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# Averting Depletion in a Two-Player Common Pool Resource Game: Being Seen, the Expectation of Future Encounters, and Biophilia Play a Role in Cooperation

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**Abstract**

Using a two-player common pool resource game, we investigated the influence of multiple factors on cooperation: (1) probability of future rounds, (2) visibility of other participants, (3) biophilia, (4) future discounting, and (5) life history. In each round, participants simultaneously and independently (without conferring) decided how much of the common pool to consume. Participants ($n = 116$) were informed that the shared resource would be fully replenished in the next round—but only if—both players together consumed $\leq$ 50% of the common pool in the current round. Additionally, participants were told the probability (0–100%) of further rounds of play with the same player (this probability was not real; it was purely to manipulate the player's expectations). To assess the effect of the probability of future rounds, we developed a mathematical model to predict the threshold that would permit a Nash Equilibrium of Conditional Cooperation (CC). To manipulate visibility, half the pairs were tested in the same room (seen condition) and half in separate rooms (unseen condition). To measure biophilia, the "Nature Relatedness" (NR) scale was used. To measure future discounting, the "consideration of future consequences" (CFC) scale was used. To measure life history, the participant's UK postcode was obtained (indicating possible residence in a deprived neighbourhood). Participants in our study were not paid. In our results, there was a significant effect showing more cooperation in the visible than not visible condition, but no significant effects of NR, CFC, nor postcodes (but NR was significant in interaction with visibility). For predictability of future rounds, we found a number of significant effects using different tests. A notable result was that there was significantly more CC when the probability of future rounds was $\geq$ 69% (congruent with one of our model predictions).

**Keywords** Common-pool resources · Laboratory experiments · Cooperation · Nash equilibrium · Future discounting · Biophilia

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## 1 Introduction

When you catch a fish in the sea, it leaves one fewer fish for someone else to catch [15, 54]. A patch of open-access water is easy for a fishing boat to enter. Hence, it is an example of a "common-pool resource" (CPR) [15, 21, 54, 56]: where it is difficult to exclude appropriators (e.g. fishing boats) from an area with a depletable resource (e.g. fish stock). The tragedy of the commons [29, 55, 63] occurs when a group of self-interested appropriators take too much, causing the depletion of the resource (case study: [21], pp. 347–349), a depletion which might be permanent [15]. Overconsumption most likely occurs when the resource itself is valuable and there are no constraints imposed by an external institutional body [54]. Overfishing is just one example. Other examples include: the consumption of fresh air resources (e.g. pollution through vehicle use, transport/ travel decisions and energy usage), the generation of waste (e.g. recycling behaviour, use of plastics, littering); and consumption and economic decisions (e.g. consumption of endangered/ threatened species, destruction of habitat, patronage of environmentally damaging organizations). In CPR problems, the appropriator has an incentive to overconsume (e.g. to overfish—creating the conditions of a *social dilemma* [11, 40], van [74]: "tension between what is good for the individual and what is good for the population" [61], p. 413). The crux of the problem [11] is that the *instant* payoffs of defection (e.g. overconsumption) seems always more attractive than the *delayed* payoffs of cooperation (e.g. limiting one's consumption). Moreover, the consequences of defection may seem too far in the future to be of concern [41]. In dilemma situations, actions are typically *distal* to the consequences. Think of a person who fails to recycle a plastic bottle. That person is likely unaware that more than 250,000 tonnes of plastic debris are floating in our oceans [16] and, consequently, that microplastics are found in fish consumed by humans [65]. Humans eating plastic is a *distal* consequence of a human discarding a plastic bottle. To most people, that causal link is unseen and anonymous.

Each appropriator is an individual person. Because of the distal consequences, that person might be myopic in their decision-making—focussed on self, perhaps not understanding that they are operating within a social dilemma situation [11]. Even if that person *does* understand, then it is possible that some extent of overconsumption seems a justifiable strategy ("I take too much because I need it"). How do you solve the tragedy of the commons when appropriators feel so little incentive to refrain from overconsuming? One way to investigate real-world CPR problems is "to study a simplified version in an experimental laboratory" [54], p. 150), a methodology which allows close scrutiny of the appropriator's behaviour. Experiments allow a focus on the core decisions that are foundational to real-life CPR problems [2]. In one early study (see [21], pp. 350–354), the participants were given tokens at the beginning of the game and given the opportunity to anonymously invest their tokens in an unregulated, simulated, marketplace (consisting of 7–8 players). In the CPR condition, the return on investment ("rent") was dependent on the total number of tokens donated by all players in the game. Comparing the results of experienced versus inexperienced players, the former group appeared to play more strategically (better understanding the dynamics of the CPR problem) than the latter group. In studies like these (and behavioural economics in general), there is always individual variation in the way that players play: see [56], pp. 659–661): individuals have their own backgrounds, their own norms, and their own way to reacting to the context of the game environment. In our study, we focussed on personal characteristics in a CPR game as a way of exploring the influence of individual background on appropriation decisions [41]. Here, we chose four predictors: (1) life history, (2) future discounting, (3) residence in deprived community, and (4) biophilia. We conjectured that all four would influence consumption decisions.

The predictor of "life history" [44, 75] has its roots in what was originally a zoological framework to allow different species of animal to "be classified along a fast–slow continuum, with high reproductive rate and low survival at one end versus slow reproductive rate and high survival at the other end" ([44], p. 3951). For example, rodents are "fast" species because they reproduce *quickly* and live a *short* life [70]. In contrast, elephants are a "slow" species because they reproduce *slowly* and live a *long* life [3]. *Life history theory* is a way of studying evolution [37, 71]. In this context, a slow life history or a fast life history are both definable as a "strategy" [75]. In our study, we are not focussed on evolution. Instead, we follow more recent literature which applies the fast-slow continuum to *human life cycles*. For example, Pepper and Nettle [58, 59] posited that humans with deprived upbringings tend to adopt strategies consistent with a faster life history strategy (such as having children at a younger age than people who are not deprived). This is because people in a lower socio-economic status (SES) tend to face an uncertain future. In this context, it is rational to focus more on the present than the future ("future-discounting", our second predictor). Accordingly, we made the conjecture that participants with deprived backgrounds are more likely to overconsume in a CPR game. The tendency of individuals to discount the future is considered a contributing factor to various individual and societal challenges [74]. To identify those future-discounting participants, we used the "Consideration of Future Consequences" (CFC) scale [72], which provides a convenient metric to assess the extent to which individuals prefer a lesser immediate reward to a delayed greater reward [6]. In a study by Kortenkamp and Moore [41], participants with high scores on the CFC scale cooperated more than participants with low scores in a resource dilemma game (even in treatments when the consequences of defection were described as uncertain and far in the future). In our study, we also collected data on the participants' current or recent UK postcodes (showing the location of residence). UK postcodes are a useful index of deprivation [47]. Here, we presumed that participants resident in deprived areas will adopt faster life history strategies. Next, the predictor of "biophilia" is based on the biophilia hypothesis [76] which suggested that human beings have an instinctive need to connect with other living things [38]. Although in modern times humans mostly reside in cities, distal from natural environments, it is unlikely that the importance of nature embedded in human biology has been erased [30, 36, 50, 74]. In our study, we conjectured that higher levels of biophilia should mitigate against overconsumption in a CPR game, based on the idea that high-biophilia individuals should have greater awareness of human impacts on nature (however distal that nature is), and consequently adopt fairer strategies in a social dilemma situation. Here, we used the NR-6 nature relatedness scale [50].

