

Identifying priority recreational fishing objectives for inclusion in harvest strategies

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Abstract

Harvest strategies are considered best practice for fisheries management and are increasingly being used to achieve stakeholder and policy objectives. However, the objectives of recreational fishers are often poorly understood by fisheries practitioners and rarely integrated into harvest strategies, reducing the likelihood of achieving desired fisheries performance for this sector. We developed a two-phase approach to identifying and prioritizing recreational fishing (RF) objectives and applied it to three fish stocks of recreational importance in New South Wales, Australia. Workshops with experienced recreational fishers identified a broad range of operational objectives for these stocks that spanned the four pillars of sustainability—ecological, economic, social, and managerial. A state-wide preference survey was then used to determine priorities among those objectives that could be addressed within a harvest strategy. Objective preferences were generally similar among stocks, respondent groups, and fisher types, with ecological objectives found to be most important, particularly maintaining enough fish overall and regionally to ensure healthy stocks and avoid localized declines. Social objectives were more important than economic objectives, although “trophy-sized” fish were considered relatively unimportant. Our findings suggest that objective preferences of recreational fishers within NSW are relatively consistent across fish stocks and sub-groups of the RF community.

Keywords: harvest strategies; recreational fishing; fishing objectives; prioritization; preference survey

Introduction

Recreational fishing (RF) is a popular activity and an important component of fisheries globally. It is distinguished from other types of fishing through the primary motivation of leisure rather than sale or subsistence. Approximately 10% of the developed world fishes recreationally (Arlinghaus et al. 2015, 2019) and 190 billion USD is spent on RF each year (World Bank 2012). The magnitude of RF catch is also substantial, with recreational harvest now equal to, or greater than, commercial catch for many species (Coleman et al. 2004, Cooke and Cowx 2006, Lewin et al. 2006, Ihde et al. 2011, Brown 2016, Hyder et al. 2018, Radford et al. 2018, 2019).

RF is often poorly managed compared to commercial fishing, despite the significance of the activity (Arlinghaus et al. 2019, Potts et al. 2020, Fowler et al. 2023). RF is not included

in fisheries policies or governance structures in many nations (Bower et al. 2020), and when included, is often managed using ineffective methods (Arlinghaus et al. 2019, Potts et al. 2020). In addition to threatening broader sustainability goals, this situation is likely to constrain the quality of RF experiences, increase angler dissatisfaction, and generate conflict between recreational fishers and other stakeholder groups due to inequity concerns. Inclusion of the RF sector in fisheries policy, legislation, and management frameworks, alongside other sectors, is therefore essential for achieving equitable and satisfactory fishery performance.

Harvest strategies provide an opportunity to integrate RF into fisheries management and achieve desired fishery performance for the sector and overall stock sustainability. Harvest strategies are a formal framework for resource management

that are increasingly being applied to fisheries globally due to their improvements on previous management approaches (Sainsbury et al. 2000, Froese et al. 2011, Dowling et al. 2015). Harvest strategies specify the monitoring, assessment, and management measures required to achieve fishing objectives (both stakeholder and mandated objectives; Sloan et al. 2014). Fishing objectives therefore lie at the core of harvest strategy development, and success of a harvest strategy relies on the inclusion of suitable objectives for all sectors in a fishery (Pascoe et al. 2019, Dichmont et al. 2020, Dowling et al. 2020). Yet to date, harvest strategies have focused on commercial fishing (Dowling et al. 2015, Dichmont et al. 2020), with RF either omitted entirely or included at a high level without specification of operational objectives or the harvest strategy components to achieve these (Ihde et al. 2011, Sloan et al. 2014, Griffiths and Fay 2015, Fowler et al. 2023). It is often assumed that fishery performance for the RF sector will be achieved by reaching commercial sustainability targets (e.g. biomass at maximum sustainable yield, B_{msy}), yet this is rarely confirmed with recreational fishers due to limited inclusion in consultative processes. Importantly, harvest strategies are distinct from decisions regarding allocation of resources among sectors (e.g. catch shares). Allocation decisions should be made prior to the development of harvest strategies but do not negate the need for inclusion of all sectors within the harvest strategy development process. A harvest strategy may, however, include an objective to maintain pre-determined allocations among sectors.

Limited understanding of the fishing objectives of recreational fishers (hereafter “RF objectives”) remains a major barrier to inclusion of the sector in harvest strategies for multi-sector fisheries. RF objectives are diverse and challenging to investigate due to the large and often untraceable number of individuals typically involved (Fedler and Ditton 1994, Pascoe et al. 2009, Fowler et al. 2022). While some catch-oriented objectives (e.g. high catch rates) are shared with other sectors, many additional objectives have been elicited from recreational fishers across the globe (Arlinghaus 2006, Young et al. 2016, Magee et al. 2018, Stephenson et al. 2018, Pascoe et al. 2019, reviewed by Fowler et al. 2022). These span all four pillars of sustainability—ecological, economic, social, and managerial—indicating the need to consider harvest strategy frameworks that can accommodate multiple indicator types and manage trade-offs among competing objectives (termed Quadruple-Bottom-Line harvest strategies, Fletcher et al. 2016, Stephenson et al. 2018, Dichmont et al. 2020). RF objectives may differ among fisheries, stocks targeted by different recreational subgroups, the type of utility provided by the target stock (e.g. eating quality), environments, and fishing methods used. Detailed investigation of RF objectives at the level of individual stocks is therefore required to understand the extent of variation in objectives and how this may affect the objectives and harvest strategy frameworks used for multi-sector fisheries. It should be noted that a large proportion of RF objectives lie outside the scope of a harvest strategy because performance against them is not related to stock abundance or life-history parameters influenced by fishing (Dowling et al. 2020, Fowler et al. 2022). These objectives need to be clearly identified during the objective elicitation process to avoid development of harvest strategies that cannot achieve performance for the sector.

Prioritization of fishing objectives is important for harvest strategy development. Harvest strategies function best with a

small number of objectives (Dowling et al. 2020), which is easily exceeded in a multi-sector fishery if each sector has specific objectives. Knowledge of the most important objectives across all stakeholder groups is therefore required to develop harvest strategies that can maximize fishery performance from the limited number of objectives included. While such information can be provided by sector representatives during the harvest strategy development process, the representativeness of their views is usually unknown. This issue is potentially magnified for the RF sector due to the diversity of sub-groups and their potentially divergent motivations and priorities. Structured surveys that adequately account for numerous sources of variation would assist with identifying priority objectives in a representative manner.

In this study, we identified RF objectives for three marine fish stocks of importance to the RF sector in New South Wales (NSW), Australia, and explored potential variation in priorities of fishers among stocks and recreational fisher sub-groups. Recreational fisheries in the state include both independent recreational fishers (line and spear) and charter operators that are hired by independent recreational fishers. The current study is timely because harvest strategy development has only recently commenced in the state and will include numerous stocks and fisheries with a substantial RF interest, including the three stocks examined here. RF is a substantial activity in NSW, with a participation rate of 11.9% and estimated total fishing effort of 1.7 million days per year (West et al. 2015, Murphy et al. 2023). Recreational fishers in NSW catch more than 140 species of bony fish, sharks, rays, crustaceans, molluscs, and polychaete worms each year, with 7.7 million organisms caught in the most recent survey year (2021/22, Murphy et al. 2023). Most fishing occurs in estuarine and marine waters.

A comprehensive list of objectives was first developed for each stock with experienced recreational fishers in a workshop setting, including charter operators. Participants were instructed to consider all potential objectives that any member of the RF community in the state of NSW might have. These included both objectives immediately related to a fishing event, often referred to as “motivations” (e.g. catching many fish, catching large fish), and broader objectives related to the state of the recreational fishery as a whole (e.g. stock sustainability, economic performance of the charter industry). Preferences among the harvest strategy objectives were then elicited from recreational fishers throughout NSW using a state-wide offsite survey. Respondents were instructed to focus on their own objectives when completing the survey, to ensure preferences related to their own fishing operations and demographic characteristics. The two-stage approach balanced the need for specialist knowledge to identify objectives for specific stocks with the need to obtain objective preferences from a broad cross-section of the RF community. The preferences will inform decisions regarding inclusion of particular objectives for the RF sector in harvest strategies for the three stocks investigated.

Methods

Ethics

This study was approved through the NSW DPI Fisheries Research Human Ethics process in accordance with the National Statement on Ethical Conduct in Human Research 2007

(“National Statement,” updated 2018, www.nhmrc.gov.au). Participation in this study was voluntary, and participants could opt out at any time. The identities of individuals contacted for the random survey component are kept confidential, consistent with the National Statement. Online surveys were completed anonymously.

Selected fish stocks

Three fin-fish stocks were identified as both important to recreational fishers in NSW and of interest for harvest strategy development in the near-term: Mulloway (*Argyrosomus japonicus*), Yellowtail Kingfish (*Seriola lalandi*), and Snapper (*Chrysophrys auratus*). All three stocks are distributed throughout coastal NSW, inhabiting all saline waters from estuaries through to coastal offshore, depending on season and life-cycle stage. All three species are prized sportfish with excellent eating qualities. Mulloway are often targeted in estuaries in NSW, where large individuals can be accessed using small boats or from shore. Yellowtail Kingfish and Snapper are primarily targeted on coastal reefs, with larger Yellowtail Kingfish typically found offshore. The most recent estimates of recreational harvest of Mulloway, Yellowtail Kingfish, and Snapper in NSW were 55 t, 114 t, and 94 t, respectively (Murphy et al. 2022). The recreational harvest of Yellowtail Kingfish exceeded the commercial harvest in that time period (57% of total harvest), with the recreational harvest of Mulloway and Snapper composing 44% and 34% of total harvest, respectively. The Mulloway stock has declined since the mid-1970s (Silberschneider et al. 2009) and was classified as depleted at the time of the workshops (Hughes et al. 2020), while both Yellowtail Kingfish and Snapper were classified as sustainable (Hughes and Stewart 2020, Stewart et al. 2020).

Workshops

Fishing objectives were elicited from RF stakeholders in NSW during online workshops held by NSW DPI Fisheries in March 2021. Workshops were held outside normal working hours, to increase participation of fishers located throughout the state and to comply with COVID-19 restrictions. Twenty active RF stakeholders were invited to attend the workshops based on their knowledge and experience targeting the selected stocks in NSW. These included independent recreational fishers and fishers associated with the charter and tackle industries. They were identified through other roles on representative committees and involvement in previous projects. Some RF participants had experience targeting all three stocks, while others specialized in just one of the three stocks. Other workshop attendees included fisheries scientists and managers from NSW DPI Fisheries, and fisheries scientists from CSIRO, the University of Wollongong, and the University of Tasmania. Workshops were facilitated by an independent scientist (J. Poppel) specializing in recreational fisheries.

