The randomised response technique: A valuable approach to monitor pathways of aquatic biological invasions

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Abstract

Anglers can be significant vectors for non-native species (NNS) in freshwater ecosystems, and monitoring their behaviour can be a useful way to counteract biological invasions. However, anglers may be unwilling to reveal their real behaviour in conventional surveys. In this study, the Randomised Response Technique (RRT) and the Bean Method (BM) survey technique were compared using direct questions to obtain frequency estimates of four angler behaviours that may affect NNS management in freshwater ecosystems: angling without a license, release of macroinvertebrates in the environment, use of fish bait and unauthorised fish restocking. Higher estimates were obtained from responses to RRT than BM questions, and BM provided contradictory results. Use of the RRT is recommended in those human dimension studies that explore angler behaviour as a vector for aquatic invasions.

Keywords: anglers, baits, bean method, freshwater, invasive species, randomized response technique

Introduction

In freshwater ecosystems, commercial and recreational boating are often regarded as the main pathways for biological invasions (Johnson, Ricciardi & Carlton, 2001), which can have devastating impacts on the biodiversity and functioning of recipient ecosystems. However, other human activities, such as recreational angling, aquarium trade and aquaculture, are also important introduction vectors for aquatic invasions (e.g. Anderson, White, Stebbing, Stentiford & Dunn, 2014; Gozlan, Britton, Cowx & Copp, 2010). Of these, recreational angling contributes to the introduction and dispersal of aquatic non-native species (NNS) in four main ways: (1) improper cleaning of angling equipment does not eliminate NNS propagules (Anderson et al., 2014), which can lead to inadvertent introductions (Zięba, Copp, Davies, Stebbing, Wesley & Britton, 2010); (2) deliberate releases of NNS to enhance the angling experience (Hickley & Chare, 2004), which has serious implications for freshwater management (Benejam, Carol, Benito & García-Berthou, 2007); (3) improper disposal, that is release to the environment of live bait at the end of the fishing session (e.g. Kilian et al., 2012); and (4) contaminated consignments of fish (Gozlan et al., 2010) and aquatic plants (Copp et al. 2017) for stocking, leading to inadvertent NNS introductions.

Inclusion of a human dimension in NNS management can provide considerable benefits, as human behaviour is a major source of uncertainty in fisheries (Fulton, Smith, Smith & Van Putten, 2011). Various approaches are available to measure and understand human use of natural resources and stakeholder compliance with existing regulations, and surveys certainly represent one of the most cost-effective and adopted tools for this goal (Vaske, 2008), but various doubts have been raised towards direct-answer questionnaires as a tool to monitor rule violation (Nuno & St John, 2015). In fact, formal and informal sanctions associated with non-compliant behaviour often lead respondents to adopt protective strategies, such as non-response or the provision of perceived, socially-desirable answers (Krumpal, 2013). Surveys about natural resources are no exception, as respondents in violation of the law can be fined or prosecuted or lose their licence (Gavin, Solomon & Blank, 2010). Furthermore, even with anonymous questionnaires comprising direct (potentially sensitive) questions, individuals may be reluctant to admit to questionable behaviours, such as the underreporting of actual catches (McCormick, Whitney, Schill & Quist, 2015).

To deal with sensitive questions, various specialised questionnaire-based techniques have been developed (Krumpal, 2013; Nuno & St John, 2015) based on the assumption that an increase in privacy-protection enhances the respondent's trust in the anonymity of the results and thus their honesty. Specialised questionnaire-based survey techniques do not reveal sensitive behaviour at the individual level, yet they enable researchers to obtain aggregate estimates (Fox & Tracy, 1986). This study aims to demonstrate how two specialised types of survey, the Randomised Response Technique (RRT; Warner, 1965) and the Bean Method (BM; Lau, Yeung, Mui, Tsui & Gu, 2011), can be used to monitor anglers' behaviour.