Beyond the study of personal characteristics, we investigated two additional predictors. These predictors were related to the structure of the game itself: (1) probability of future rounds, and (2) visibility of other participants. First, for the "probability of future rounds", we deliberately added *uncertainty* into the game: we created a situation where the participant did not know how long the game would last. Uncertainty has been shown in previous studies to have a significant impact on cooperation. Duffy and Ochs [14] found that cooperation increased when the probability of another round of play was higher, momentarily decreasing uncertainty. Kortenkamp and Moore [41] found that participants cooperated more when the consequences of resource depletion were described as "high probability" (more certain) rather than "moderate probability" (less certain). Next, for the predictor of visibility, we partitioned our sample into "seen" and "unseen" conditions (where participants were either face-to-face with the other player, or in separate rooms not seeing each other). Anonymity is a further dimension that can be modelled through economic games. As shown in experimental studies (e.g. [46], as well as computer simulations [52]), anonymity plays a role in the occurrence of cooperation towards the use of a CPR (see [2], potentially due to the reputational consequences of being seen not to cooperate [25, 45, 67]. Research has shown that when there are opportunities for the formation of reputation, the level of cooperation significantly increases [18]. Reputation can be developed through direct or indirect interactions, thus, collecting information about another individual [1, 66–68]. However, some studies have found that cooperation can also occur in circumstances of total anonymity, with individuals who have no information regarding others' actions behaving cooperatively in one-shot games [23]. Although these are striking results, since—theoretically, cooperation is highly irrational (self-defeating) in such conditions—it also raises another question: what happens when individuals interact repeatedly, hence, having information regarding others' actions, but never seeing each other and not knowing their identity (e.g. name or appearance)? In fact, such circumstances can be observed in real life, where people see the *results* of others' appropriation behaviours of a common good, but have little or no knowledge of the individuals that made those prior appropriations.

To understand how people make decisions in their behaviours and decisions in relation to distally distributed CPR resources, we report here the findings of an empirical study using an appropriation game developed by the authors. We assess the influence of five factors altogether. The first involves a comparison of the behaviour of participants during an iterated version of the appropriation game to the strategies prescribed by an analytic solution to the game (shown in Appendix C), proving the existing Nash Equilibrium (NE) [49] strategies that rational players could adopt. We assess the degree of convergence/ divergence from equilibrium strategies. Studies have shown that indefinitely repeated games can produce more reliable results when investigating CPR dilemmas. For example, Dal Bó [10] conducted an experiment aimed at understanding the difference between indefinite and finite games. He investigated the effect of the shadow of the future in a controlled environment and gathered insights regarding the influence of payoff matrix on players' behaviour. To do so, Dal Bó [10] used a common PD game (Prisoner's Dilemma, see [7]), where players choose whether to cooperate or defect in each round. He set up two different conditions—one where participants knew exactly how many rounds were going to be played (1, 2 or 4) and a second one, where the game became indefinite due to a dice that was rolled at the end of each round in order to determine the continuation probability of the game ($\delta = 0$, $\delta = 1/2$ or $\delta = 3/4$). Moreover, there were two additional conditions, where the payoffs changed slightly (these were called PD1 and PD2)—the main difference was that for probability $\delta = 1/2$, the equilibria in PD1 were DD, CD, and DC, whereas in PD2 the equilibria were only DD and CC. Dal Bó [10] found that players cooperate more in the indefinitely repeated version of the game compared to the finite one. Furthermore, findings support the theoretical assumption that a greater shadow of the future results in higher cooperation between individuals, indeed, participants cooperated significantly more in $\delta = 1/2$ compare to $\delta = 0$ and when was $\delta = 3/4$ compared to $\delta = 1/2$. Finally, payoffs matrices seem to have an effect on people's decisions. Dal Bó [10] found that in PD2, where CC was one of the equilibria, there was higher cooperation than in PD1, where CC was not an equilibrium. Analogously to Dal Bó [10], the current study uses an indefinitely repeated game that has a similar structure of the PD but with a different payoff matrix. Nevertheless, Dal Bó [10] uses only three different probability conditions to represent the shadow of the future ($\delta = 0$, $\delta = 1/2$ or $\delta = 3/4$), while the current paper applies a total randomised system of probability that ranges from 0 to 100 per cent in each round (see Methods).

The second factor in our study was visibility [2]: to compare the behaviour of players between games where the opponent can be seen (sitting in the same room) and where the opponent cannot be seen (sitting in different rooms). The remaining factors in our study relate to the psychological and life history traits that may influence the use of cooperative or self-interested strategies: participants' "biophilia" connection to nature (third factor), tendency to discount the future in favour of present rewards (fourth factor), and calibration to harsh and unpredictable environments (fifth factor). The following predictions were made for the above aims: First, participants would conditionally cooperate—cooperating when the other player cooperated and defecting by destroying the resource when the other player defects—when the probability of another round was sufficiently high. The analytic solution showed an NE of conditionally cooperating when the probability of a further round was 11/16 (~ 69%). Second, participants would show more cooperation in the "seen" vs. unseen condition (cf. [2]). Third, those who score high in nature relatedness would play sustainable strategies—defined as conditionally cooperative strategies that do not overuse the resource and sustain the game over multiple rounds. Fourth, individuals that discount the future less steeply will play more sustainable strategies. Fifth individuals who live in more deprived areas will experience greater cues of environmental stress and this will influence resource allocation strategies. Behaviourally this will result in individuals from stressed/ deprived environments playing less sustainable strategies. Finally, we predicted that those who live in stressed environments will also discount the future more steeply [58, 59]. Importantly, we also mention that we were not able to pay our participants (see Methods).

In our study, broadly speaking, we found good support for two out of five factors. In Table 1, we can see that the first factor was investigated using eight different analyses. Participants demonstrated a significant departure from the predicted Nash equilibrium proposed by the analytic solution, challenging the assumption of self-interested behaviour. Cooperation, represented by the strategy CC, was more prevalent than expected, constituting 26% of all plays. The study revealed a non-significant effect of probability on players' strategies, contrary to predictions that players would exclusively choose defections when the probability of another round was below a certain threshold ($\rho < 0.69$). The observed frequent cooperation suggested a conditional cooperative strategy. Notably, participants adopted a strategic approach favouring Pareto Efficient CC when the probability of another round was $\rho \geq 0.69$, indicating a conscious effort to maximise individual payoff rewards while maintaining a sustainable strategy that does not harm the resource base. Despite expectations, nature relatedness (NR) did not significantly influence consumption or cooperation, with the non-significant finding attributed to potential ecological validity issues in the laboratory setting. The visibility condition (Seen/Unseen) significantly impacted behaviour, with the Unseen condition, featuring anonymity, leading to higher consumption. Cooperation, however, was influenced by the Seen condition, highlighting the role of reputation and social cues. Moreover, an interaction between Nature Relatedness and the Unseen condition suggested that participants with high NR were more cooperative in the absence of social obligation, indicating intrinsic motivation. Life history predictors, including consideration of future consequences (CFC) and index of multiple deprivation (IMD), did not significantly affect consumption or cooperation, failing to support hypotheses regarding the impact of economic status and mortality cues on decision-making. In the Discussion, we contextualise the results theoretically, and consider explanations for why some of our predictors were not significant.

**Table 1** Analyses conducted to address the research questions and hypotheses

| Analysis | Predictor(s) | Response variable | Model |
|---|---|---|---|
| *Comparing behaviour against strategies prescribed by the analytical solution* | | | |
| Effect of probability on strategy | Probability ($\rho$<.69; $\rho \geq$.69) † | Strategy (Defect; cooperate) | Binary logistic GEE |
| Effect of probability & Strategy on Conditional cooperation | Probability ($\rho$<.69; $\rho \geq$.69); Strategy (Defect; cooperate)** | Conditional cooperation (CC; Non-CC) | Binary logistic GEE |
| Effect of strategy on conditional cooperation when $\boldsymbol{\rho} \geq$.69 | Strategy (Defect; cooperate); probability ($\rho \geq$.69 only)** | Conditional cooperation (CC; Non-CC) | Binary logistic GEE |
| Differences between strategy in terms of frequency of NE play | Strategy (Defect; cooperate) † | Conditional cooperation (Pareto CC; Non-CC) | Binary logistic GEE |
| Differences between strategy in terms of frequency of NE play | Strategy (Defect; cooperate); probability ($\rho \geq$.69 only) ** | Conditional cooperation (Pareto CC; Non-CC) | Binary logistic GEE |
| Differences in consumption payoff for strategy | Strategy (Defect; cooperate)* | Mean consumption | Mann–Whitney U-test |
| Differences in consumption payoff between conditional cooperation strategies | Cooperation (CC; Non-CC)** | Mean consumption | Mann–Whitney U-test |
| Differences in consumption payoff between conditional cooperation strategies (only pareto NE) | Cooperation (Pareto CC; Non-CC)** | Mean consumption | Mann–Whitney U-test |
| *Psychological and life history predictors of cooperation and consumption* | | | |
| Effect of psychological, life history and experimental factors on consumption decisions | NR†, CFC†, IMD† and Condition (seen/ unseen)** | Mean consumption | GEE Gamma model with log link |
| Effect of psychological, life history and experimental factors on number of cooperation played | NR*‡, CFC†, IMD† and Condition (seen/ unseen)* | Number of times cooperation played | Negative binomial generalised linear model with log link |

