditions setting economic constraints appear more powerful in general and with relevance to stocking. Further work on testing the systematic impact of governance, economic, social and psychological variables following the Ostrom SES framework is needed to understand whether our findings can be generalized towards other SESs.

## Author contributions

M.F. and R.A. conceived and designed the study; T.P., J.C., M.B., F.S., R.L, R.A. collected the data; M.F. and R.A. performed the research; M.F. and C.R. compiled the data and contributed analytical tools; M.F., C.R. and R.A. analyzed the data; and M.F. R.A., C.R., and J.C. wrote the manuscript.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary Materials

Supplementary materials for this article can be found online at https://doi.org/10.1016/j.gloenvcha.2020.102125.

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