Study area and methods

Study area and data collection

The study area is located in the basin of the River Arno, Tuscany, Central Italy (Figure 1). The Arno is 241 km long (catchment area = 8,228 km2), originates in the Northern Apennines, drains six water courses located in different provinces with a high degree of urbanisation and discharges into the Tyrrhenian Sea. It is estimated that 69% of the aquatic animal species occurring in the Arno are non-native, including some major ecosystem engineers such as European catfish *Silurus glanis* L., red swamp crayfish *Procambarus clarkii* (Girard) and zebra mussel *Dreissena* *polymorpha* (Pallas) (Mari, Casagrandi, Pisani, Pucci & Gatto, 2009; Nocita, 2007). Fishing is regulated through regional legislation (Regione Toscana, law n.7, 12/01/2005). Anglers can fish in fresh waters provided they possess an annual license. Fishing without a license, unauthorised restocking and unauthorised holding of live fish are subject to fines of € 80–480. Furthermore, in several mountain water catchments, anglers cannot release live bait into the environment, as this constitutes a form of littering.

From November 2016 to January 2017, a sample of anglers (n = 750) was involved in a survey about compliance with existing regulations on angling and non-native species. Anonymous questionnaires were administered at fishing shops, where anglers were asked by survey operatives to complete a questionnaire and briefly explained to them the aim of the study. They also explained that questionnaires were anonymous and that they were not interested in individual answers but in having a global estimate of respondents' behaviour. Random sampling was impossible, as no public list of anglers existed for the study area, and purposive sampling (aka as judgemental, selective or subjective sampling), a type of non-probability sampling, was adopted. Respondents were randomly assigned to three different groups. The first group (n = 276) received conventional, direct-answer questionnaires (DQ), the second group (n = 260) received RRT questionnaires, and the third group (n = 240) was surveyed using the BM.

The RRT (Warner, 1965) and its variants are widely used to estimate the frequency of deviant behaviours and rule (law) violations (Blair, Imai & Zhou, 2015; Krumpal, 2013), even in natural resource management (Nuno & St John, 2015; Solomon, Jacobson, Wald & Gavin, 2007). These techniques require the respondent to use a randomising device (e.g. cards, coins, dice, spinners) to select which question will be answered. The outcome of the randomising device is known by the respondent only, and investigators are unable to know whether the respondent answered the sensitive question or a surrogate, thus maintaining the respondent's privacy. The RRT requires that respondents comply with the instructions (Loewenstein, Acquisti & Vosgerau, 2016), but this assumption is generally met when an adequate setting is created by the survey conditions (Lensvelt-Mulders, Hox, Van der Heijden & Maas, 2005). The RRT usually underestimates the real incidence of a sensitive behaviour, although with a much smaller deviation from the true value than direct questions (Lensvelt-Mulders et al., 2005).

The forced response design of the RRT, introduced by Boruch (1971) and refined by Fox and Tracy (1986), was used in this study. In the forced response design, the randomisation device determines whether respondents truthfully answer the question or just answer a forced “yes” or “no.” In the present case, a die was adopted, asking respondents to answer “yes” if the outcome was 1, to answer “no” if the answer was six and to answer honestly if the outcome was a number between two and five. This design is one of the most popular in applied research because it is relatively easy to implement and it is one of the most statistically efficient versions of the RRT (Blair et al., 2015).

In the BM (Lau et al., 2011), originally proposed to measure risky sexual behaviours among prostitutes in China, participants are instructed to answer one or more questions by moving small coloured units (e.g. pieces of cardboard, small plastic balls) from a small jar, to a bigger and sealed jar, with a known number of units. If the answer is positive, then respondents are asked to move a coloured unit, whereas in the case of negative answer they are asked to move a non-coloured unit (black or white). Privacy is protected because respondents are left alone when they answer the questions and because respondents can choose the unit they move, avoiding potential identification strategies, such as secret identifiers of invisible ink. At the end of the survey, the sealed jar is opened and the prevalence of each behaviour is estimated as the proportional increase in the number of coloured units. Although the BM is relatively easy to implement, it has never been applied in human dimension studies (Nuno & St John, 2015).