Asterisks in predictor column denote significant results
*$p < 0.05$; **$p < 0.001$; † not significant; ‡ only significant in interaction with Condition

# 2 Methods

## 2.1 Participants

All participants were volunteers and students or alumni from Middlesex University, London, UK. A total of 116 participants (58 dyads) took part in the experiment and no data were excluded following screening. The sex of participants was 37 males and 79 females, age range from 18 to 44 ($M$ = 21.92, SD = 4.79). Participants were aware that they would not receive payments commensurate to their earnings in the game (see [64], on the topic of participant payment; [11], pp. 183–185; also [2], p. 1577). Instead, only a subset of our participants received an actual reward at the end. Those participants who were first-year psychology students ($n = 33$) received course credit for their participation. All the others ($n = 73$) were offered an incentive, where their details were entered into a prize draw for the opportunity to win a £5 Amazon voucher (independent of their actual performance during the experiment). Note that, we were unable to conduct analyses comparing participants who had received course credit to those had not because our data file did not link this information to their case number.

## 2.2 Materials

We used a two-player economic game framed around the appropriation of a CPR. In the game, participants made simultaneous decisions (without conferring) about the proportion of a generalised resource they would like to consume (e.g. they could choose 20% of the resource). Points were gained from consumption decisions, with a participants' score being the sum of their consumption. Overconsumption could reduce the resource following rules set out prior to playing the game. Games started with total resource value ($V$) from which participants made consumption decisions $\alpha$ and $\beta$ (for player 1 and 2, respectively). The resource $V$ was communicated to participants as units of a generalised resource with $V$ set at 100 units at the start of the game, for ease of comprehension. Each player could choose to take any nonzero amount from the units available (e.g. if $V$ is 100, one can make an appropriation decision of integer values ranging from 1 to 100).

After players' decisions in a round, the resource value refreshed to the starting value of $V$ units only if the sum of consumption was less than 50% of $V$. As shown in Eq. (1) below, if the total consumption exceeded 50% of the units available at the beginning of a round but not the total value ($V$), the resource did not refresh, and the consumption was subtracted from the available units. Thus, each player cannot take more than 25% of the units available in order for the resource to refresh. In all proceeding rounds the resource could only refresh to the total units available at the start of that round. So, once depleted it could not refresh back to the max value at the start of the game ($V = 100$ units). A game ended when the consumption equalled or exceeded the available resource.

$$V_{t+1} = \begin{cases} V_t & if\ \alpha + \beta \leq \frac{1}{2}V_t \\ V_t - \alpha - \beta & if\ \frac{1}{2}V_t < \alpha + \beta < V_t \\ 0 & if\ \alpha + \beta > V_t \end{cases} \tag{1}$$

where $\alpha$ and $\beta$ are consumption proportions of $V$ at time $t$.

To allow analysis of strategies in a categorical way, following the above rules, we defined play where a participant took $\leq$ 25% of the resource in a given round as a strategy of 'Cooperation'. If a participant took $>$ 25% of the resource available, in a given round, we defined this as a strategy of 'Defection'.

Games were iterated and in each round the experimenter used a random number generator (https://www.random.org) to generate a probability of another round. This generator is widely used in scientific studies (e.g. [48]). Its randomness comes from atmospheric noise, which is regarded to be more suitable than pseudo-random numbers typically generated by computer programs [62]. Random.org uses a discrete uniform distribution, meaning that the probability of each draw being a 0 or a 1 is approximately equal. The probability of continuation was communicated verbally as a percentage to players before they made their consumption decisions in the current round. This served the purpose of manipulating the shadow of the future for participants, to assess whether strategies changed across rounds and aligned with the probability for conditional cooperation when the likelihood of a further round was 11/16 (~ 69%) or greater. Further, it conveyed the impression that the number of rounds a game could last varied to prevent backwards induction strategies from the expectation of a fixed number of rounds. It is important to acknowledge that this probability was not used to terminate the game but was presented to manipulate participants' expectations. Participants were unaware of such manipulation and were led to believe that with a low continuation probability (e.g., 5%) the game could end during the occurring round, In truth, there was no system that actually decided whether the game would continue, or terminate, based on the percentage conveyed to them. The game's actual termination rules were based on the consumption of resources. In other words, the game would end when the consumption equalled or exceeded the available resource. This approach allowed the researchers to observe participants' behaviour in strategic situations without being influenced by the actual termination of the game based on the randomly generated probabilities.

In cases where both participants decide to consume the entire resource, they were credited with the number of units they individually chose to consume. This procedure ensured a fair representation of participants' choices, particularly in the context of responses to the probability of a next round. While such instances were expected to be rare, this approach aimed to accurately capture participants' behaviour during the experiment.

Players' appropriation decisions were recorded on paper datasheets that contained their player number and a grid consisting of two columns. One column showed the round of the game, the second was blank to allow players to record their decision for each round (See Appendix B).

A mathematical proof was developed for the game which showed the existence of two Nash equilibria (NE). Only pure and symmetric Nash Equilibria were considered since the scenario and questions about individual behaviour under examination are relatively simple. In other scenarios, where sophisticated players (who had studied the game, etc.) are considered, the Bayesian might have been more appropriate. The first NE showed that if the probability of another round is ~ 69% (11/16) or greater, then individuals should adopt a conditionally cooperative (CC) strategy. Such a strategy follows a simple concept: start by cooperating and continue to cooperate if the second player cooperated in the previous round; or defect, by taking all the available resource units, if the second player did not behave in a cooperative manner. Conversely, if the probability of there being another round is less than ~ 69% (< 11/16) then players should always defect (by taking all of the resource units). The second NE showed that it was always rational to defect (DNE), regardless of the probability of a further round and prior knowledge of behaviour of the other player. A copy of the proof is shown in the Appendix C. We acknowledge the existence of alternative stable strategies and the potential applicability of the folk theorem for repeated games [20]. We have focussed on the above two NE, and the conditionally cooperative strategy where a participant took $\leq$ 25% of the resource when the probability of another round was sufficiently high (~ 69% or 11/16), as this was the sustainable NE for the game in Appendix C and the Pareto efficient equilibrium whereby participants obtained their highest payoff whilst still playing a sustainable strategy that did not reduce or destroy the resource.

Participants also completed a 21-item paper-and-pencil questionnaire assessing how connected they feel to nature, the NR-6 nature relatedness scale [50]. This scale uses a 5-point Likert scale that ranges from 1 (disagree strongly) to 5 (agree strongly) and includes statements such as "I enjoy being outdoors, even in unpleasant weather" or "My feelings about nature do not affect how I live my life". The consideration of future consequences (CFC) scale [72] was used to assess the degree to which participants discount future rewards. This is a 12-item paper-and-pencil questionnaire, using a 5-point Likert scale that ranges from 1 (extremely uncharacteristic) to 5 (extremely characteristic). Statements such as "My convenience is a big factor in the decisions I make or the actions I take" and "I only act to satisfy immediate concerns, figuring the future will take care of itself" are presented. Participants were also asked to provide their current, and previous postcode (if applicable), with at least five years of residency. Postcode data (the UK equivalent of a zip code for mail) were used to obtain data on indices of multiple deprivation (IMD) at the lower super output area (LSOA) level [47]. This is neighbourhood level data with each LSOA providing a deprivation index for localities consisting of about 850 residences. A participants' postcode was used as an indirect correlate of life history cues in their home neighbourhood. The IMD data were a discrete scale variable ranking all LSOA's in England on a scale from 1 (most deprived area) to 32,844 (least deprived area).