Workshops consisted of a series of short (1.5–2 h) sessions designed to accommodate personal schedules and minimize fatigue. Workshops commenced with an information session that included (1) an outline of the project and purpose of the workshops, (2) a presentation on harvest strategies, and (3) presentations on current stock status, assessment, and management for each of the three stocks. RF stakeholders were then asked to consider their preliminary objectives for each stock in preparation for the next session.

Subsequent sessions were held separately for each of the three stocks. Facilitated group discussions were used to build a preliminary list of objectives for each stock. A generic list of RF objectives sourced from the scientific literature was provided as a guide (Table 1, reviewed by Fowler et al. 2022). Generic objectives were organized into three tiers—broad, sub-, and specific. The broad tier reflected the four major categories of fishing objectives—ecological/biological, economic, social, and managerial (Stephenson et al. 2018). Objectives then became increasingly specific through the lower two tiers. Participants were first divided into small (2–4 person) groups online to consider which of the generic objectives should be retained for a particular stock, which should be removed, and which objectives needed to be added. Findings from the small groups were then discussed with all attendees and different objectives across the small groups were combined for the stock. Between sessions, scientists and managers consolidated objectives that were similar and classified them according to whether they were suitable for inclusion in a harvest strategy (hereafter “harvest strategy shortlist”) or likely needed to be addressed through other management processes. These decisions were based on whether the objective could be achieved through control of harvest. The preliminary lists of objectives were then refined through further group discussion in remaining sessions. Following the sessions, scientists translated objectives in the harvest strategy shortlists into non-technical language, to increase comprehension within the state-wide survey component of the project (see below).

Survey implementation

Preferences among objectives in the harvest strategy shortlists were elicited from recreational fishers in NSW using online surveys. A separate survey was used for each of the three stocks, due to the minor differences in the objectives identified for each stock during the workshops (Table 2), and because preferences among objectives may differ among stocks, even when the objectives themselves are common.

Three groups of fishers were surveyed: (1) a random spatially stratified sample of NSW residents that hold either a 1- or 3-year RF licence (hereafter “random” group), (2) a self-selecting group that accessed the survey via the NSW DPI Fisheries website (hereafter “self-selecting” group), and (3) workshop participants (hereafter “workshop” group). For the random group, a sample of 20 000 fishers was randomly drawn from the database of NSW RF licence holders. This sample included charter operators, although the number of responses from this sub-group was low (see the “Discussion” section). The sample was spatially stratified across nine residential survey strata defined by the Australian Bureau of Statistics (Fig. 1), with the number of individuals selected from each stratum weighted according to the relative proportion of licence holders located in each stratum. Due to the much larger number of licence holders within the metropolitan Stratum 1 (greater Sydney, 49% of fishers), the number of individuals sampled from this stratum was down-weighted by two-thirds. This allowed greater sampling effort in other strata, increasing the chance of identifying target respondents in less populated areas. Stratum 10 was excluded from the survey because this represents a separate jurisdiction from NSW, the Australian Capital Territory (ACT). Fishers from the random group were sampled using a two-step telephone-online approach, where initial contact was made via telephone (mobile or landline)

Table 1. Generic list of RF objectives developed from a review of the scientific literature and provided to workshop participants as a base to assist their development of objectives specific to Mulloway, Yellowtail Kingfish, and Snapper in NSW.

Ensure ecological sustainability	
Catch fish	Reduce the number of fishless trips Maximize the number of fish caught per fisher day
Receive bites or strikes	Maximize the number of strikes or bites per fisher day
Obtain food	Maximize the number of legal-sized fish caught per fisher day
Catch large or “trophy” fish	Ensure “trophy” fish are available in the fishery Increase the chance of catching large fish
Ensure a sustainable fishery	Maintain sustainable stock biomass Increase fisher awareness of sustainable fishing practices Increase RF understanding of population biology and stock assessment Reduce fishing infringements
Avoid environmental impacts of fishing	Minimize mortality of bycatch species Minimize mortality of undersized fish Minimize interactions with Threatened, Endangered, Protected (TEP) species Minimize pollution generated by RF Reduce habitat damage Limit the transfer of aquatic pest species
Enhance economic performance	
Maximize the value of the recreational experience	Maximize the value of the recreational experience
Generate economic value for the RF industry	Maximize profit for RF charter industry Maximize profit for RF tackle industry
Generate economic value for communities	Maximize flow-on economic benefits to local communities
Minimize financial costs	Minimize cost of managing the fishery Minimize cost of compliance for charter industry
Maximize social outcomes	
Easy access to fishing locations	Improve physical access to fishing locations Optimize the number, size and quality of boat ramps
Improve participation in RF (“grow the sport”)	Increase the number of individuals participating in RF each year Increase time spent fishing
Compete against other fishers	Increase opportunities to compete in fishing tournaments
Equitable access to fish stocks	Maintain equitable allocation of catch among fishing sectors
Enhance social networks, or social capital	Increase networking opportunities within the RF community
Foster a positive public image of RF	Minimize negative public perception of environmental impacts Improve public understanding of socio-economic benefits of RF Minimize negative interactions with other aquatic users
Improve fishing knowledge	Increase knowledge of fishing techniques Increase knowledge of fishing locations Increase knowledge of target species
Enjoy the outdoors/nature	Maintain/improve the aesthetic beauty of fishing locations
Spend time with friends and family	Increase the time spent fishing with friends and family
Relaxation, or to reduce stress	Enhance the relaxative effect of fishing
To be on your own	Avoid interactions with other people
Enhance management performance	
Flexible management to meet RF needs	Broaden the range of rec-specific harvest strategy components used Optimize the period between harvest strategy reviews Include “breakout” rules for RF in harvest strategies
Transparent management	Increase consultation periods on management changes Improve the clarity of fisheries management documentation Improve the distribution of fisheries management information Simplify fishing regulations
Involvement in fisheries management processes	Increase recreational representation in fisheries management advisory processes Improve partnerships between recreational fishers and fisheries management Provide opportunities for co-management

Objectives are organized into three tiers of specificity; broad objectives (bold headings), sub-objectives (left column), and specific objectives (right column).

and a weblink to one of the three online surveys (see below) was then provided to the respondent if they (a) indicated willingness to complete the survey, and (b) had fished for at least one of the three stocks in the previous 12 months.

The survey was initially completed by the workshop group who were provided with weblinks to electronic versions immediately after completion of the workshops in March 2021. The random and self-selecting survey components then com-

Table 2. RF objectives hierarchy for Mulloway (*Argyrosomus japonicus*) in NSW.

Broad objective	Sub-objectives	Specific objectives
Ensure ecological sustainability	Ensure a sustainable fishery	Maintain enough fish overall to ensure a healthy stock Maintain enough fish regionally to avoid local declines in numbers Ensure a decent proportion of the stock can reach maximum size Ensure a decent proportion of the stock can reach legal size Ensure protection of spawning aggregations Ensure released fish have a high chance of survival Rebuild stocks in habitats previously known to support fish
	Minimize lost fishing gear and other waste	
Enhance economic performance	Maximize the dollar value of your RF experience Generate economic value for the RF industry	Maximize the dollar return for the charter fishing industry Maximize the dollar return for the fishing tackle industry
	Increase development of quality regional fisheries to promote tourism Minimize the cost of adhering to management regulations for the charter fishery Increase investment in the fishery to obtain best management outcomes	
Ensure social outcomes	Increase the number of individuals participating in RF each year Increase time spent fishing (with family and friends) Increase opportunities to compete in fishing tournaments Ensure that the share of catch between sectors is fair, according to pre-agreed proportions Improve RF experiences	Ensure a decent proportion of the stock can reach a trophy size Maintain enough fish overall to ensure quality fishing Maintain enough fish regionally to ensure quality fishing in local areas Ensure a good chance of encountering fish

Objectives here are considered suitable for inclusion in a harvest strategy and represent a subset of the full list (see Table S2). Bold objectives are additional objectives proposed for Yellowtail Kingfish and Snapper.

menced in the following year (March 2022). Simultaneously, telephone calls to the random group commenced, while social media posts were made on fishing-specific pages to communicate the survey's objectives and provide weblinks to potential self-selecting participants. A weblink to the survey was also provided on the RF homepage on the NSW DPI Fisheries website. Telephone calls to the random group commenced on 14 March 2022. The survey remained open for 6 weeks. The survey was provided in six different languages, including English, and was smart-phone-compatible. The surveys were produced using Qualtrics software (Qualtrics LLC). Fisheries scientists and managers involved in the study and workshop process did not complete surveys.

Survey content and calculation of preferences

The survey consisted of three parts, outlined below (example survey in Supplement 24):

Part 1—"Fishing practices"—contained questions about the respondent's fishing background, experience, and operations as they related to the specified stock within NSW waters.

Part 2—"Recreational fishing objectives"—asked respondents to score the relative importance of RF objectives for the specified stock within NSW waters.

Part 3—"About you"—contained questions on demographic characteristics of the respondents, including age and gender.

Multiple-choice responses were provided for questions in Parts 1 and 3. The objectives used in Part 2 were those from the harvest strategy shortlists developed during the workshops (Table 2). The hierarchy from broad to specific objectives was maintained in the survey by grouping objectives according to their position in the hierarchy. The three broad types of objectives (ecological, economic, and social) were presented to the respondent first (Fig. S1), then the sub-objectives within each broad group were compared, then the specific objectives within each sub-objective. The fourth broad category of objectives, managerial, was not included because the managerial objectives identified during the workshops are unlikely to be achieved by controlling harvest and hence lay outside the scope of a harvest strategy (see the "Discussion" section). Respondents were asked to score objectives according to their relative importance on a nine-point Likert-like scale, from

Weights for each objective (w_i) were then calculated using the geometric mean method (GMM; Crawford and Williams 1985), which performs better than the original method based on eigenvalues with respect to the influence of extreme preferences (Pascoe et al. 2019):

$$\omega_i = \frac{\left(\prod_{j=1}^n \alpha_{i,j}\right)^{1/n}}{\sum_i \left(\prod_{j=1}^n \alpha_{i,j}\right)^{1/n}}, \quad (3)$$

where $\prod_{j=1}^n \alpha_{i,j}$ is the product of relative scores across row i , and n is the total number of objectives being compared within a hierarchical group.