During the data collection, respondents in the RRT and DQ groups received a paper-and-pencil questionnaire, which took ≈10 min to complete. The questionnaire was structured in three sections. In the first, respondents were asked about their demographics, and they described their angling technique and sites. Furthermore, respondents expressed their beliefs about the likelihood that an angler engaged in four behaviours, based on a ten-point rating scale ("In your opinion, from 1 to 10, how likely is it that an angler"... "Goes angling without owning a fishing license"/"Throws away leftover worm baits, in the environment"/"Throws away leftover fish baits, in the water/"Releases some fish, fished somewhere else, in a river/lake"). Respondents also expressed their beliefs over the perceived level of discomfort experienced by an angler in admitting the four behaviours to other people, on a seven-point rating scale ("Please think again about the four behaviours mentioned above and imagine an angler, who is asked if he/she ever did them. In your opinion, how much would this angler feel uncomfortable answering? "... "Going angling without owning a fishing license"/"Throwing away leftover worm baits, in the environment"/"Throwing away leftover fish baits, in the water/"Releasing some fish, fished somewhere else, in a river/lake"). These projective questions measuring the perceived sensitivity of the various behaviours were not retained for data analysis, because we were not able to obtain unbiased information about respondents" real non-compliant behaviour, a necessary pre-requisite to test their predictive power towards individual non-compliance.

The second section aimed to quantify how many respondents engaged in the four behaviours constituting the focus of our study. Respondents were asked about three behaviours with potential consequences for aquatic invasions: releasing worm bait into the environment ("After a fishing session, do you ever throw away leftover worm baits, in the environment?"), releasing fish bait ("After a fishing session, do you ever throw away leftover fish baits, in the water?") and practicing fish restocking ("Do you ever release some fish you fished somewhere else, in a river/lake"). Fishing without a license was also included in the survey as a fourth target behaviour because it is a major form of non-compliance with profound implications for monitoring anglers and their behaviour ("Do you ever go angling without owning a fishing license?). A positive framing of the

RRT was achieved by introducing the technique as a “game” developed by researchers to ensure respondent’s anonymity.

In the last section of the questionnaire, respondents were asked to rate various items measuring their beliefs about illegal fish restocking on a seven-point rating scale. Once respondents filled out the questionnaire, they put it in a sealed urn that was opened at the end of the study: this guaranteed anonymity beyond the individual level (St. John et al., 2016). In the study, only the first and the second section of the survey were retained for data analysis.

In the BM, respondents were invited to participate by a survey operative, who introduced them to the technique and left them alone with a copy of the instructions to minimise further interactions. The two jars contained cardboard pieces of four different colours, one for each target behaviour (n = 1,000), as well as white cardboard pieces for negative answers. For each question, respondents were asked to move a piece of cardboard with a specific colour if the answer was “Yes,” or a white piece if the answer was “No.” The sealed jar was opened at the end of data collection.

A complete English version of the questionnaire, altogether with the instructions for the BM are available in the Supplementary Informations (Appendix S1, the Italian version is available on request).

Data analysis

To detect major sampling bias, the distributions of age, gender, level of education and anglers’ preference for various angling techniques in the RRT and DQ samples were compared. Age distributions were compared through Wilcoxon’s test and gender, level of education, fishing techniques and angling sites via the $\chi 2$ test. Respondents’ beliefs about the likelihood that an angler engaged in the four behaviours were compared with the Kruskal-Wallis test. As the protection mechanism of the BM minimises respondent’s interactions with survey operatives, individual demographic parameters in the BM sample were not collected.

To estimate the incidence of each one of the four target behaviours in the DQ and RRT samples, four logistic regression models were fitted with known conditional misclassification probabilities derived from a randomisation device (Van den Hout, van der Heijden & Gilchrist, 2007). As a response variable, a dummy question was used to learn whether respondents engaged in each behaviour or not. The models thus contained a dummy predictor that identified observations as RRT or DQ, and it was possible to compare prevalence estimates for the two groups. Standard errors were estimated with a sampling-based approach with 20,000 replicates from point estimates and the covariance matrix (Heck & Moshagen, 2014). In the BM, prevalence estimates were obtained by calculating the proportional increase in the number of coloured cardboard pieces in the sealed jar.