## 2.3 Design

A between-subjects manipulation of two game conditions was used. In the first, participants played in the same room, face to face with the other player (Seen). In the second, participants played the game in separate rooms, never encountering the other player face to face (Unseen). Psychological scales, life history proxy and game conditions were used as independent variables. The dependent variables were players consumption decisions within rounds and the total number of cooperation decisions within games.

## 2.4 Procedure

Pairs of participants were alternately assigned to the different conditions of the game: (1) "Seen" ($N = 60$), and (2) "Unseen" ($N = 56$). After reading an information sheet about the study and giving informed consent, participants provided information on age, sex, postcode and then completed the questionnaires described. They were then provided with information explaining the rules of the appropriation game in the form of written instructions (see Appendix A) and a verbal explanation by the experimenter. In the Seen condition, the researcher was in the same room with participants, from the start to the end of the game. In the Unseen condition the researcher communicated with players through walkie-talkies.

At the start of each round, the researcher verbally announced the units available and the probability of a further round. Participants wrote their decision—number of units they wanted to consume—on the datasheet and a piece of paper. The paper was collected by the experimenter to record consumption decisions. After each round the researcher calculated the sum of the units taken by both participants. If the sum was 50% or lower than the available units, the available resource was refreshed for the next round, whereas if is the sum exceeded 50%, only the difference (available units minus consumption) was left for the next round. In both cases, this information was communicated to participants. The game continued until the resource was destroyed, meaning that the available units reached zero. An example of the data collection pack used by participants is provided in the Appendix B.

## 2.5 Statistical Analysis

### 2.5.1 Investigation of the Analytical Solution

The first analyses investigated how participants' behaviour differed from the analytical solution of the game (see Appendix C). Strategies played in each round were coded into a binary variable (0 for defection and 1 for cooperation). A second binary variable was also coded to analyse whether cooperation decisions were NE (i.e. cooperate only when the other player cooperated in the previous round)—0 for Non-CC play and 1 for CC. This second variable also accounted for whether defections were NE, which occurred only when participants defected by taking the entire resource (thus CC), ending the game (any other defection was not NE—Non-CC). Finally, Probability was also coded into a binary variable—0 for $\rho < 0.69$ and 1 for $\rho \geq 0.69$. Hereafter, Strategy (Cooperate; Defect), Probability ($\rho < 0.69$; $\rho \geq 0.69$), and Conditional Cooperation (Non-CC; CC) are used to refer to the variables used in the models. A further binary variable was also added for a follow-up analysis investigating differences in the frequency of Defect and Cooperate NE. This variable applied a tighter criterion to cooperate NE by restricting cooperative plays, assessed as NE, to only Pareto Efficient choices. These are choices where a player took exactly 25% of the resource when the probability of a further round was 69% or greater. A set of cross-tabulations and binary logistic generalised estimating equation (GEE) models were used to analyse the data.

To examine participants' behaviour against the analytical solution over the various rounds played throughout the 58 games, the three variables (Strategy; Probability; Conditional Cooperation) were added to the models, depending on the analysis. Four main steps were undertaken:

1. Investigation of the extent Strategy played in each round (cooperation; defection) was affected by Probability ($\rho < 0.69$; $\rho \geq 0.69$).
2. Examination of the effect of Probability and Strategy on the occurrence of NE plays. (i.e. do people play more CC when $\rho \geq 0.69$ compared to $\rho < 0.69$? Or, do people play more CC when they cooperate compared to when they defect?).
3. As there were two possible NE when $\rho$ was 69% or higher (contrary to $\rho < 0.69$), investigation of the effect of Strategy on Conditional Cooperation when $\rho \geq 0.69$ (i.e. when $\rho \geq 0.69$, did people play CC more when they cooperated or when they defected?).
4. Comparison of the relative payoffs (mean consumption) of the strategies and their respective NE, to identify and assess any systematic behaviour that might explain convergence to, or divergence from, optimal play given by the analytic solution.

### 2.5.2 Explanatory and Predictive Modelling of Influential Factors

Four predictors were included in the analysis: NR, CFC, IMD, and Condition (binary nominal variable, coded 0 for the Seen and 1 for the Unseen condition).

Two different approaches were undertaken—explanatory and predictive. For the explanatory approach, the influence of the four predictors was investigated using consumption decisions as the dependent variable. Consumption was a continuous variable, which included every consumption decision made by participants in each round ($N = 588$). A One-Sample Kolmogorov–Smirnov Test and examination of residuals, indicated the data were not normally distributed. For the predictive approach, number of cooperations was used as the dependent variable. This was a count variable that involved the sum of all the cooperations played during a game by each participant (this included cooperation that were not CC and, thus, non-NE).

To investigate the effect of the predictors on Consumption, a Gamma GEE model with log link was employed to account for the non-normal distribution of the data as well as the non-independence of data points. The four predictors were adjusted to allow a within-subject analysis.

For the predictive approach—using number of cooperations as the response variable—data were analysed using a series of generalised linear models. Due to observed overdispersion in the count data point ($\chi^2/\mathrm{d}f = 2.640$), a Negative Binomial (NB) model with a log link function was used. The NB accounted for overdispersion by loosening the restrictive assumption of the Poisson model that the data variance needs to be equal to the mean [32]. Table 1 summarises the different analyses conducted to address the main research questions.

## 3 Results

The descriptive statistics for the number of rounds throughout the games indicate that, on average, participants played approximately 5.06 rounds per game. The range of rounds played varied from a minimum of 1 round to a maximum of 15.

In only one instance, during the first round of one game, one participant consumed 100 units, while the second participant consumed 59 units, resulting in a total consumption surpassing the initial resource. Given the singularity of this situation, both participants were credited with the number of units they individually chose to consume. This decision was made to accurately track participants' behaviour, particularly in relation to their responses to the probability of a next round. Across all other games, the depletion of the total resource occurred gradually over successive rounds. On occasion, in the final round, there were instances where a few units collectively consumed by both players exceeded available resource. However, since the number of units were always considerably small (e.g. between 1 and 5 units), we maintain the belief that these minimally impact the overall findings and interpretations of the study.

### 3.1 Comparing Behaviour Against Strategies Prescribed by the Analytical Solution

#### 3.1.1 The Effect of Probability of Another Round on Strategy Played

A series of GEE analyses were conducted to assess the extent to which strategies played in rounds were affected by probability of another round. A binary logistic GEE with Strategy (Cooperate; Defect) as response variable and Probability ($\rho < 0.69$; $\rho \geq 0.69$) as a categorical predictor variable showed a non-significant result, Wald $\chi^2(1) = 2.058, p = 0.151$. Indicating there was no significant difference between the frequency with which Cooperate and Defect were played, relative to the predicted switch-point for cooperation to be an optimal decision, when the probability of another round was $\rho \geq 0.69$.

#### 3.1.2 CC Play as a Function of Probability and Strategy

A GEE model was fitted with Conditional Cooperation as the dependent variable and Strategy (Cooperate; Defect) and Probability ($\rho < 0.69$; $\rho \geq 0.69$) as predictors. This investigated the influence of Probability and Strategy on the probability of playing a CC in each round.

The results showed a main effect of Probability on CC, Wald $\chi^2(1) = 91.667$, $p < 0.001$. Specifically, showing that the odds of playing a CC when $\rho \geq 0.69$ are estimated to be exp (3.032) = 20.732 times the corresponding odds of when $\rho < 0.69$. In other words, when $\rho \geq$ 0.69 there was a 95% probability of playing a CC, whereas, when $\rho < 0.69$, the probability of playing a CC was only 32%. Further, a significant main effect of Strategy on Conditional Cooperation was found, Wald $\chi^2(1) = 45.289$, $p < 0.001$. When participants cooperated the odds of playing a CC were estimated to be exp (1.767) = 5.854 times higher than when people defect. Indicating that when individuals played a cooperating strategy there was an 85% probability of being a CC, compared to a 15% probability when they defected.

To specifically investigate the effect of Strategy on CC when $\rho \geq 0.69$, a further GEE analysis was conducted holding $\rho \geq 0.69$ constant and adding CC as the dependent variable and Strategy as the predictor. The findings showed a significant main effect of Strategy, Wald $\chi^2(1) = 92.883$, $p < 0.001$. When p is 69% or higher, the estimated odds of playing a CC when participants cooperate were exp (3.257) = 25.954 higher than when they defected. This means that, when $\rho \geq 0.69$, there is a 96% chance that individuals who cooperated played a CC, whereas, if they defect there was only a 3% chance they played a CC.