The GMM was applied within each group of objectives within each level of the hierarchy (e.g. Fig. S1). Weights for the three broad objectives were calculated together in a single GMM analysis. Then, weights were calculated for the sub-objectives within each broad objective, for example, weights were calculated for “ensure a sustainable fishery” and “minimize lost fishing gear...” within the “ecological” broad objective. Finally, weights for the specific objectives were calculated within each of the sub-objectives. Final weights for each objective were obtained by multiplying up through the objectives hierarchy, such that the final weight for a specific objective was obtained using $w_{\text{specific}} \times w_{\text{sub}} \times w_{\text{broad}}$. For example, the final weight for the specific objective “Maintain enough fish overall to ensure a healthy stock” would be obtained by multiplying the weight calculated at this level of the hierarchy by the weights calculated for the sub-objective “Ensure a sustainable fishery” and the broad objective “Ensure ecological sustainability” (Table 2).

Statistical analyses

Identifying respondent sub-groups

Respondent characteristics were first explored to identify potential sub-groups of recreational fishers within the pool of survey respondents. Identified sub-groups were then included as a categorical factor (“Cluster”) in preference models (see below), to test for potential differences in objective preferences among them. This was only undertaken for the random sample, because individuals in the other two respondent groups (self-selecting and workshop) were not drawn at random and may not, therefore, be representative of the operational and demographic characteristics of the broader RF population.

Responses regarding fishing operations and demographics from the random group were pooled across the three stocks and explored together using multivariate distance-based hierarchical clustering on nominal data types. Priority was given to operational characteristics of fishers that define when, where, how, and how often they fish, because operational objectives are most likely defined by characteristics of their fishing circumstances. Age and gender were then included because these were considered to be some of the most important demographic characteristics. Additional variables were not included to avoid potentially spurious clustering that can arise from the inclusion of extraneous variables that mask true cluster structure (Fowlkes and Mallows 1983, Milligan 1989). Given the clustering was only possible for the random response group, there was also the potential issue of including too many variables for the available data (Fraiman et al. 2008). The continuous variables of age, years of fishing experience and days fished per year were converted to categorical

variables for the cluster analysis by dividing the data range into seven categories of 10 units each.

Clustering was done using the *nomclust* package (Šulc et al. 2022) in R (v. 4.3.1), with the “Lin” dissimilarity measure (Lin 1998) combined with the average linkage method. Lin is based on the relative frequencies of the observed categories, assigning higher weights to more frequent categories in the case of a match and lower weights to less frequent categories in the case of a mismatch. The average linkage method uses the average pairwise dissimilarity between objects in two merged clusters, which differs from other linkage methods that use only a single dissimilarity value to determine the distance between clusters. The combination of Lin dissimilarity and average linkage has been found to provide the most coherent clusters (Šulc and Rezanková 2019). Evaluation of the optimal number of clusters was done using a suite of methods that differ in how cluster quality is determined. Methods were the pseudo-F index based on entropy (PSFE), the pseudo-F index based on mutability (PSFM), the “Best K” index (BK), the modified Akaike’s Information Criterion (AIC) and Bayesian Information Criterion (BIC) indices, and the silhouette index (SI). PSFE, PSFM, BK determine cluster quality based on the degree of within-cluster variability, BIC and AIC are likelihood-based, and SI determines cluster quality using within- and between-cluster distances. The optimal number of clusters (four) was determined according to majority consensus across these methods (Šulc et al. 2022). Dendrograms of three- and five- cluster scenarios were also produced to visually examine cluster integrity.

To identify specific variables contributing to cluster separation in the optimal scenario, each operational and demographic variable was compared between the four clusters using univariate statistical methods. ANOVA was used for the original continuous data for age, years fished and days, while chi-squared tests were used for the nominal variables (targeting, habitat, region, method, fishing platform, and gender).

Modelling of preference weights

Preference weights were compared among objectives, stocks and respondent groups using generalized linear mixed models (GLMMs; Bolker et al. 2009). Each level of the objectives hierarchy was analysed separately; for example, broad objectives were analysed separately from specific ecological objectives. This was done because final preference weights are determined by multiplying individual weights through the hierarchy, such that final weights tend to become smaller at lower hierarchical levels that are subject to greater multiplication. All three respondent groups (random, self-selecting and workshop) were predictors in each analysis. All three stocks were included as predictors, where each stock had the same objectives within a level of the hierarchy. The full model structure, when all stocks were included, was

$$W = \beta_0 + \beta_1 x_{1,ij} + \beta_2 x_{2,ij} + \beta_3 x_{3,ij} + \beta_4 x_{1,ij} x_{2,ij} + \beta_5 x_{1,ij} x_{3,ij} + a_{1,i} + \varepsilon_{ij},$$

where W represents the preference weight, β_0 is the vertical intercept, β_1 , β_2 , and β_3 are the regression coefficients for the independent parameters Objective (x_1, ij), Stock (x_2, ij), and Group (x_3, ij), β_4 and β_5 are the regression coefficients for the two-way interactions between Objective and Stock and Objective and Group, $a_{1,i}$ represents the random variable Respondent and, ε_{ij} represents the error term.

Objective was treated as a fixed categorical effect, with the number of levels varying depending on the number of objectives within each analysis. Stock was treated as fixed with three levels—Mulloway, Yellowtail Kingfish, and Snapper. Group was treated as fixed with three levels—random, self-selecting, and workshop. Key model terms relevant to the study aims were Objective, which tested for differences in preference weights among objectives within a level of the hierarchy, Objective:Stock, which tested whether the pattern of weights across objectives differed among stocks, and Objective:Group, which tested whether the pattern of weights across objectives differed among respondent groups. The Respondent term was a unique identifier for each survey respondent, treated as a random effect to address the fact that each respondent provided data for multiple objectives. A normal distribution for the random effect was assumed. This term was included in all models.

Preference weights were also compared among the clusters identified within the random respondent group using the same GLMM approach as above. The full model structure was

$$W = \beta_0 + \beta_1 x_{1,ij} + \beta_2 x_{2,ij} + \beta_3 x_{1,ij} x_{2,ij} + a_{1,i} + \varepsilon_{ij},$$

where β_1 and β_2 are now the regression coefficients for the independent parameters Objective (x_1, ij) and Cluster (x_2, ij), β_3 is the regression coefficient for the two-way interaction between them, and $a_{1,i}$ represents the random variable Respondent.

Cluster was treated as a fixed categorical effect with four levels (from the optimum scenario, see the “Results” section). Note that data were pooled across stocks for cluster analysis, so a Stock term was not included within these models. The focus of these analyses was to test whether the preference weights among objectives differed among clusters of recreational fishers; hence, the focal model term was Objective:Cluster.

The best combination of fixed effects was identified using model selection based on model fit and parsimony determined by AIC. Models were initially run using maximum likelihood estimation, to ensure comparable likelihood among candidate models. The best model was then rerun using restricted maximum likelihood to produce unbiased estimates of the variance components (Bolker et al. 2009). Efron’s pseudo- r^2 was calculated for each model, which is a suitable metric for examining variance explained in logistic models (Efron 1978). Tukey’s tests adjusted for multiple comparisons were used to compare means among objectives within respondent groups. Expected (mean) values were estimated conditional on the predictor values and random effect.

Data used in the GLMMs were explored prior to analysis using boxplots, Cleveland plots, and scatterplots following the protocol of Zuur et al. (2010). These visual tools were used to identify potential data errors, outliers, and examine variable distributions. Given that the response variable (Weight) was continuous and bounded by 0 and 1, the ordered beta distribution with logit link was used (Kubinec 2023). The suitability of this distribution was confirmed visually using standard model diagnostic plots, including Q–Q plots of residuals.

The dichotomous key of Leroux (2019) was used to check for potentially uninformative parameters within selected models; specifically, that all terms included in the best models improved the AIC value by more than 2, or, if two models were within AIC of 2, the selected model and included terms did not

incorporate any parameter from lower-ranked models with more parameters. Wald tests of coefficients are also provided for model terms within best models (Table 4, Tables S5–S23).

Modelling was done in R (ver. 4.3.1, R Foundation for Statistical Computing, Vienna, Austria) using the *glmmTMB* function from the “glmmTMB” package (Brooks et al. 2023). Model diagnostics were produced using the “DHARMA” package (Hartig 2022).

Results

Objectives from the workshops

Eight workshop sessions were completed, involving a total of 14 h of contact time with participants. Most sessions were attended by at least 10 recreational fishers, while objective sessions for Snapper were attended by six fishers.

Here, we focus on the shortlists of harvest strategy objectives, which were a subset of the complete lists developed in the workshops and used in the preference surveys. The complete lists of objectives, including objectives judged to lie outside the scope of a harvest strategy, are presented in Tables S2–S4. Objectives in these lists retain the technical language used during initial development, prior to translation into non-technical language for the preference survey.

The shortlist of harvest strategy objectives developed for Mulloway in the workshops is presented in Table 2. Objectives were similar among the three stocks, hence a single list has been presented for brevity, and the minor variations among stocks are indicated in Table 2 and outlined below. The three separate lists were used in the survey. The shortlists included 20–21 sub- or specific objectives, depending on the stock (Table 2). They spanned three of the four broad categories—ecological, economic, and social. None of the managerial objectives were considered suitable for inclusion in a harvest strategy because they were unlikely to be achieved by controlling harvest. Ecological objectives primarily related to aspects of sustainability, such as maintaining healthy stocks and ensuring a reasonable proportion of fish reached legal size. Economic objectives included maximizing the value of the RF experience, generating revenue for RF industries, and promoting quality regional fisheries. Social objectives included growing the sport, increasing time spent with friends and family, and improving recreational experiences. Numerous social objectives were related to ecological objectives, for example, the social objective “Ensure a decent proportion of the stock can reach trophy size” relates directly to the ecological objective “Ensure a decent proportion of the stock can reach maximum size.” Maintaining stock biomass was considered an ecological objective in the context of stock sustainability, but also a social objective from the perspective of ensuring quality fishing.

Minor differences in ecological and social objectives were observed among stocks (Table 2). Concern regarding post-release mortality of Mulloway led to the inclusion of an additional sustainability objective for that stock: “Ensure released fish have a high chance of survival.” Tournament fishing was also not considered an objective for this stock, hence the social objective “Increase opportunities to compete in fishing tournaments” was omitted. A desire to recover localized populations of Snapper led to the inclusion of the ecological objective “Rebuild stocks in habitats previously known to support fish” for that stock.