Results

The proportions of missing answers in the RRT and DQ samples were low (Table 1) and were comparable for gender, level of education, angling technique and sites. The RRT sample was younger than the direct response sample (Table 1). The Kruskal-Wallis test with the Tukey-Kramer post hoc comparison revealed significant differences in respondents' beliefs about the likelihood that an angler engaged in the four behaviours (Figure 2).

The RRT provided higher estimates of anglers' behaviour than direct questions (Figure 3). Differences between the RRT and the DQ were always significant at least at the $\alpha = 0.10$ level, which was the desirable threshold for the sample size (Blair et al., 2015). However, it was impossible to estimate the differences between the RRT and the DQ for fish restocking because the logistic regression did not converge. The BM always provided lower estimates than the RRT. Furthermore, the BM provided contradictory results, as its estimates were higher than the DQ for two behaviours only (fishing without a license, releasing worm baits), whereas it provided similar estimates for the release of fish bait and fish restocking.

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Discussion

Respondents to the RRT and DQ questionnaires were similar, yet the RRT provided higher estimates of all the four target behaviours. Despite the RRT respondents being on average 10 years younger than DQ respondents, this age difference is not believed to have undermined the findings. It could be hypothesised that older respondents might be more prone to rule-breaking behaviour, because social norms and sanctions about angling were different decades ago, but this is not the case for the present study area. All the behaviours considered in the present study maintained their normative status through time, with the exception of fish restocking, which was only banned in 2005: fishing without a license was always penalised in the study area, and local sanctions for improper live bait disposal have been enforced for decades. Although non-compliant behaviour tends to peak in late adolescence and decline with age (Sampson & Laub, 2003; Steffensmeier, Allan, Harer & Streifel, 1989), a younger sample could have had a higher proportion of non-compliant respondents. However, only a small proportion of the respondents were <20 years old and therefore, it was considered this did not create any substantial difference between the two groups.

The present results highlight the potential of the RRT in monitoring angler behaviour as a pathway for NNS introductions to aquatic ecosystems. Monitoring bait release is crucial to counteract biological invasions because bait species can have serious impacts on soil dynamics (Bohlen et al., 2004; Fugère, Bradley & Vellend, 2017), intertidal ecosystems (Watson, Murray, Schaefer & Bonner, 2016) and freshwater food webs (Nowak & Szczerbik, 2009). Of concern is a high proportion of anglers in the present study releasing alien macroinvertebrates and fish used as bait after fishing. The RRT provided higher prevalence estimates for these behaviours than conventional DQ: 47% vs 25% for macroinvertebrates and 27% vs 18% for fish. On the other hand, the logistic regression did not converge, and the RRT did not estimate the prevalence of fish restocking. This probably occurred because only a few anglers might actually engage in fish restocking. This conclusion seems to be supported by the low observed frequency in the DQ sample (≈12%), and respondents believing fish restocking was not as likely as the other behaviours among anglers (Figure 2). Previous evidence suggested that the RRT usually failed to estimate low-prevalence behaviours, and in the last few years, various studies have proposed more efficient approaches to accomplish this task, such as a multidimensional variant of the RRT (Cruyff, Böckenholt & van der Heijden, 2016) or practical applications of the Benford illusion (Diekmann, 2012). In future, it is recommended to test the effectiveness of these approaches, as low-prevalence behaviours can be critical for the release of aquatic NNS and fisheries managers need to adequately assess them to effectively counteract biological invasions. Moreover, the multidimensional RRT can also test respondents' compliance with the instructions and it would enable researchers to assess the quality of prevalence estimates. The results from the BM are contradictory, and it is currently not possible to explain why the method provided higher estimates than the DQ for the first two target behaviours but not for the last two. Also inexplicable is why the BM performed well for releases of worm bait but not for releases of fish bait, as these two behaviours imply the same formal sanctions. Various factors could be responsible for the inadequate functioning of the BM and future research about this technique and its cognitive processing by respondents is needed before its further application. Instead, other techniques should be adopted to triangulate prevalence estimates obtained with the RRT (Nuno & St John, 2015).