These results were not unexpected as the CC for defection was a single point-estimate (take all available resource units), whereas the CC for cooperation included any value in a range up to 25% of the available resource. To further investigate if there was an actual difference between strategies in terms of CC play, an analysis was conducted comparing Defection NE (DNE) with the stricter Pareto efficient CC for cooperation (a player takes exactly 25% of the available resource). This permitted a more valid comparison of two point-estimates, one for each strategy. A binary logistic GEE model, with CC (Pareto CC; Non-CC) as the response variable and Strategy (Cooperate; Defect) as the predictor variable, showed no significant difference between strategies in the number of CC played, Wald $\chi^2(1) = 1.217$, $p = 0.27$. However, a further GEE model using the same response and predictor variables but analysing only play when probability of a further round was $\rho \geq 0.69$ showed a significant main effect of strategy, Wald $\chi^2(1) = 11.130$, $p < 0.001$. Specifically, when probability of a further round was greater than 69%, those who defected played significantly fewer CC than those who cooperated. The odds of not playing a CC when defecting was exp (1.010) = 2.745 times the odds of not playing an CC when cooperating, reflecting a 73% probability of not playing a CC when defecting compared to a 27% probability when cooperating.

Assessing if the above differences between strategies in CC play reflected a difference in consumption payoffs for the strategies being used was conducted by examining the mean consumption (payoff) for each strategy across various conditions. Analysis of the full range of probabilities of a further round, showed that consumption was higher for Defect (Mean: 18.89, SD: 18.70) than for Cooperate (Mean: 13.41, SD: 8.98). A Mann Whitney U test confirmed that this was a statistically significant difference in consumption, $U = 38{,}484.50$, $p = 0.022$. A similar analysis just examining mean consumption payoff for plays that were CC showed the reverse pattern of means. The mean consumption for Defect (Mean: 5.65, SD: 16.41) being lower than that for Cooperate (Mean: 15.78, SD: 8.13). This was also confirmed as a statistically significant difference, $U = 4092$, $p < 0.001$. The same comparison with Cooperate constrained to only Pareto efficient CC also showed a statistically significant higher mean consumption for Cooperate (Mean: 18.40, SD: 9.77) compared to Defect (Mean: 5.95, SD: 17.04), $U = 1403.50$, $p < 0.001$. These results indicate that, when playing Cooperate CC or Pareto efficient Cooperate CC, participants gained more resource units than when they used a DNE strategy. Our interpretation of this was that use of DNE as a strategy was largely used by players when the resource pool had been depleted considerably. This was confirmed by examination of descriptive statistics for DNE which showed that, despite a wide range

(Range: 1, 100) of consumption, the median value for DNE was 1 unit. Indicating that in many cases participants only grabbed the whole pot when it had been almost completely exhausted and playing a sustainable strategy was no longer realistic.

#### 3.1.3 Analysis of Strategy Employed, Within Rounds, by Each Player Relative to Other Player's Behaviour

A crosstab investigation was conducted to analyse the number of cooperations and defections that occurred as a result of conditional play, independently from the NE. Results showed that 82% of all cooperations were conditional to the other player's behaviour, whereas 62% of all defections followed a defective behaviour initiated by the other player.

### 3.2 Psychological and Life History Predictors of Cooperation and Consumption

Table 2 shows descriptive statistics for CFC, NR and IMD by Conditions (Seen; Unseen).

#### 3.2.1 Consumption as the Response Variable

A GEE Gamma model with log link was performed to assess the effect of psychological, life history and experimental factors on consumption decisions made by participants in each round. NR, CFC, IMD and Condition were added to the model as main effects, Consumption was the response variable. The results display a non-significant effect of NR, Wald $\chi^2(1) = 2.225$, $p = 0.136$; a non-significant effect of CFC, Wald $\chi^2(1) = 0.539$, $p = 0.463$; and a non-significant effect of IMD, Wald $\chi^2(1) = 0.022$, $p = 0.882$. However, a significant effect of Condition was found, Wald $\chi^2(1) = 5.882$, $p = 0.015$. When participants were in the Unseen condition, their consumption decisions were exp $(0.190) = 1.209$ times (21%) higher than those in the Seen condition.

#### 3.2.2 Cooperation as the Response Variable

A series of Generalised Linear Models ($N = 45$ models), using a Negative Binomial model with log link and a parameter set at 0.5 to address overdispersion, were developed to investigate the main effects and interactions between the four independent variables—NR, CFC, IMD and Condition—and an outcome variable Number of Cooperations. A sequential approach was taken where predictor variables and interactions were added to the models one at a time. The first criterion used for model selection was the associated Akaike Information Criterion (AIC) value. The AIC is a measure of the goodness of fit, normally implemented using a lower is better approach [81]. An initial selection of ten models with lowest AIC

**Table 2** Descriptive statistics for NR, CFC and IMD

| | Total M (SD) | Seen condition M (SD) | Unseen condition M (SD) |
|---|---|---|---|
| NR | 3.33 (.580) | 3.32 (.582) | 3.34 (.583) |
| CFC | 3.59 (.524) | 3.53 (.520) | 3.65 (.521) |
| IMD | 12,673.2 (7000.7) | 13,197.4 (7304.5) | 12,112.2 (6679.9) |

values was made (details of all models are outlined in the supplementary material: S3). Moreover, as shown by the Omnibus test (likelihood-ratio chi-square test), only three of the 45 models were significantly better than an intercept only model. These were part of the initial ten selected models (model 8, 9 and 10—see supplementary material: S3) and were the ones that yielded the lowest AIC values.

Final model selection was based on significance of the variables included as well as the overall simplicity of the model. Model 8 contained NR and Condition as main effects as well as an interaction between Condition and NR. From the main effects, NR was not significant ($p = 0.151$), while Condition as well as the interaction between Condition and NR were significant at $p = 0.01$ and $p = 0.02$, respectively. Model 9 included three main effects—Condition, IMD and NR—and the interaction between Condition and NR. Condition and the interaction between Condition and NR were significant; IMD ($p = 0.089$) and NR ($p = 0.222$) were not significant. Model 10 included all four main effects as well as an interaction between Condition and NR. However, the model contained three non-significant main effects: IMD ($p = 0.075$), CFC ($p = 0.284$) and NR ($p = 0.315$). Similar to Model 8 and 9, Condition and the interaction between Condition and NR were significant. This suggested that the more complex models, adding three or four main effects, were no better at accounting for information in the data than the simpler model. Model 8 was retained as the best fitting model.

NR was found to make a non-significant contribution to the model. Including NR in the model did not significantly increase its fit. Therefore, NR, as a main effect, was subsequently excluded from the final model (model 8a), which contained Condition and the interaction between Condition and NR—this yielded almost the same AIC value and lower standard errors (Table 3).

In the final model (Model 8a), condition showed a significant main effect, Wald $\chi^2(1) = 5.919$, $p = 0.015$. Specifically, when the condition is Seen, the number of cooperations played by participants are expected to be exp (1.184) = 3.266 times (227% increase) higher than the Unseen condition.