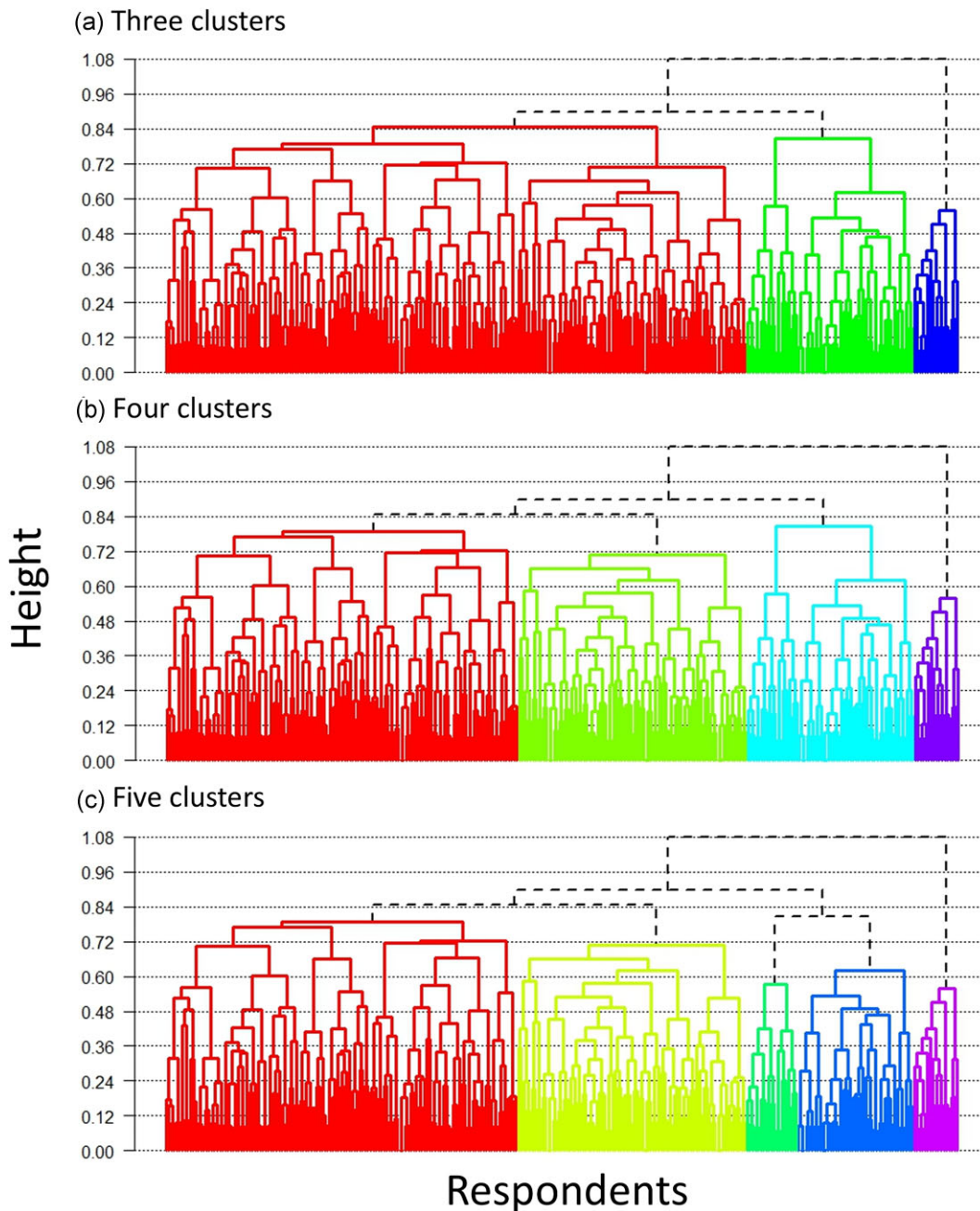


Figure 2. Dendrograms produced from distance-based hierarchical clustering of operational and demographic characteristics of the random respondent group. The result for the optimal number of clusters is shown in Panel b, while results for lower and higher cluster scenarios are shown in Panels a and c, respectively. Colours indicate separate clusters.

Survey responses

A total of 562 complete survey responses were received (Table S1). The greatest number was received from the random group (321), followed by the self-selecting group (224) and then the workshop group (17). The response rate for the random group was 5.9%. The response rate for the self-selecting group cannot be calculated, because the number of individuals that became aware of the survey is unknown.

Survey responses were spread relatively evenly across the three stocks (30%–39% each). Given the relatively few surveys available from the workshop participants, information on demographics and fishing practices are not presented for this group. This group was, however, included in

analyses of preference weights. Nearly all respondents indicated they were independent recreational fishers with no other type of involvement in the fishery. A small proportion (1.3%) of respondents indicated their main involvement was as charter operators, and all but one of these indicated secondary involvement as an independent recreational fisher.

Across both the random and self-selecting surveys, the average age of respondents was 47 years, and 94% of respondents were male. Respondents had an average of 19 years' experience fishing for the stock for which they elected to complete a survey and had spent an average of 29 days per year fishing for that stock during the previous three years.

Respondent clusters

Based on the operational and demographic variables provided, four clusters of respondents within the random respondent group were determined to be optimal by the majority of cluster evaluation methods (PSFE, PSFM, BIC, and BK, Fig. S2). The remaining two methods, AIC and SI, identified six and two clusters, respectively. The agglomerative coefficient was 0.85.

Primary cluster separation within the optimal scenario (four clusters) occurred between a small group of respondents and the remainder (Panel b, Fig. 2). This small cluster was maintained across the lower and higher cluster scenarios (Panels a and c, Fig. 2). Remaining respondents in the optimal scenario were then separated into three larger clusters, with one cluster (light blue, Panel B) being maintained in the three-cluster scenario (green, Panel a), and the other two clusters (red and green, Panel b) being maintained in a five-cluster scenario (red and yellow, Panel c).

Most operational and demographic characteristics differed among the clusters (Fig. 3). Univariate comparisons for continuous variables indicated that age, years fished, and days fished per year all differed among clusters in the optimal (four cluster) scenario (ANOVA: age— $F_{3,291} = 14.63$, $P < .001$, years— $F_{3,291} = 9.96$, $P < .001$, days— $F_{3,291} = 4.39$, $P = .005$; Fig. 3). Respondents in Cluster 2 were the oldest, while respondents in Cluster 3 were the youngest (Tukey's HSD: $P < .05$; Fig. 3). Respondents in Clusters 1 and 2 spent more years fishing for one of the three target stocks than respondents in Clusters 3 and 4 (Tukey's HSD: all $P < .05$; Fig. 3), with mean years' experience in Cluster 2 more than double that of Cluster 4. Respondents in Cluster 1 spent more days per year fishing for one of the three target stocks than respondents in Clusters 3 and 4 (Tukey's HSD: all $P < .05$; Fig. 3).

With respect to categorical variables, the proportion of respondents fishing in each region did not differ significantly among clusters ($\chi^2(6, 295) = 9.43$, $P = .151$). Respondents were spread relatively evenly among North, Central, and South regions (Fig. 3A). A greater proportion of respondents in Cluster 2 fished offshore compared to other clusters ($\chi^2(6, 295) = 88.99$, $P < .001$; Fig. 3B). With respect to targeting behaviour, a large proportion of respondents in Cluster 1 considered the stock in question to be a primary target, whereas most respondents in other clusters considered the stock to be one of numerous targets ($\chi^2(6, 296) = 69.79$, $P < .001$; Fig. 3C). Most respondents in Cluster 3 fished from land, whereas most respondents in other clusters fished from a boat ($\chi^2(3, 295) = 127.87$, $P < .001$; Fig. 3D). A greater proportion of respondents in Cluster 1 used live bait compared to other clusters; the majority of respondents in other clusters used dead bait ($\chi^2(12, 301) = 100.88$, $P < .001$; Fig. 3E). All respondents in Cluster 4 were female, whereas all, or nearly all, respondents in other clusters were male ($\chi^2(3, 298) = 223.59$, $P < .001$; Fig. 3F).

Although the proportion of respondents completing surveys for each of the three stocks also differed significantly among clusters ($\chi^2(6, 295) = 48.12$, $P < .001$), clusters were not aligned with single stocks, and all three species were represented in each cluster (Fig. 3G). Clusters 1 and 3 had similar composition to each other with respect to the stock of interest, as did Clusters 2 and 4.

Preference weightings—comparisons among objectives, stocks, and respondent groups

The best model identified for most levels of the objectives hierarchy included the terms Objective, Group, and the interaction between Objective and Group, but did not include Stock or the associated interaction term (Table 3). There were only two departures from this; the best model for specific ecological objectives for Snapper did not include the interaction between Objective and Group, and the best model for specific social objectives included all terms, including Stock and the interaction between Objective and Stock. Models explained between 24% and 80% of variability in preference weights (Table 3). No uninformative parameters were identified using the approach of Leroux (2019), with AIC for the best model exceeding the next most supported model by ≥ 2 in all but two cases—economic sub-objectives (Analysis 6) and specific social objectives (Analysis 10). In neither of these cases was the extra parameter in the next most supported model included in model interpretation. P -values supported the inclusion of all model terms at the 0.05 level.

For the analysis of broad objective types (Analysis 1, Table 3), preference weights for ecological objectives were higher than those for either economic or social objectives in all respondent groups (Table 4; Fig. 4). Preference weights for social objectives were higher than those for economic objectives, except in the workshop group where these did not differ. For ecological sub-objectives (Analysis 2, Table 3), preference weights for ensuring a sustainable fishery were higher than those for minimizing lost fishing gear and other waste in all respondent groups.

Analyses for specific ecological objectives were completed separately for each stock due to the slightly different objectives among them (Analyses 3–5, Table 3). Despite the selection of an interaction term for Mulloway and Yellowtail Kingfish, patterns of preference weights across objectives were relatively consistent among respondent groups and stocks (Panels 3–5, Fig. 4). Preference weights for maintaining enough fish overall to ensure a healthy stock were generally the highest, while those for ensuring protection of spawning aggregations and ensuring released fish have a high chance of survival were generally the lowest (Panels 3–5, Fig. 4). Preference weights for other objectives were typically intermediate and rarely differed from each other. Preference weights from the workshop group had a greater range and variance than other respondent groups.

For economic sub-objectives (Analysis 6, Table 3), preference weights were highest for increasing investment in the fishery to obtain best management outcomes, except for the workshop group which also highly weighted increasing development of quality regional fisheries to promote tourism (Panel 6, Fig. 5). The objective of minimizing the cost of adhering to management regulations for the charter fishery received the lowest weights.

For specific economic objectives (Analysis 7, Table 3), preference weights were higher for maximizing the financial return for the fishing tackle industry than the charter fishing industry, and this pattern was consistent across all respondent groups (Panel 7, Fig. 5).