The present results have practical implications for managing recreational anglers. In methodological terms, RRT could provide a more realistic picture of angler behaviour and should be considered in future studies. All of the known studies about NNS-reelated angler behaviour have adopted direct questions, and this could have led researchers to obtain strongly-biased prevalence estimates. However, as the RRT is more demanding than conventional questions, an assessment of the potential sensitivity of the target behaviour is recommended prior to the survey. Vignette analysis could be a valuable approach to achieve such a goal (Auspurg & Hinz, 2014; Jasso, 2006). The use of the RRT can also provide valuable information to manage biological invasions in the study area. This extensive spread of non-native baits in freshwater ecosystems makes the case for normative changes in bait trading to mitigate the risk of biological invasions in Europe in the next few years. To obtain an effective reduction of the risk in the short term, current research indicates that proper bait disposal by anglers is crucial to avoid biological invasions of freshwater and estuarine ecosystems (Kilian et al., 2012). Because many anglers do not regard improper bait disposal as an undesirable be- haviour, information campaigns about aquatic invasions should be a first step towards improving disposal behaviour (Seekamp et al., 2016; Sharp, Cleckner & DePillo, 2016; Shaw, Howell & Genskow, 2014), provided that increased awareness will be coupled with an increased availability of waste bins around water bodies and fishing ponds.

The RRT showed that a high proportion of anglers in the study area (≈30%) fish without a license, and although non-compliance is not a vector of NNS per se, it poses serious constraints to the human dimension of research in the field of aquatic biological invasions and fisheries management. In survey research, random sampling is regarded as the gold standard because it rules out the unobserved sources of variability, allowing for robust inference about the statistical population (Vaske, 2008). Furthermore, some specialised questioning techniques that are commonly adopted to measure non-compliance, such as list experiments, require the random allocation of respondents to control groups (Nuno & St John, 2015). In human dimension research about fisheries, random sampling is traditionally ensured by drawing respondents from available angler registries (Bruskotter & Fulton, 2008), as this approach minimises the costs of sample recruitment and because randomising survey administration in the field is often impossible. However, this approach also assumes that the total angler population coincides with the population of listed anglers. The present results stress the need to obtain adequate preliminary information about angler non-compliance before drawing random samples of respondents to avoid sampling bias: when a high proportion of anglers fish without owning a license, available registers might provide a poor picture of the total population of anglers. Capture-mark-recapture methods, time-location or respondent-driven surveys could circumvent these sampling issues (Marpsat & Razafindratsima, 2010), yet they also require a careful planning phase, and future applications in this field of research are recommended.

The questionnaires used in the present study were in Italian, so the results may be representative of Italian-speaking anglers only. The study area hosts various cultural groups, notably one of the largest communities of Chinese descent in Europe (Denison & Johanson, 2009) and a significant proportion of Eastern European citizens. Previous research showed the importance of investigating ethnic minorities to understand better their traditions as potential pathways of biological invasions (Cole, Choudhury, Nico & Griffin, 2014), and future studies should address this issue by performing cross-cultural comparisons among anglers of different cultural groups.

In conclusion, this study used specialised questionnaire-based techniques, such as the RRT and the BM, to collect sensitive information about angler behaviour in invasion biology. Even when asked about relatively common behaviours, anglers may adopt self-protecting strategies that seriously bias their answers. This can lead researchers to underestimate pathways of NNS introductions into aquatic ecosystems, with serious consequences on the effectiveness of mitigation policies. However, the use of specialised questioning techniques, such as the RRT, provided higher prevalence estimates of those behaviours, but the BM did not provide any clear result and its use should be avoided. Finally, a high proportion of anglers fished without a license, and this form of non-compliance needs to be accounted for in future human dimension studies about anglers and aquatic invasions because it has profound influences on experimental design.