Condition became significant as a main effect only after the interaction with NR was added to the model. The interaction showed a non-significant negative relationship between

**Table 3** Final Model. Model 8a, including Condition as main effect and interaction between Condition and NR

| Model | 95% Wald CI | Std. error | P | Deviance | Df | Omnibus test(Sig.) | AIC |
|---|---|---|---|---|---|---|---|
| 8a | | | | 127.36 | 112 | 0.039 | 478.36 |
| Condition | | | | | | | |
| Seen | [0.2300, 2.1369] | 0.4864 | 0.015 | | | | |
| Unseen | – | – | – | | | | |
| Condition:NR | | | | | | | |
| Unseen:NR | [− 0.2270, .1077] | 0.0854 | 0.024 | | | | |
| Seen:NR | [0.0317, 0.4581] | 0.1087 | 0.485 | | | | |

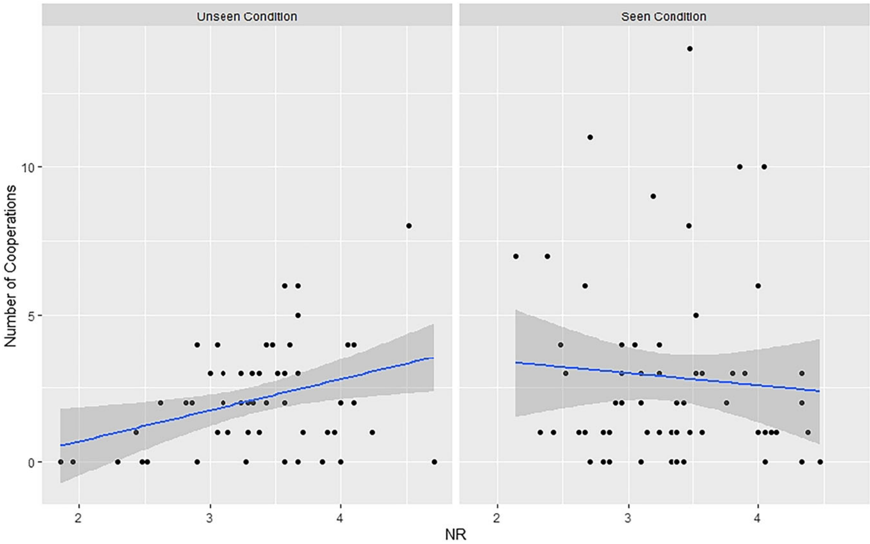


**Fig. 1** NR means plotted against Number of Cooperations. Plots shown for Unseen and Seen condition with fitted regression lines

the Seen condition and NR, Wald $\chi^2(1) = 0.488$, $p = 0.485$. A significant relationship was found between the Unseen condition and NR, Wald $\chi^2(1) = 5.070$, $p = 0.024$. Differences between the two levels, and their interaction with NR, were investigated graphically by plotting Number of Cooperations against NR in two graphs divided by Condition (Fig. 1). A positive correlation was apparent between Number of Cooperations and NR when the condition was Unseen.

In summary, when the condition is Unseen individuals tend to cooperate significantly less compared to the Seen condition. However, Fig. 1 shows that, when the condition is Unseen, players who score higher on the NR scale are also likely to play a more cooperative strategy compared to those who scored lower.

## 4 Discussion

Our aim was to investigate the predictors of cooperation, pertinent to real-life common-pool resource problems. We acknowledge the artificiality of our lab-based study [2]. For example, our replenishment rule ($\geq 0.5$ it all comes back, $< 0.5$ none comes back) is likely not realistic for real resources, but we chose the rule for clarity (both in terms of the understanding of the participants, and for conceptual reasoning/ calculations). Despite the artificiality, the results of our study show patterns of behaviour which are likely to operate in the real word in response to analogous cues. Our main significant results pertained to our model predictions and the visibility manipulation. The results relating to the individual characteristics of the players (CFC, NR, IMD, postcode) were mostly nonsignificant. All of these are discussed in detail below.

### 4.1 Comparing Behaviour Against Strategies Prescribed by the Analytic Solution

Behaviour deviated significantly from the NE suggested by the analytic solution. Results showed that 26% of all the plays were CC. The non-significant effect of Probability on strategy played suggested that when $\rho < 0.69$, players did not play only defections, as predicted, but cooperated almost as equally as they defected. Additional analyses investigating this divergence from the analytical solution showed a significant difference between $\rho \geq 0.69$ and $\rho$ <0.69 in the number of CC played (52% of the plays were CC when $\rho \geq 0.69$, only 6% were CC when $\rho$ <0.69). While $\rho \geq 0.69$ included two possible NE (cooperate (CC) or defection (DNE), $\rho$ <0.69 allowed only defection as NE. To be considered a NE, defection had a narrower requirement (taking the entire resource) compared to cooperation (taking any amount within ¼ of the available resource). Further analysis confirmed a significant effect of Strategy—participants were more likely to play a CC when they cooperated compared to when they defected. This finding could be attributed to the narrowed characteristic required to play an "optimal" defection. A DNE involved the selection of a single specific value (the present quantity of the resource available) whereas a cooperation NE afforded the choice from a range of values (up to ¼ of the resource presently available in the round).

Further analysis, making a more valid comparison of two-point estimates (DNE or Pareto Cooperate CC), showed that the number of CC did not differ significantly across the whole range of probabilities for a further round but Pareto Cooperate CC was significantly more frequently played when the probability of a further round was $\rho \geq 0.69$. This reflected a strategic approach to play where players seem to be maximising their individual payoff reward in a round whilst playing a sustainable strategy that does not degrade the resource base. When players used NE strategies (either Defect, Cooperate or Pareto Cooperate) the cooperative strategies resulted in them being better off in the long-run and obtaining a higher mean payoff. This may to some extent be attributable to the gradual accumulation of points over games that lasted more rounds because they had not been prematurely ended by one individual playing a DNE. However, in this case, the difference seems to be explained by players in many cases only using DNE as a last resort strategy by grabbing the remains of an almost completely exhausted resource, with the median value for DNE being only 1 unit.

Behaviour tends to differ from predicted NE when this assumes that players care only about self-interest, thus trying to always maximise their outcome [79]. In truth, "people pursue a wider range of aims than just profit maximisation" ([2], p. 1577). Defection NE in our current study, requires that individuals maximise their consumption regardless of the negative consequences that such behaviour may cause to the other player (i.e. future unavailability of the resource due to its destruction). Evidence in various studies suggests individuals tend to behave cooperatively even in situations where the only NE is defection [5, 12, 13]. Previous studies have found that participants care about fairness while playing the games [31]. That is not to say individuals cooperate unconditionally even when it is not reciprocated. In fact, punishment for defective behaviour has been commonly observed. This study showed equal numbers of cooperation and defections played overall—80% of all cooperations were played as a response to the opponent's cooperative behaviour and 64% of all defections followed a previous defection played by the opponent. These insights denote behavioural variation because of continuous adaptation to the other player's actions.

The current results contrast with previous findings. For instance, Dal Bó [10] found that cooperation significantly increases along with the probability of future encounters. The disparity between Dal Bò's (2005) results and the present findings could be attributed to differences in methodology. The probability of continuation communicated to the participants in the current study utilised a continuous, randomised, approach. Whereas, Dal Bó

[10] adopted a categorical approach, although still randomised, which presented only three treatments—$\delta = 0$, $\delta = 1/2$ or $\delta = 3/4$. It can be argued that this simplification may have favoured the understanding of the shadow of the future and, consequently, promote more rational and strategic decisions during the game. As suggested by Hope and Kelly [33], probability plays an important role in every society, however, probabilistic reasoning can be hard to master. Earlier, Slovic et al. [69] found that even after specific instructions, individuals have significant difficulties in developing a good intuition about central ideas of probability. Consequently, they tend to fail in tasks that involve probable events. More recent studies have tested the understanding of probabilistic weather forecasts (e.g. "30% chance of rain") and found that probabilities are interpreted by individuals in multiple, mutually contradictory ways [22]. This may confirm the assumption that participants' decision-making during the game was influenced by a difficulty in understanding the probability of another round communicated to them, thus, unable to fully comprehend its implications on the continuation of the game. On the other hand, Dal Bò's [10] approach simplified such a process, limiting individuals' cognitive workload and leaving more room for strategic thinking.

We also acknowledge that our use of deception may seem slightly controversial. As mentioned earlier (§2.2), participants were led to believe that the game terminates according to the probability stated by the experimenter. This falsehood was not revealed until the participants had finished. We aver that, if participants had known the real termination rules, it would have confounded our results. Therefore, we believe that our mild deception was necessary. Although deception is relatively rare in experimental economics, there is mixed opinion about whether it is justifiable [9]: it depends on the cost–benefit, if deception provides more experimental control, and the question is whether the benefits of deception outweigh any negative impacts on the participants. Negative impacts on participants might include negative emotions and discomfort, suspicion regarding the information provided by the experimenter, and potential differences in behaviour as a result of that suspicion [53]. In conducting the study, we observed no indication of negative impacts.