For social sub-objectives for Mulloway (Analysis 8, Table 3), preference weights were highest for the objectives of ensuring that catch share between sectors is fair according to

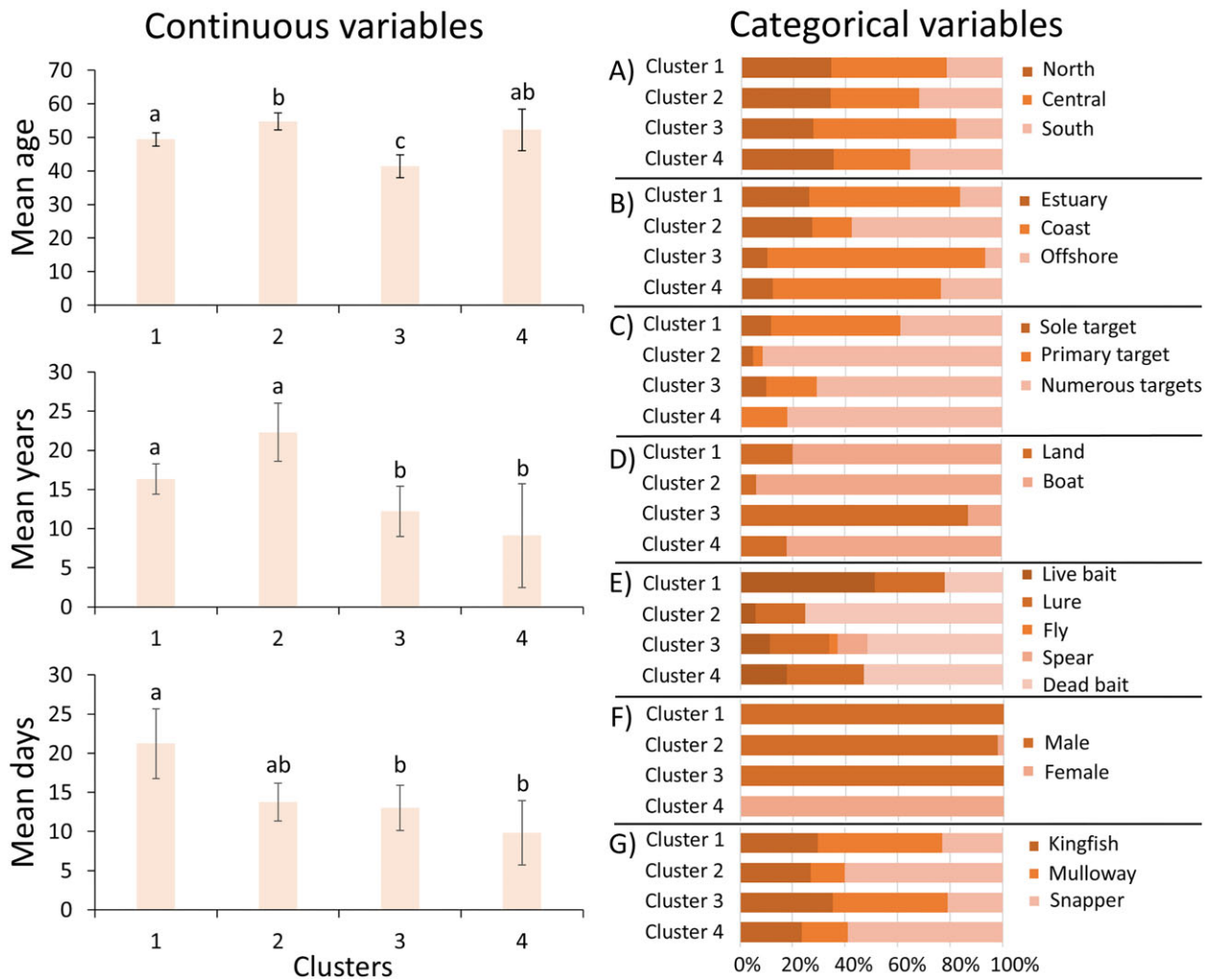


Figure 3. Continuous and categorical characteristics of survey respondents within the four clusters identified in the optimal scenario. Error bars indicate 95% confidence intervals. Clusters that share a lowercase letter were not significantly different from each other. Proportional composition of clusters are shown for seven categorical characteristics: (A) region fished, (B) habitat fished, (C) targeting behaviour, (D) fishing platform, (E) fishing method, (F) gender, and (G) target species.

pre-agreed proportions and improving catch-related RF experiences (Panel 8, Fig. 5). Increasing the number of individuals participating in RF each year received consistently low weights across respondent groups (Panel 8, Fig. 5). Increasing the time spent fishing with family and friends also received a lower weighting from the self-selecting and workshop groups. Results for Yellowtail Kingfish and Snapper (Analysis 9, Table 3) were similar to those for Mulloway, with the additional objective of increasing opportunities to compete in fishing tournaments also receiving relatively low weight (Panel 9, Fig. 6).

For specific social objectives (Analysis 10, Table 3), most objectives received similar preference weights, except for ensuring a decent proportion of the stock can reach a trophy size, which received the lowest weights for both Yellowtail Kingfish and Snapper (Panel 10a, Fig. 6) and the lowest weight from the random and self-selecting respondent groups (Panel 10b, Fig. 6). Trophy-sized fish received a similar weight to other objectives from the workshop group.

Preference weightings—comparisons among objectives and clusters

The best model identified for most levels of the objectives hierarchy included only the Objective term, not Cluster (Table 5). There were two departures from this; the best models for specific economic objectives (Analysis 7) and specific social objectives (Analysis 10) both included Cluster and the interaction between Objective and Cluster. Models explained between 14% and 79% of variability in preference weights (Table 5). The effect of Objective on preference weights is already outlined in the preceding section and is presented in Figs. 4–6. For the interaction between Objective and Cluster for specific economic objectives (Analysis 7, Table 5), preference weights were higher for maximizing the dollar return for the fishing tackle industry than the charter fishing industry for Clusters 1 and 2 but not Clusters 3 and 4 (Panel 7, Fig. 7). For the interaction between Objective and Cluster for specific social objectives (Analysis 10, Table 5), preference weights were similar among objectives, except for ensuring a decent proportion

Table 3. Best models identified from GLMM analyses of preference weights among objectives, stocks, and respondent groups.

Analysis description	Model structure/terms	Pseudo r^2 (Elfron's)	Model description
1. Broad objectives—All stocks included	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.53	Objectives, respondent groups and their interaction
2. Ecological sub-objectives—All stocks included	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.24	Objectives, respondent groups and their interaction
3. Specific ecological objectives—Mulloway	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.42	Objectives, respondent groups and their interaction
4. Specific ecological objectives—Yellowtail Kingfish	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.52	Objectives, respondent groups and their interaction
5. Specific ecological objectives—Snapper	Weight ~ Objective + Group + (1 Respondent)	0.47	Objectives and respondent groups, no interaction
6. Economic sub-objectives—All stocks included	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.47	Objectives, respondent groups and their interaction
7. Specific economic objectives—All stocks included	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.80	Objectives, respondent groups and their interaction
8. Social sub-objectives—Mulloway	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.43	Objectives, respondent groups and their interaction
9. Social sub-objectives—Yellowtail Kingfish and Snapper	Weight ~ Objective + Group + Objective:Group + (1 Respondent)	0.52	Objectives, respondent groups and their interaction
10. Specific social objectives—All stocks included	Weight ~ Objective + Stock + Objective:Stock + Group + Objective:Group + (1 Respondent)	0.66	Full model

Separate analyses were conducted for each level of the objectives hierarchy (see Table 2). Separate analyses were also conducted for stocks where their objectives differed within a level of the hierarchy. Model selection was based on AIC. Respondent was included as a random effect in all models.

of the stock can reach a trophy size, which received the lowest weights across all clusters (Panel 10, Fig. 7).

Discussion

The broad range of objectives identified for Mulloway, Yellowtail Kingfish, and Snapper by recreational fishers during the workshops indicates the sector has diverse interests in these stocks in NSW. While numerous ecological and economic objectives were identified, including those often associated with maintaining sustainable stocks and generating revenue for RF-related industry, many social and managerial objectives were also retained from the generic list provided to workshop participants (Tables S2–S4). This finding suggests that maximizing fishery performance for the NSW RF sector will require consideration of objectives that extend beyond the objectives typically addressed in harvest strategies. This finding in NSW is consistent with investigations into RF motivations globally, which have shown that satisfaction of recreational fishers is linked to both catch- and non-catch-related motivations (Arlinghaus 2006, Beardmore et al. 2011, Cooke et al. 2018, Arlinghaus et al. 2020).

Given that all ecological objectives, most economic objectives, and some social objectives identified in the workshops were considered suitable for inclusion in harvest strategies, such strategies appear to have considerable potential to deliver fishery performance for the RF sector in NSW. Decisions regarding suitability for inclusion were based on whether objectives were likely to be influenced by harvest—a prerequisite for achieving an objective through harvest control (Deroba and Bence 2008). The effect of this control was expected to be indirect for some objectives, for example, it was still considered possible for harvest control to promote tourism, by assisting the development of quality regional fisheries through increases in fish abundance. Such links with ecological performance may also help to achieve some of the numerous social objectives identified. We recommend a thorough exploration of RF objectives be undertaken prior to, or during, the initial phase of harvest strategy development, to understand both direct and indirect performance potential of a harvest strategy for the RF sector. While the extent of consultation achieved in the current study is unlikely to be feasible for every fishery, some exploration of objectives can be achieved via a smaller number of RF representatives, providing they are included early enough in the harvest strategy development process. Despite their considerable potential, harvest strategies are likely unsuitable for achieving fishery performance against many social and managerial objectives identified for recreational fishers. Addressing such objectives via alternative management processes is likely essential for maximizing fishery performance for the sector; for example, development of an allocation policy prior to harvest strategy development.

Results from the preference surveys suggest that recreational fishers within NSW have distinct priorities regarding fishing objectives that are relatively consistent across fish stocks and sub-groups of the RF community. The shortlists of harvest strategy objectives developed separately for each of the three stocks exhibited few differences, despite considerable differences in targeting methods and fishing locations. With respect to preferences among those objectives, the model interaction term “Objective:Stock” was only selected for in one of the ten statistical models across the objectives’ hierarchy, indi-

Table 4. Model results for the best model of preference weights for broad objectives (Analysis 1, Table 3) showing model terms, coefficients on the logit scale and original scale, and *P*-values representing the results of Wald tests of difference from 0.