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Figures

Figure 1. Study area: the Arno river and its basin, in dark grey.

Figure 2. Respondents' beliefs about the perceived likelihood that an angler engages in the four behaviors ($\chi 2 = 90.544$, df = 3, $p < .01$). Boxplots represent the median and quartiles of the distributions. The y axis represents a 10-point rating scale.

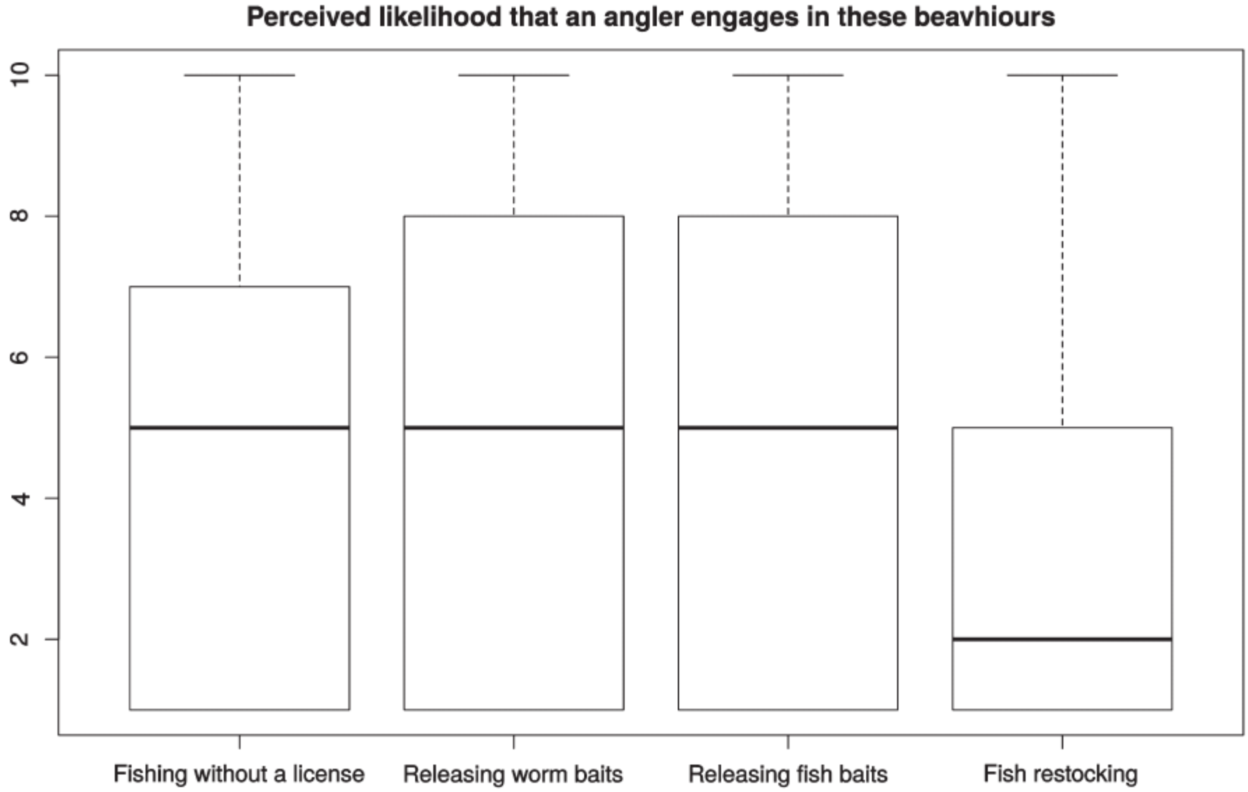
Perceived likelihood that an angler engages in these beavhiours
10
8
6
4
2
Fishing without a license
Releasing worm baits
Releasing fish baits
Fish restocking