### 4.2 Psychological and Life History Predictors of Cooperation and Mean Consumption

To investigate psychological and life history factors that influenced participant behaviour while playing the game, analyses were undertaken using two approaches: explanatory and predictive. For the explanatory approach, a GEE with Gamma log link model was used to account for the non-normality and non-independence of the data. Only the independent variable of Condition had a significant effect on the amount of consumption during the game. Specifically, when players were in the Unseen conditions (two different rooms), their consumption was 21% higher compared to in the Seen condition. These findings support the results of previous studies that have looked at the effect of anonymity in strategic interactions [8, 27]. These results add insight by showing that cooperation is harmed by anonymity, regardless of the occurrence of repeated encounters between two individuals. Although other studies [46, 52] have shown cooperation through formation of reputation: in certain strategic situations two individuals may interact in complete anonymity without detriment to their reputations. The increase of defective behaviour in such situations must be taken into consideration when dealing with the administration of a common resource.

A non-significant effect of NR, CFC and IMD on participants' consumption within rounds was found. Life history theory suggests that individuals living in a stressed environment, which can have different forms of mortality cues, tend to favour short-term reward due to future uncertainty [80]. The present research used the IMD as an indicator of participants' economic status as well as mortality cue since it takes into consideration some crucial factors of a given neighbourhood—income, employment, health, crime etc. [57]. The lower the IMD linked to one's neighbourhood, the higher the number of mortality cues assumed to be present [77]. IMD and CFC were taken as likely highly correlated, following Griskevicius et al. [26]. It was assumed that IMD would impact players' time preference—their consideration of future consequences. However, a non-significant effect of both IMD on CFC was observed.

Although several studies have looked at the effect of low socioeconomic status (SES) and its negative consequences (e.g. [19, 24, 58, 59], this is the first attempt to link it to strategic thinking. Griskevicius et al. [26] attempted to understand how an individual's SES is influenced by the impact of mortality cues and, as consequence, the tendency to take risks as well as time preference. For the experiments used in the Griskevicius et al. [26] study, participants were asked to report their current and childhood SES through responses– to discrete options on a Likert scale and then mortality cues were presented by exposure to stimuli. Their results showed individuals who reported higher childhood SES were less influenced by mortality cues, took less risk, and preferred greater future rewards. Moreover, contrary to childhood SES, current SES had little or no effect on people's decision-making [26]. The important influence of childhood SES [26] suggests individuals may unconsciously calibrate their life history strategy towards daily occurrences during a 'critical period' in childhood. The current study did not take into consideration participants' childhood SES, but only current SES which seems to have no impact on how people are affected by mortality cues. As stated, IMD was taken as an indicator of SES as well as an indirect indicator of mortality cues occurring in participants' lives. However, since the experiment was conducted in a lab environment, it is likely that without exposure to specific stimuli mortality cues were not salient in a controlled setting. IMD may therefore not be a good indicator of an individual's economic status since it involves an average of different aspects found within a neighbourhood. One could hold a low SES but live in an area with a moderate/high IMD (or vice versa). This may be especially true for those who relocate for educational and working purposes and the present study considered only participants' past five years of residency.

In our present experiment, we were interested in understanding whether players had a preconditioned level of CFC, as a result of their environment, and how this would impact their strategic decisions. It could be argued that the lack of a significant effect of CFC is due to the difference in methodology when compared to Griskevicius's et al. (2011), who actively manipulated the exposure to mortality cues during the experiment. The use of CFC, instead of any other time preference indicators, was motivated by the hypothesised measuring of a stable construct [72]. In fact, according to Strathman et al. [72], the various measures developed during the years to analyse time preference (e.g. Future Time Perspective, Stewart Personality Inventory, Time Perspective Inventory, etc.) typically test a general preoccupation with the future or worry towards future events. Whereas, the CFC indicates the extent to which people reflect on probable distant outcomes, caused by their current behaviours, and the degree to which they are impacted by these potential outcomes. It embodies an internal struggle between present behaviour and its connection to immediate and future outcomes—one's decision to favour present or future is hypothesised to be a stable feature. Thus, participants should be influenced in their decision independent of experimental stimuli [34, 35, 43]. A certain situation could involve different levels of decision-making processes that shadow the influence of other individual differences such as temporal discounting and temporal preference. As argued by Wischniewski et al. [78], the contextual situation plays a crucial role in how people behave and make decisions. In other words, there are scenarios when almost anyone would cooperate, and others when most individuals would defect, regardless of general tendencies [61]. As previously mentioned, most consumption decisions followed a reciprocity approach (conditional cooperation). Such behavioural strategies have been well studied and shown to be crucial to avoid the proliferation of "free-riders" within a social group [17, 28, 73]. As a result, the possibility exists that the players' level of CFC was shadowed by the presence of strategic aspects that were at the core of every round of the game.

Furthermore, some studies have provided results that would seem to contradict the presumption that lower SES individuals would donate less than higher SES individuals. For example, Piff et al. [60] investigated the relationship and SES and prosocial behaviour, using a variety of different dependent and independent variables across four studies (i.e. different ways to measure SES and different ways to measure generosity). Their results showed that lower SES individuals were indeed more generous, seemingly because "lower class individuals experience less personal control and depend on others to achieve desired outcomes" ([60], p. 772) and hence they "are motivated to behave in ways that increase social engagement and connection with others" ([60], p. 772). If this is what was happening in our sample, then it might be that—even if those with lower CFC scores are less generous [41]—that some kind of inherent prosociality (as described by Piff et al. [60]) among the lower classes were cancelling out our CFC effect in our study. However, it is difficult to interpret a null result, and therefore future research will need to disentangle these effects.

The non-significant effect of NR could be attributed to an ecological validity issue, due to the lab setting used for the experiment. Nature relatedness is believed to define an individual's cognitive and affective connection with nature, so high levels of NR should predict sustainable approaches and behaviours. These beliefs follow the assumptions of Wilson's [76] biophilia hypothesis, which argues that humans have an innate connection with the wildness of nature (e.g. plants, animals, etc.). Exposing oneself to nature fulfils this innate need and fosters well-being [39]. Although the resource used during the game had the same properties as a CPR, it was a generalised resource consumed in 'units' (instead of a specific common resource—e.g. water, oil, fish, etc.). While such design is beneficial for avoiding confounding effects caused by subjective perceptions towards a specific resource, it can be argued that NR specifically predicts pro-environmental behaviour, whereas the resource used in the game lacked the features necessary to be perceived as an environmental resource.

For the predictive analyses, a series of GLMs using a negative binomial model were employed to assess the factors that predict cooperation in strategic situations. Results showed that visibility Conditions—Seen and Unseen—as well as their interaction with NR score were significant predictors of the number of cooperations played. Indeed, there was a significant effect of Condition, indicating that when individuals are in a Seen condition, they play more cooperations compared to an Unseen condition. Additionally, the significant interaction observed between Condition and NR showed that when a participant is in an Unseen condition, although individuals are expected to cooperate less compared to the Seen condition, the number of cooperations increased when participants scored high on NR. The interaction between the Seen condition and NR was non-significant, showing no significant difference in the number of cooperations between those who score high and those who score low in NR when the condition is seen.

The findings of the predictive analyses support the result of the initial explanatory approach. Condition was shown to be a good predictor of cooperation in both approaches. This agrees with previous research that suggests reputation plays an important role in strategic situations. If an individual is considered to be 'trustworthy', then others tend to be more cooperative with them [1, 4, 42, 51, 68]. Moreover, as found by Haley and Fessler [27] and Charness and Gneezy [8], having some information—visual, auditory or just representative (i.e. simply knowing the other player's name)—about the other player significantly increases the chances of cooperation even when the only rational behaviour should be defecting (e.g. in the dictator game) [8]. Thus, compared to a scenario where anonymity is present (Unseen Condition), the mere presence of another individual (Seen Condition) benefiting from the same resource encourages cooperative behaviour, even if there is no communication between the agents. Interestingly, a significant interaction between Condition and NR appeared as a predictive factor. Similar to the explanatory model, there was no significant effect of NR as a main effect, however, its interaction with the Unseen Condition may suggests that, in the absence of the social obligation, cooperation might be attributable to the participants intrinsic motivation. Hence, it is predicted that when an individual anonymously consumes a CPR, they tend to be more cooperative if they score highly on NR. Although a predictive design cannot be taken as ultimate evidence, it still is an important outcome that confirms the need for further investigations into NR and its potential consequences on behaviour.