Model term	β	Back-transformed	<i>P</i>
		β	
(Intercept)	0.130	0.532	<.001
Objective—Economic	− 1.507	0.181	<.001
Objective—Social	− 1.115	0.247	<.001
Group—Self-selecting	0.155	0.539	.006
Group—Workshop	0.356	0.588	.025
Objective—Economic : Group—Self-selecting	− 0.239	0.441	.006
Objective—Social : Group—Self-selecting	− 0.258	0.436	.002
Objective—Economic : Group—Workshop	− 0.417	0.397	.086
Objective—Social : Group—Workshop	− 0.642	0.345	.007

Full model results for all best models are presented in Tables S5–S23.

cating little difference in objective preferences among stocks. Although the best performing models typically included an interaction between objectives and respondent groups, the pattern of preferences among objectives was mostly consistent across the three groups examined. Objective preferences also rarely differed among sub-groups (or clusters) of recreational fishers identified by their demographic and fishing operational characteristics. Our findings contrast with those of numerous studies that have found differences in motivational importance among stocks, angler types, or both (e.g. Fedler and Ditton 1994, Wilde et al. 1998, Beardmore et al. 2011, Arlinghaus et al. 2020), perhaps indicating an effect of regional context, given that much of the previous research has been completed in North America and Europe. The preferred objectives identified in the current study may represent the core interests of a broad range of recreational fishers in NSW and should be considered when developing harvest strategies for the three stocks examined. Given objective preferences differed little among stocks, the preferred objectives from the current study may also provide a useful reference when developing harvest strategies for other stocks in the state, although the extent to which these objectives for the three stocks examined represent those of the breadth of stocks fished recreationally in NSW is unknown.

While considerable research has been conducted on the interests, motivations, and objectives of recreational fishers (Fedler and Ditton 1994, Arlinghaus 2006, Young et al. 2016, Magee et al. 2018, Stephenson et al. 2018, Pascoe et al. 2019, Fowler et al. 2022), this has rarely been in the context of harvest strategy development. It is therefore unclear whether previously determined preferences for the RF sector are suitable for identifying priority objectives for harvest strategies. For broad types of harvest strategy objectives, our findings are similar to those identified for recreational fishers in the Coral Reef Finfish Fishery (CRFFF) in Queensland (Qld), Australia, where ecological objectives received higher preference weights than economic, social, and managerial objectives (Pascoe et al. 2019). While the number and type of objectives included in the decision hierarchy of Pascoe et al. (2019) differed to some extent compared to the current study, the broad (highest level) objectives were similar, and preference weights for these objectives are not influenced by the weights determined for objectives lower down in the hierarchy (see weight multiplication in the “Methods” section).

A recreational preference for ecological objectives potentially simplifies harvest strategy development for multi-sector fisheries, because these are likely to be shared with other

sectors to a large extent. Maintaining a sustainable stock biomass, for example, is a prerequisite for all forms of fishery performance and therefore represents a common objective, although the preferred amount of biomass (i.e. target reference point) may differ among sectors. Common objectives among sectors will help limit the total number of objectives that need to be included in multi-sector harvest strategies, which will reduce the complexity associated with developing control rules that optimize trade-offs among competing objectives (Dowling et al. 2020). Prioritization of ecological objectives may also reduce the number of economic and social objectives that need to be included within harvest strategies, further limiting the complexity and data limitations often associated with addressing the Triple- or Quadruple Bottom Line (TBL/QBL, Elkington 2006, Dowling et al. 2020). For example, considerably more RF data is available in NSW to monitor fisheries performance against ecological objectives than either economic or social objectives (Fowler et al. 2022). A hierarchical priority of objective types is warranted, where economic and social objectives are pursued only once ecological performance is achieved. This can be achieved by linking trigger and limit reference points to ecological performance, while target reference points address a broader suite of ecological, economic and social goals. The ecological objectives developed in the current study focused on the ecological aspects of target stocks, which are distinct from ecosystem objectives that extend beyond the target stock. Knowledge of sectoral preferences regarding broader ecosystem objectives, including the need to limit harvest of target stocks to reduce catch of vulnerable non-target species, would assist development of TBL/QBL harvest strategies.

The preference for specific ecological objectives related to maintaining “enough fish” (both locally and population-wide) might be expected, given that the alternate ecological objectives offered within the survey were related to more specific aspects of stock biology and ecology (e.g. “Ensure released fish have a high chance of survival”). The finding suggests that survey respondents possessed an understanding of the general benefit to fishery performance arising from sufficient stock biomass. However, it should be made clear to recreational fishers, and indeed all fishery stakeholders, that temporary reductions in harvest may be required to build stock biomass to a desired level. This may conflict to some degree with catch-related objectives that centre on fish retention. The minimal differences in preference weights among most specific ecological objectives in the current study are likely due in part to the “dilution” of weightings at lower levels of the objectives

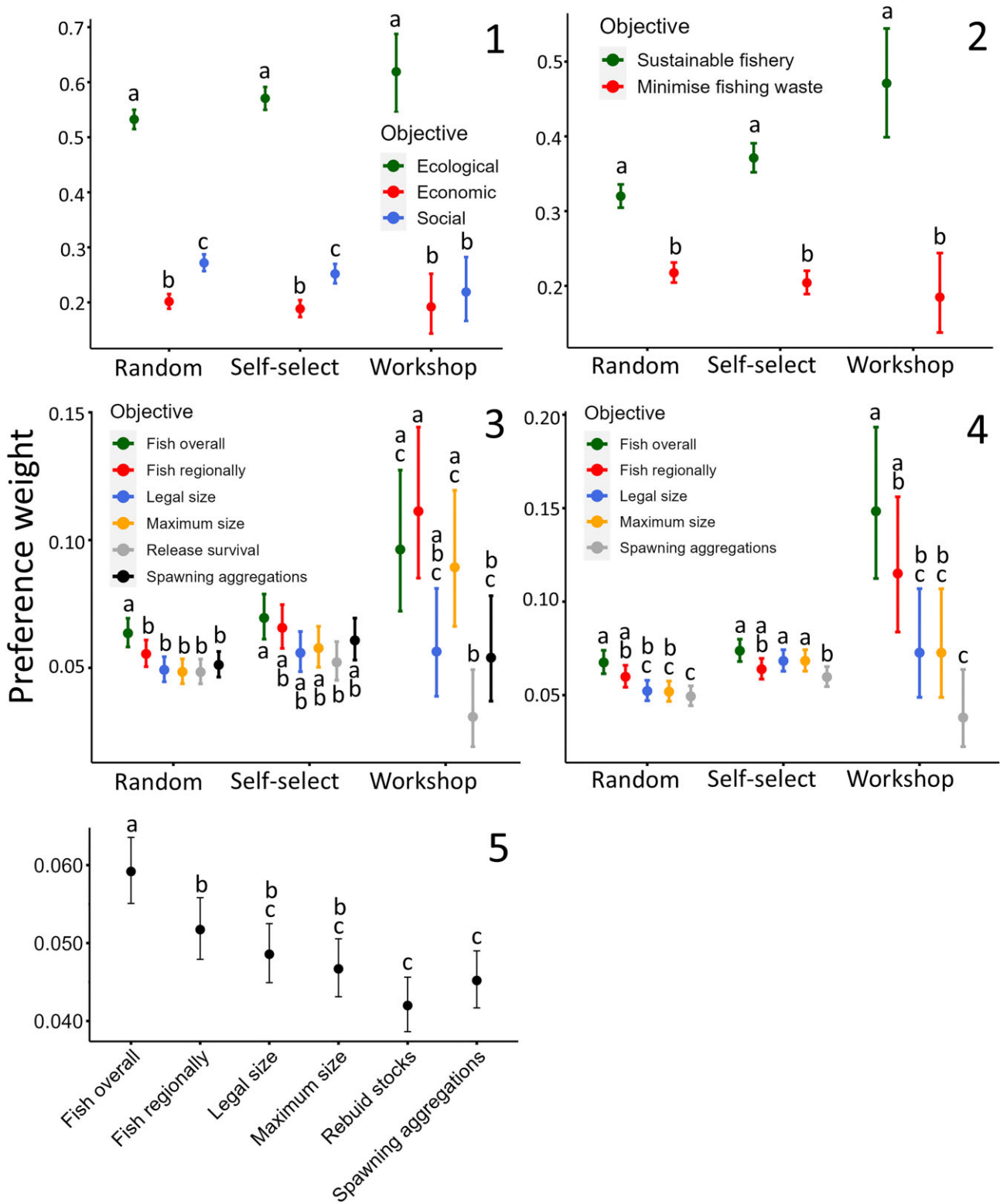


Figure 4. Mean preference weights (marginal effects) from GLMM analyses of: (1) broad objectives, (2) ecological sub-objectives, (3) specific ecological objectives for Mulloway, (4) specific ecological objectives for Yellowtail Kingfish, and (5) specific ecological objectives for Snapper (analysis numbers relate to Table 3). Weights are displayed for objectives within each respondent group, except for Snapper, where an interaction between Objective and Group was not included in the best model. Objectives that share a lowercase letter were not significantly different to each other within a respondent group.

hierarchy (Pascoe et al. 2019). This arises from the distribution of higher-level objective weights over many specific objectives during the final weight calculation. However, the vari-

ance of preference weights relative to the mean was greater for specific objectives than that for broad objectives, potentially indicating greater differences in opinion among respondents

