ISSN: 3064-9846
Research Article

Journal of Agricultural, Earth and Environmental Sciences

A Review on Participatory Multi-criteria Decision-Making Methods for the Sustainable Management of Fisheries

Negar Akbari, Pierre Failler, Andy Forse*, & Benjamin M Drakeford

Centre for Blue Governance, Faculty of Business and Law, University of Portsmouth, Portsmouth, UK

***Corresponding author:** Andy Forse, Centre for Blue Governance, Faculty of Business and Law, University of Portsmouth, Portsmouth, UK.

Submitted: 11 September 2024 **Accepted:** 16 September 2024 **Published:** 24 September 2024

https://doi.org/10.63620/MKJAEES.2024.1050

Citation: *Akbari, N., Failler, P., Forse, A., & Drakeford, B. M. (2024). A review on participatory multi-criteria decision-making methods for the sustainable management of fisheries. J of Agri Earth & Environmental Sciences, 3(5), 01-11.*

Abstract

This paper presents a review on the participatory multi-criteria decision making (MCDM) methods applied in fisheries management. Marine fisheries are an important part of the ecosystem which are under the threat of overexploitation partly due to ineffective management measures. With a significant economic and social role in coastal communities, fisheries are an important natural resource and contributor to food security, livelihoods and employment, export earnings, and economic growth. Fisheries have a complex multi-dimensional dynamic involving aspects related to the marine environment, social and cultural issues and a unique governance structure due their public resource nature. Hence the sustainable management of this resource requires methods that incorporate these aspects as well as the incorporation of multiple stakeholders such as fishermen, processors, NGOs, and policy makers which often have different (conflicting) preferences. This review shows how MCDM methods could be applied for different groups of stakeholders in the marine fishery sector and which set of criteria have been applied more commonly as well as highlighting the gaps that exist in the literature. Participatory MCDM techniques, especially value measurement techniques such as AHP have experienced increased application in the period between 1998-2020 and have been applied globally in single species and multi-species fisheries management.

Keywords: Sustainable Fishery Management, Multi-criteria Decision Analysis, Stakeholders' Engagement, Natural Resources Management.

Introduction

Marine fisheries are significant contributors to food security, sustainable livelihoods, and are considered a source of wealth in many coastal communities [1]. However, many fisheries face the threat of overexploitation since the proportion of fish stocks that are within biologically sustainable levels decreased from 90% in 1974 to 65.8% in 2017 [2]. The threat of unsustainable fish stocks is exacerbated when implementation of policy measures in unsuccessful and lead to poor economic performance of the sector in many regions [3]. Hence sustainability may not only be defined as the catch levels that could be maintained (Maximum Sustainable Yield) i.e. the conservation paradigm of sustainable fisheries with focus on protecting the ecological system, but it also has to consider fisheries within the wider socio-economic-environmental context [4].

In a top-down and state led governance mechanism approach, the fishermen would often have low influence in the decision-making process which could lead to their marginalisation and resulting in ineffective policy interventions [5]. Therefore, command and control measures of governance enforced from above may also be ineffective to address the bio-ecological, economic and social concerns of fisheries [6]. As a common pool resource, fisheries could benefit from co-management to improve human equity and ecological sustainability since such approach is based on the assumptions that participation of all resources users in decision making may promote ecologically sustainable outcomes vs top down management approaches [7]. In order to achieve this, measures such as ecosystem-based management, which aims to be an integrated approach including the entire ecosystem, including humans has been developed, however amongst the challenges

that this approach faces is the impact evaluation of human activities on ecosystems as well as the trade-off between different social, economic and environmental objectives [8].

Herath and Prato show that using multi-criteria decision analysis methods (MCDM) in the management of natural resources can significantly improve the design and implementation of policies [9]. Fisheries as one of the most important natural and food resources are complex socio-biologic-ecological systems involving many stakeholders, which leads to the need for the co-production of knowledge for policy making allowing different actors to work collaboratively [10]. Stakeholders, are defined as relevant organized group of individuals who could affect or maybe affected (or both) by a decision and MCDM provides a useful and effective framework for involving stakeholders in resource management decisions [11]. Fisheries management has increasingly turned to using participatory approaches to improve stakeholder satisfaction with management institutions and policies, reducing conflict, improving sustainability, increasing productivity and enhancing compliance with regulation [12]. The main groups who actively take part in fisheries management are i) scientists, who provide advice on stock levels, ii) tactical decision makers who make decisions based on additional considerations such as economic objectives, and iii) stakeholders such as fishers, industry representatives and non-governmental organisations providing support to the former groups [13]. Different interest groups push for several, often conflicting objectives for which MCDM approaches may be appropriate and expert judgements and preference elicitation are ways to integrate the subjective opinion of different stakeholders to provide decision support in conservation management [14].

The main objective of this paper is to provide a systematic review of application of MCDM methods in sustainable fisheries management focusing on the studies with stakeholder participation in commercial fisheries management, case study regions, the criteria, and the anticipated future trends. In particular, this review aims to answer the following questions:

- Which multi-criteria decision-making methods have been frequently used in the literature for stakeholders' engagement in decision making?
- What type of management measures have been analysed using participatory MCDMs and which criteria and case study regions have been included?
- What are the future trends in participatory MCDM application for sustainable fishery management?