## 5 Conclusions

Play diverged from the analytic solution, but not in a systematic way that has been seen in other behavioural Game Theory studies such as the dictator game [8, 13, 27]. Players frequently cooperated when the probability of another round was below the threshold value $\rho = 0.69$. In line with the first prediction, players did seem to play a conditionally cooperative strategy, tracking the behaviour of the other player, however, they did this regardless of whether the probability of a further round was high or not. Investigations of the life history and psychological factors influencing appropriation decisions showed a non-significant effect of nature relatedness (NR), consideration of future consequences (CFC) and index of multiple deprivation (IMD). Players' tendency to play sustainable and cooperative strategies was best predicted by whether they exploited the resource face-to-face with another player rather than anonymously.

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**Author Contributions** MB conducted the experiment, computed the statistical analyses, and wrote the first draft of the manuscript. RS is the principal investigator. He has supervised the research process made a substantial contribution to writing the manuscript. MB computed the mathematical proof. YIR made a substantial contribution to writing the manuscript and co-supervised the research project. All authors reviewed and co-wrote the final manuscript.

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**Data Availability** The data collected for the experiment are available on the Open Science Foundation website—accessible with the following link: https://osf.io/65p94/ Spencer, R. (2023, December 7). Decision Making in Common Pool Resource Games.

### Declarations

**Competing interests** The authors declare no competing interests.

**Ethical Approval** The research was approved by the Research Ethics Committee in the Psychology Department at Middlesex University (application no. 8122). The REC follows BPS guidelines.

## Appendix A

## Instructions for Players

In this game you have access to a resource. The total amount of this resource that exists is 100 units.

You accumulate points by consuming units from this resource and your aim is to accumulate as many points as possible in the game. The game lasts for a number of rounds, you will not be told how many rounds the game is going to last but, in each round prior to making your consumption decision, you will be told the actually probability of there being another round after the current round.

You are playing the game against one other player, they have access to the same resource you are consuming, so the resource is shared and anything you consume is not available for them to consume.

In each round of the game you have to choose how much of the resource you would like to consume. The minimum you can take is 1 unit in a round and the maximum is the total resource available (100 units).

When making your choice about how much to consume in a given round you should be aware of the following rules of the game.

Once all players have made their consumption choices in a round, the experimenter will add up the consumption choices of all players:

- If that total consumption is less than or equal to 50% of the total resource available then the resource will refresh back to the starting value for the next round.
- If that total is greater than 50% of the total resource available but less than all of the resource, the resource will be reduced by the amount extracted by all players and the value of the resource in the next round will be this reduced value (e.g. if the value of the resource in round one is 100 units and the total consumed by all players was 80 units then the resource available in the next round would be 20 units). The experimenter will state the actual reduced value of the resource at the start of the next round. If players then use less than 50% of this reduced resource in the next round then the resource will refresh to the reduced value. (e.g. If the resource is reduced to 40 units and the total consumption of all players in the next round is 20 units or less, then the resource will refresh to 40 units in the following round but not back to the original starting value of 100 units).
- If the total consumption for all players is equal to or greater than the total amount of the resource available then the game ends and the points accumulated by a player are totalled up to give their final score for the game.
- Prior to making their consumption decisions in a round players will be told the exact probability that there will be another round after the one being currently played.

Your task during the game is to complete the participant datasheet by recording how much of the resource you would like to consume in that round in row 1 under the column consumption decision. You will then write your consumption decision on a separate piece of paper and discreetly pass it to the experimenter without communicating that information to the other player in the game. You make your decision without conferring or knowing what choice the other player will make.

## Appendix B

See Table 4.

**Table 4** Example of participant datasheet used during the experiment

| Date: | Location: |
|---|---|
| Player URN: | Game: |
| Round: | Consumption Decision: |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| 11 | |
| 12 | |
| 13 | |
| 14 | |
| 15 | |
| 16 | |
| 17 | |
| 18 | |
| 19 | |
| 20 | |
| 21 | |
| 22 | |
| 23 | |
| 24 | |
| 25 | |
| 26 | |
| 27 | |
| 28 | |
| 29 | |
| 30 | |

## Appendix C

### Common Pool Resource Appropriation Game: 2 Player Known Reward Value

The reward starts at value $V$. If the first player takes proportion $\alpha$, and the second player takes proportion $\beta$, then the reward maintains its value if $\alpha+\beta \le 1/2$, goes to $V(1-\alpha-\beta)$ if $1/2 < \alpha+\beta < 1$ and becomes 0 if $1 \le \alpha+\beta$. In the latter case the players attempt to take $(\alpha+\beta)V$ but this is greater than $V$, so it is divided in proportion to the attempted seizure, with the first player receiving $\alpha V/(\alpha+\beta)$ and the second player receiving $\beta V/(\alpha+\beta)$.

Picking the same $\alpha$, $\beta$ in every round, with the probability of another round occurring being $\rho$, gives the following expected payoffs for playing $\alpha$ against $\beta$:

$$
\begin{aligned}
R[\alpha,\beta] &= \alpha V\left(1+\rho+\rho^2+\ldots\right) = \frac{\alpha V}{1-\rho} \quad \alpha+\beta \le 1/2 \\
&= \alpha V(1+(1-\alpha-\beta)\rho+\ldots) = \frac{\alpha V}{1-(1-\alpha-\beta)\rho} \quad 1/2 < \alpha+\beta < 1 \\
&= \frac{\alpha V}{\alpha+\beta} \quad 1 < \alpha+\beta
\end{aligned}
$$

For given $\beta$, what is the best $\alpha$? Allowable $\beta$ values are $0 \le \beta \le 1$.
For $\beta > 1/2$, $\alpha = 1$ gains $\frac{V}{1+\beta}$, and is clearly better than any other $\alpha \ge 1-\beta$.
The payoff for $\alpha < 1-\beta$ is $\frac{\alpha V}{1-(1-\alpha-\beta)\rho}$.
This is worse than choosing $\alpha = 1$ if $\frac{\alpha V}{1-(1-\alpha-\beta)\rho} < \frac{V}{1+\beta} \Rightarrow \alpha(1+\beta) < 1-(1-\alpha-\beta)\rho$ $\Rightarrow (1-\alpha-\beta)\rho < 1-\alpha-\alpha\beta$ which is true for $\rho \le 1$.
Thus, the best reply to $\beta > 1/2$ is $\alpha = 1$.
For $\beta \le 1/2$, $\alpha = 1$ gains $\frac{V}{1+\beta}$ and this is better than for any other $\alpha > 1-\beta$,
$\alpha = 1/2 - \beta$ gains $\frac{\left(1/2-\beta\right)V}{1-\rho}$ and this is better than for any other $\alpha < 1/2 - \beta$,
$\beta$ gains $\frac{\alpha V}{1-(1-\alpha-\beta)\rho}$ and this is less than $\frac{V}{1+\beta}$ as before.

Thus, the best response to $\beta \le 1/2$ is $\alpha = 1$ if $\frac{V}{1+\beta} > \frac{\left(1/2-\beta\right)V}{1-\rho}$ and is $1/2-\beta$ otherwise.
A Nash Equilibrium is a strategy that is a best response to itself. Playing 1 is thus a Nash Equilibrium and no other strategy for $1/2 < \beta \le 1$ is.

For $\beta \le 1/2$ we require for $1/2 - \beta = \beta \Rightarrow \beta = 1/4$ for a Nash Equilibrium. In addition, we need.

$$
\frac{\left(1/2 - 1/4\right)V}{1-\rho} \ge \frac{V}{1+1/4} \Rightarrow \frac{1}{4(1-\rho)} \ge 4/5 \Rightarrow 1-\rho \le 5/16 \Rightarrow \rho \ge 11/16
$$

In summary we have $\beta = 1$ is always a Nash Equilibrium, $\beta = 1/4$ is a Nash Equilibrium if $\rho \ge 11/16$ and there are no other Nash Equilibria.

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