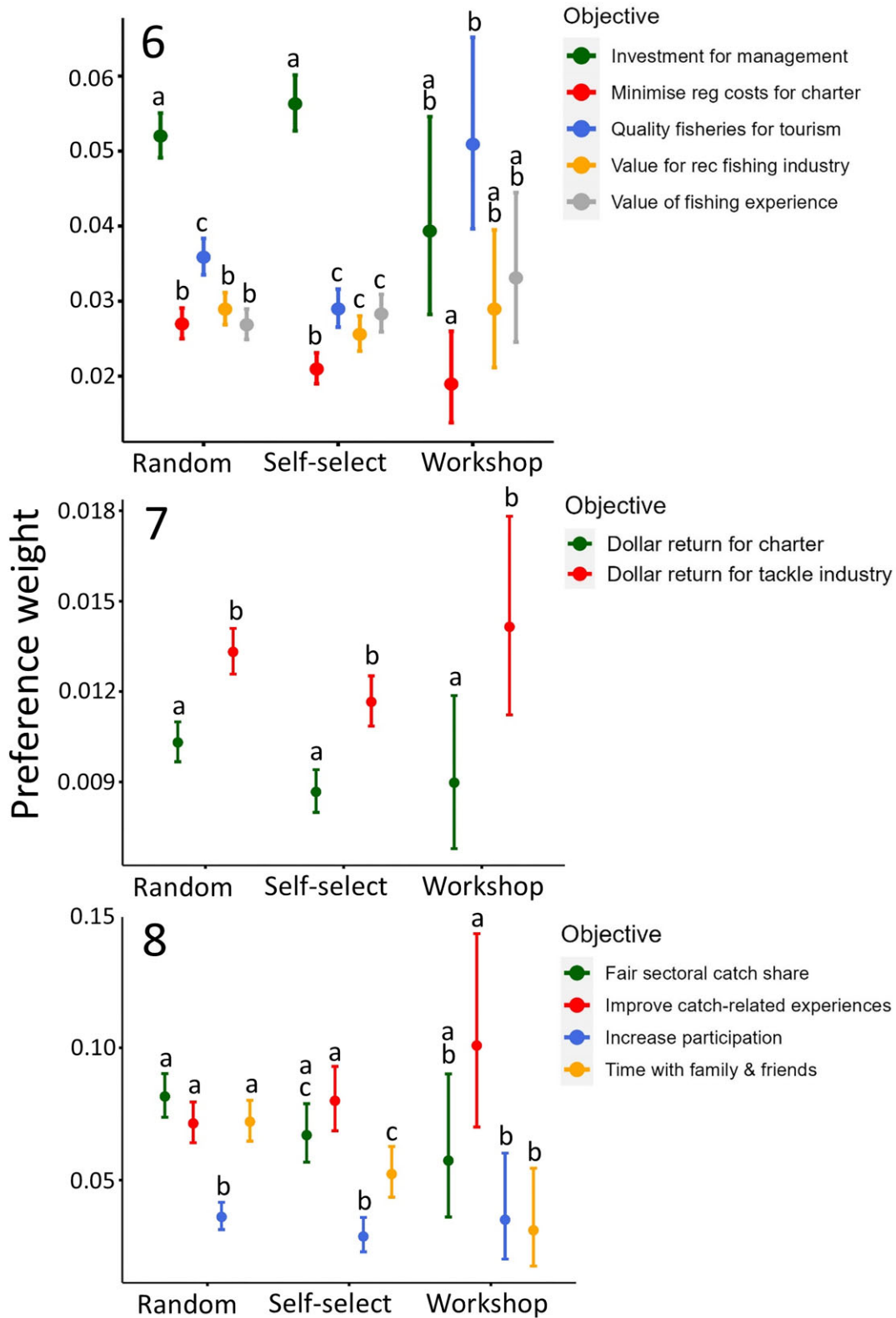


Figure 5. Mean preference weights (marginal effects) from GLMM analyses of (6) economic sub-objectives, (7) specific economic objectives, and (8) social sub-objectives for Mulloway (analysis numbers relate to Table 3). Weights are displayed for objectives within each respondent group. Objectives that share a lowercase letter were not significantly different to each other within a respondent group.

at this level. The relatively lower preference expressed generally for ensuring survival of released fish may also in part reflect a desire to retain fish, such that release survival is less applicable.

The preference for social objectives ahead of economic objectives in two out of three respondent groups in the current study indicates that social objectives should be given priority after ecological objectives when developing harvest strategies

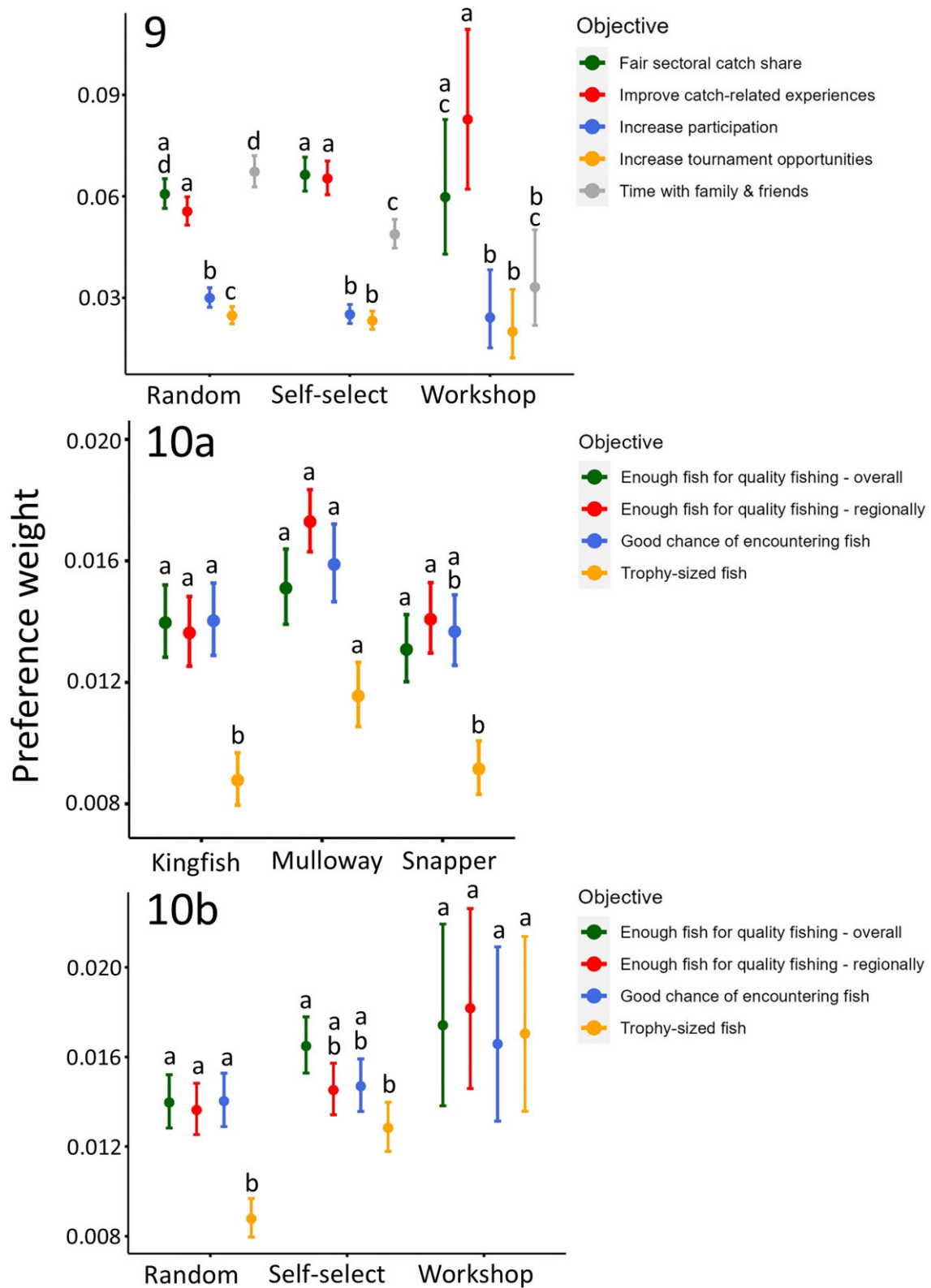


Figure 6. Mean preference weights (marginal effects) from GLMM analyses of (9) social sub-objectives for Kingfish and Snapper combined and (10) specific social objectives (analysis numbers relate to Table 3). Panel 10a shows the interaction between Objective and Stock, while Panel 10b shows the interaction between Objective and Group. Weights are displayed for objectives within each respondent group (or stock). Objectives that share a lowercase letter were not significantly different to each other within a respondent group.

that include the RF sector in NSW. While this finding differs from that of Pascoe *et al.* (2019) for recreational fishers and other stakeholder groups in the Qld CRFF, it is consistent

with a meta-analysis of recreational preferences from surveys conducted in Commonwealth, Qld and southern fisheries in Australia (Pascoe and Dichmont 2017). These surveys all used

Table 5. Best models identified from GLMM analyses of preference weights among objectives and clusters of recreational fishers within the random respondent group.

Analysis description	Model structure/terms	Pseudo r^2 (Efron's)	Model description
1. Broad objectives—All stocks included	Weight ~ Objective + (1 Respondent)	0.50	Objectives
2. Ecological sub-objectives—All stocks included	Weight ~ Objective + (1 Respondent)	0.14	Objectives
3. Specific ecological objectives—Mulloway	Weight ~ Objective + (1 Respondent)	0.39	Objectives
4. Specific ecological objectives—Yellowtail Kingfish	Weight ~ Objective + (1 Respondent)	0.52	Objectives
5. Specific ecological objectives—Snapper	Weight ~ Objective + (1 Respondent)	0.50	Objectives
6. Economic sub-objectives—All stocks included	Weight ~ Objective + (1 Respondent)	0.47	Objectives
7. Specific economic objectives—All stocks included	Weight ~ Objective + Cluster + Objective:Cluster + (1 Respondent)	0.79	Objectives, clusters and their interaction
8. Social sub-objectives—Mulloway	Weight ~ Objective + (1 Respondent)	0.37	Objectives
9. Social sub-objectives—Yellowtail Kingfish and Snapper	Weight ~ Objective + (1 Respondent)	0.50	Objectives
10. Specific social objectives—All stocks included	Weight ~ Objective + Cluster + Objective:Cluster + (1 Respondent)	0.71	Objectives, clusters and their interaction

Separate analyses were conducted for each level of the objectives hierarchy (see Table 2). Separate analyses were conducted for stocks where their objectives differed within a level of the hierarchy. Model selection was based on AIC. Respondent was included as a random effect in all models.

similar methodology for preference elicitation to the current study: the Analytical Hierarchy Process (AHP, Saaty 1987). Lowest preference for economic objectives might be considered intuitive given that numerous economic objectives related to industry performance, which may not be viewed as a priority for amateur fishers. It is unknown whether survey respondents considered the benefits they may experience via flow-on effects of economically prosperous tackle and charter industries. If not, such an understanding may have resulted in relatively higher preferences for economic objectives.

Findings for sub- and specific social objectives in the current study highlight the importance placed on catch-related experiential objectives, for example, “Ensure a good chance of encountering fish.” The result is consistent with previous findings regarding the importance of quality RF experiences (García-Asorey et al. 2011, Young et al. 2016, Magee et al. 2018). Such preferences offer further potential for simplification of harvest strategies that include the RF sector, because fishery performance for numerous catch-related experiences is likely to be achieved indirectly via ecological objectives related to stock biomass, distribution, and size-structure. The lower weighting given to an experiential objective relating to trophy-sized fish by the randomly selected respondent group, a pattern not observed in the workshop group, suggests that catching trophy-sized fish may be less of a priority for the broader, potentially less-specialized fisher base in NSW. Greater knowledge of fisher types that target trophy-sized fish and the proportion of total effort they expend doing so would help inform relative fishing pressure on large size-classes, particularly given such fishers may be more avid, successful, or both. The phrase “trophy-sized” may also not have been understood by all survey respondents, potentially contributing to the lower preference weight for this objective.