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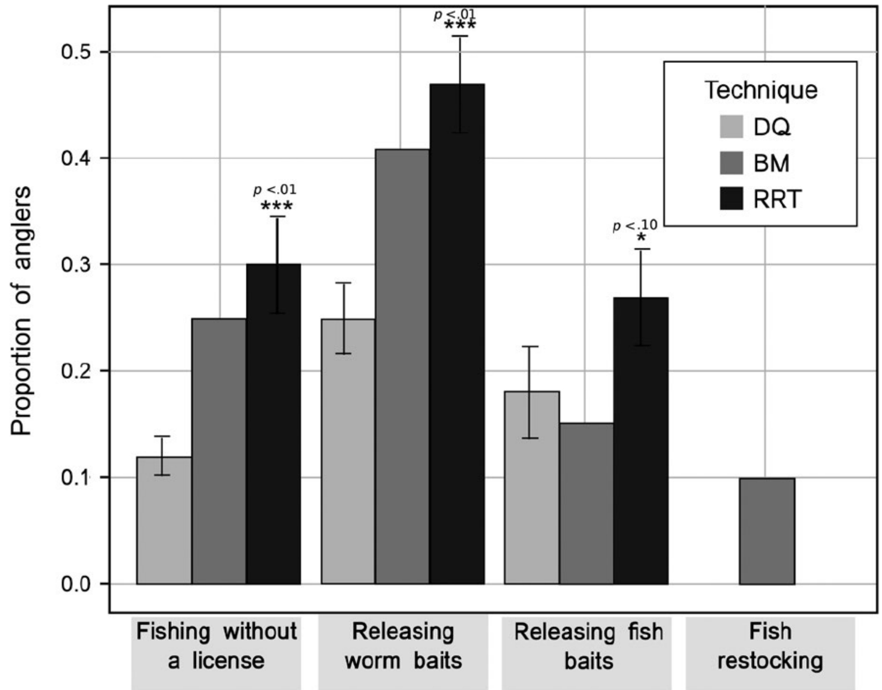
Figure 3. Estimated prevalence of the four behaviors, with the three methods. Parameter estimates and standard errors are available for Randomised Response Technique (RRT) and direct-answer questionnaires (DQ).



	Fishing without a license	Releasing worm baits	Releasing fish baits	Fish restocking
DQ	0.12 ± 0.019	0.25 ± 0.034	0.18 ± 0.043	–
BM	0.25	0.41	0.15	0.10
RRT	0.30 ± 0.045	0.47 ± 0.046	0.27 ± 0.045	–

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Tables

Table 1. Group comparison between Randomised Response Technique (RRT) and direct-answers questionnaires (DQ) according to respondents' demographics, level of education, angling site, angling technique and response rate, with mean ± SD, Wilcoxon's W and chi-squared χ2, and probability (p) values.

Variable	RRT	DQ	Statistical test
Age (years)	Mean = 39.0 ± 13.82	Mean = 49.62 ± 14.43 year	W = 38986, p < .01
Gender	Men = 98.7%,	Men = 96.9%	χ2 = 1.36, df = 1, p > .05
	Women = 1.3%	Women = 3.1%	
Level of education	Elementary school = 2%	Elementary=4%	χ2 = 4.49, df = 3, p > .05
	Middle school = 30%	Middle school = 36%	
	High school = 57%	High school = 48%	
	Degree or higher = 11%	Degree or higher = 12%	
Angling location (multiple choice)	Fishing ponds = 27.3%	Fishing ponds = 24.3%	χ2 = 2.5, df = 1, p > .05
	Fresh waters = 26.5%	Fresh waters = 27.8%	χ2 = 0.06, df = 1, p > .05
	Sea = 27.3%	Sea = 27.3%	χ2 = 0.03, df = 1, p > .05
Angling technique (multiple choice)	Coarse fishing = 30.6%	Coarse fishing = 30.0%	χ2 = 0, df = 1, p > .05
	Bait casting = 28.6%	Bait casting = 29%	χ2 = 0.12, df = 1, p > .05
	Fly fishing = 6.7%	Fly fishing = 5.9%	χ2 = 0.11, df = 1, p > .05
Overall proportion of missing answers in the questionnaire	Mean = 0.012 ± 0.017	Mean = 0.075 ± 0.23	-