The objective preferences determined in the current study are likely to benefit harvest strategy development in NSW beyond simply identifying priority objectives for inclusion. Firstly, they highlight aspects of RF data and monitoring that require consideration when developing harvest strategies for the stocks examined. For example, the relatively high weight given to objectives regarding regional fishery performance indicates a potential need to develop regional monitoring of the RF sector, not just state- or stock-wide. The primary data source for recreational catch and effort in NSW includes a regional component, but divisions are coarse (three marine regions across 1000 km of coast) and do not necessarily reflect the spatial scale of population structure or fishing operations for specific stocks. Secondly, preference weights from the current study can be used to weight the contribution of performance indicators to a harvest control rule in a multi-indicator framework. Multi-indicator harvest strategies combine the values of multiple performance indicators together to determine a management action, typically the amount of harvest that can be taken (Harford et al. 2021). Using preference weights would eliminate arbitrary decisions regarding the relative input each indicator has on the harvest control rule. Thirdly, preference weights may indicate additional management processes required to support harvest strategy development or implementation. For example, the relatively high weight given to an objective relating to maintaining pre-agreed sectoral catch shares suggests that allocation policy may be an important prerequisite for harvest strategy success in NSW. At the time of writing, NSW did not have an explicit

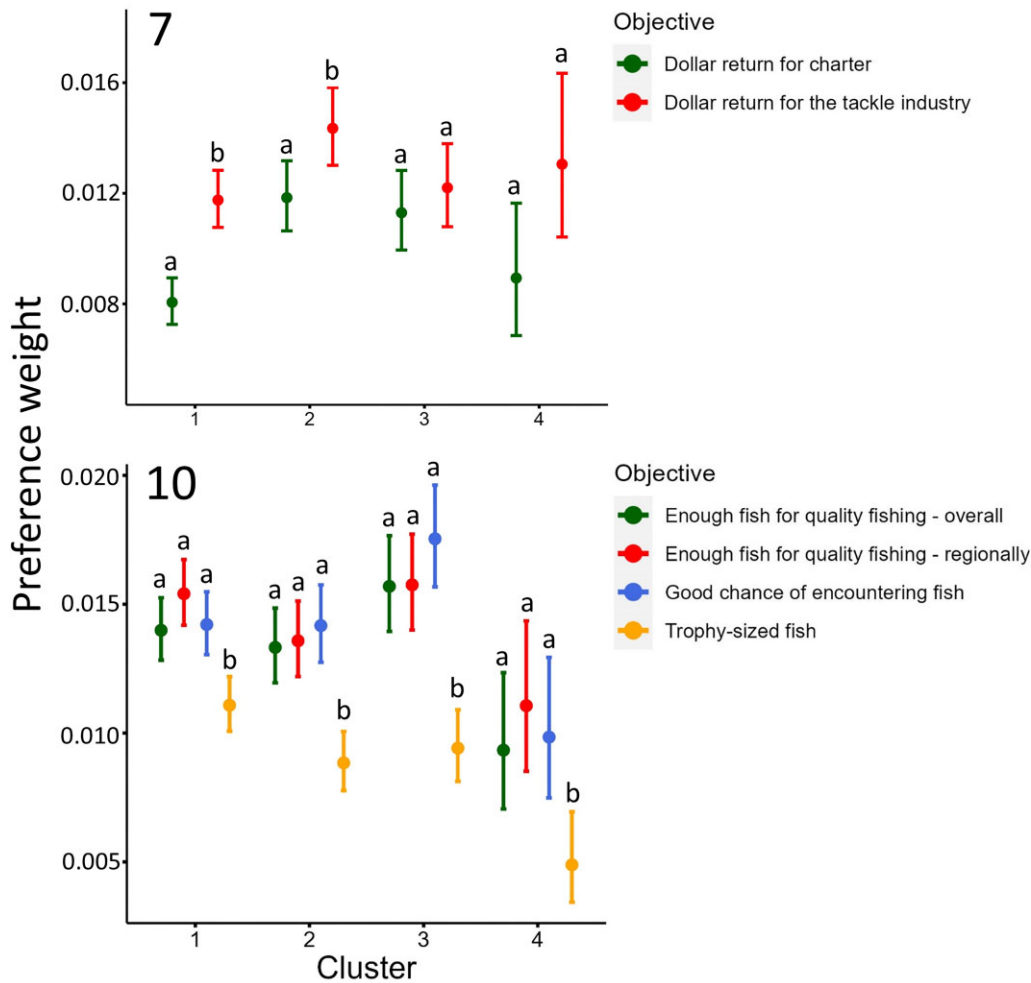


Figure 7. Mean preference weights (marginal effects) from GLMM cluster analyses of (7) specific economic objectives and (10) specific social objectives (analysis numbers relate to Table 5). An interaction between Objective and Cluster was observed for these two analyses. Objectives that share a lowercase letter were not significantly different from each other within a cluster.

policy for allocating catch among sectors within multi-sector fisheries.

As far as the authors are aware, this is the first attempt to representatively elicit objective preferences for harvest strategies within an entire fisheries management jurisdiction. The primary challenge was identifying individuals who fished for at least one of the three target stocks within the previous 12 months. This is a recognized issue when targeting specific types of fishers while adhering to an appropriate random stratified sampling design (Tracey *et al.* 2022) that is amplified in regions like NSW with many (>140) recreationally fished species (Murphy *et al.* 2023). Identification of such a subset of fishers likely contributed to the relatively low response rate. The only suitable database of recreational fishers in NSW includes every long-term licence holder in the state (~460 000 individuals), but it does not contain information on targeting preferences, thereby requiring considerable survey effort to reach respondents that target species of interest. Given the small number of complete responses from the random group (321) relative to the number of recreational fishers who likely target the three stocks in NSW, it is unclear how representative the views of this group are, despite the use of an appropriate sampling design. However, in support of the potential generality of our findings, objective preferences were mostly similar

across the three respondent groups. Each group had considerably different selection biases, e.g. random selection via telephone compared to self-selection via a website. The workshop group had a considerably higher proportion of charter operators and recreational fishers associated with the tackle industry than either the random or self-selecting group, yet this did not result in considerable differences in objective preferences.

A known source of potential bias, irrespective of the number of fishers surveyed, relates to the database only including long-term (1- and 3-year) licence holders. Preferences of individuals exempt from holding a RF licence, or short-term licence holders, may differ to some degree, driven by operational characteristics potentially linked to licence requirement or duration, e.g. avidity and specialization. Partial validation of the preferences identified in the current study might be achieved by including a short series of repeat questions within the “wash up/attitudinal” survey within the state-wide offsite-telephone diary survey of RF participation, catch, and effort (Murphy *et al.* 2023). The biennial frequency of the survey may also allow for ongoing monitoring of potential change in objectives preferences.

The current study did not present the relative costs of achieving objectives to respondents; for example, the restrictions to their catch that may be required to achieve sustain-

ability objectives. Whether or not respondents factored this into their choices among objectives is therefore unclear, as is the potential effect on relative preferences obtained from the surveys. However, the trade-offs among all objectives in the current study are likely complex, and it is unlikely respondents could factor them all into their responses consistently. It is therefore unlikely that reduced knowledge of trade-offs could account for the strong and consistent patterns identified across stocks and respondent groups. Similarly, comprehension and interpretation of objectives likely varied considerably among participants, potentially adding variability to responses and derived preferences, rather than consistent directional biases in relative preferences. While some objectives overlapped conceptually, for example, the economic sub-objective “Maximise the dollar value of your RF experience” and the social sub-objective “Improve the RF experience,” such objectives were not presented to the respondent in the same set of comparisons. Hence, the relative preference weightings remain unaffected. The conceptual “doubling up” provides additional information, i.e. information on the importance of the RF experience is now available relative to both economic and social objectives. Directional bias may have arisen for some of the more complex objectives. For example, “Maximise the dollar value of your RF experience” represents an economic approach to valuing the recreational fisher’s experience, which may not have been fully understood by respondents, leading to lower preference scores for this objective relative to similar concepts contained within the social experiential objectives.

Given the challenges involved with development of efficient and effective multi-sector harvest strategies, we recommend a flexible approach to inclusion of the RF objectives preferences identified in the current study. Explicit monitoring, assessment, and harvest controls for numerous separate objectives across sectors may be impractical due to data limitations and the difficulty in constructing control rules that effectively accommodate many performance indicators (PIs), particularly when trade-offs are required among completing objectives (Dowling et al. 2020). Initially, potential alignment of priority RF objectives with those of other sectors should be explored, to allow consolidation of objectives where possible. If RF objectives are distinct from those of other sectors, potential correlation of PIs across objectives should be considered that would allow the use of a subset for more efficient monitoring, assessment, and harvest control (Dowling et al. 2020). For example, recreational strike rates are likely positively related to stock biomass, with the latter more readily monitored and assessed using non-recreational data. If discrete PIs are required for RF objectives, these may jointly inform harvest control, along with other indicators, via the use of a multi-indicator framework (Harford et al. 2021). Such a framework can still be implemented when a primary PI originates from a model-based stock assessment. If RF-specific PIs are distinct from those of other sectors, and these are not included within the assessment, performance of the harvest strategy against these PIs may still be evaluated using management strategy evaluation (MSE). Research that explores the various options for quantitative inclusion of RF objectives, and tests the resulting harvest strategies, would assist with practical and potentially more cost-effective implementation of the findings in the current study.

Prioritization, consolidation, and quantitative inclusion of RF objectives should be considered a goal of harvest strategy development for multi-sector fisheries, because qualita-

tive and potentially superficial inclusion not only risks fisheries sustainability but also perceived and real equity among RF and other stakeholders, thereby antagonizing RF stakeholders. The latter is particularly likely if a different approach to HS inclusion is used for other sectors in the same fishery; for example, a more structured and quantitative process often applied to the commercial sector (Fowler et al. 2023). We have demonstrated an approach for representatively identifying and prioritizing RF objectives for multiple stocks and RF sub-groups in a large jurisdiction with diverse recreational interests. While somewhat onerous, this approach provides a foundation for equitable inclusion of the RF sector in harvest strategies. Without undertaking at least some elements of the approach, achievement of fisheries performance for the RF sector, if not all sectors, using harvest strategies is at best a coarse estimate, and at worst, guesswork.

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Author contributions

Conceptualization: all authors; Methodology: all authors; Data curation: A.M.F., N.A.D., J.M.H., A.M., N.G.M., R.N., F.A.O.-D., J.P., R.C.C.; Formal analysis: A.M.F., N.A.D., A.M., R.N., J.P.; Writing: all authors.

Supplementary data

[Supplementary data](#) is available at *ICES Journal of Marine Science* online.

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Data availability

The data underlying this article cannot be shared publicly due to restrictions imposed by ethics requirements. However, selected data that does not breach any ethics requirements are available on reasonable request from the corresponding author.

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