Other review studies which have assessed the application of multi-criteria decision-making methods for fisheries management are studies by Mardle&Pascoe, Leung, Bjorndal et al, and Andalecio [15-19]. This review contributes to the current literature by providing a systematic literature survey of the studies in which MCDM methods have been applied to incorporate stakeholders' participation in the context of policy making in fisheries management covering studies up to year 2020. Fisheries have a complex multi-dimensional system involving aspects related to the marine environment, social and cultural issues and a unique governance structure due their common resource nature. Hence the sustainable management of this resource requires methods that incorporate these aspects as well as the incorporation of multiple stakeholders such as fishermen, processors, NGOs, and policy makers. Furthermore, since fisheries management is sometimes considered to place a higher weight on biological criteria, relative to economic and social objectives of different stakeholders, MCDM that focuses specifically on stakeholder attributions of criteria (e.g. the expert opinions) could better help in addressing and balancing the multiple/conflicting management objectives in achieving sustainable management.

Procedure of the Review

Study Selection

The scope of this review is on scientific, peer-reviewed publications published between years 1998-2020. Studies in this section are identified by using Web of Science, Scopus and Science Direct which are international indexed electronic databases. Figure 1 shows the process of study selection.

Table 1: Shows the Search Strings used for Searching the Literature

Search engine	Search strings
Web of Science Scopus Science Direct	"stakeholders * fisheries management"
	"stakeholders * sustainable fisheries management"
	"stakeholders' engagement * sustainable fisheries management"
	"Participatory MCDM* stakeholders * sustainable fisheries management"
	"MCDM * stakeholders * fisheries management"
	"MCDM * stakeholders * sustainable fisheries management"
	"multi-criteria decision making(analysis) method * stakeholders * sustainable fisheries management"

Table 1:list of search strings

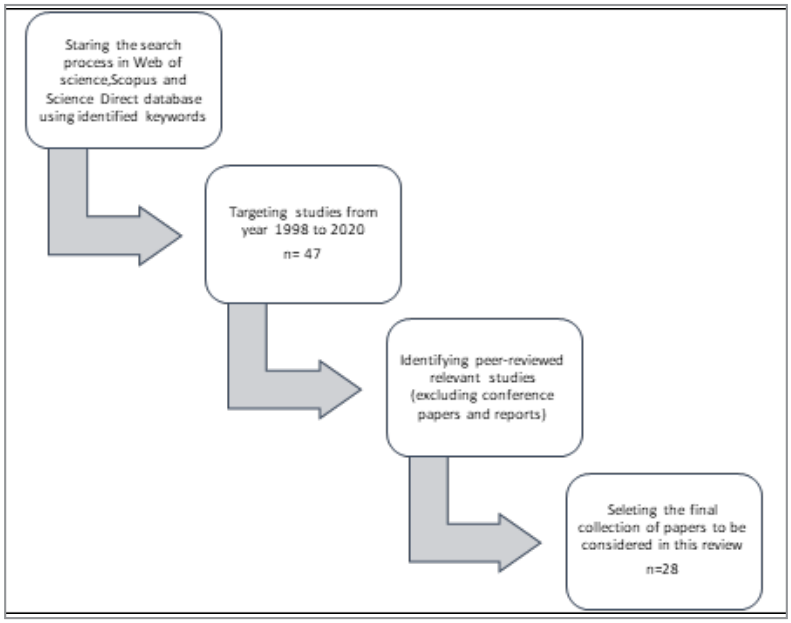

Figure 1: Literature Review Procedure

Categorisation of Multi-criteria Decision-Making Methods

Multi-Criteria Decision Making refers to methods for prioritisation and/ or making choices in the presence of a set of relevant criteria. MCDM enables the decision maker to assess various management options (i.e. alternatives) and compare them against a range of criteria. Different importance level (weights) may be applied to these criteria and the criteria are often arranged hierarchically in clusters and sub-clusters [20, 21].

MCDM methods could be categorised into two main branches of i) Multi-Attribute Decision Making (MADM) and ii) Multi-Objective Decision Making (MODM) illustrated in Figure 2.

The MADM method is appropriate when the decision maker aims to evaluate a number of predetermined alternatives (e.g. the decision maker may want to choose the most effective effort control policy). In these situations, the number of alternatives is usually limited and finite [22]. The MADM methods allow the decision maker to screen, prioritize and rank the criteria and select the most suitable alternative. MADM consists methods such as:

- **Distance based methods:** where the best solutions are located closest to the ideal solution and farthest from the non-ideal solution e.g. TOPISIS (Technique for order preference by similarity to ideal solution).
- **Outranking methods:** these methods are based on pairwise comparison of alternatives against each other, followed by a procedure which aggregates information in order to determine the strength of evidence supporting one alternative over another, e.g. PROMOTHEE (preference ranking organization method for enrichment evaluations) alternatives and ELECTRE (elimination and choice translating reality) [23].
- **Value or utility Function methods:** in this method each decision alternative is assigned a numerical score that is used to compare the alternatives and the score of an alternative is equal to the weighted sum of its evaluation rating e.g. MAUT, MAVT, SAW (Multi-attribute utility theory, Multi-attribute value theory, Simple additive weighting) [24].
- **Pairwise comparison methods:** in these methods the problem is formed into a hierarchy with the goal at the top level, followed by sub-criteria in the lower levels. The decision maker then provides a comparison between each pair of criteria to find the weight (importance) of each criterion and the alternative that has the highest score is selected as the most suitable choice. Methods such as Analytical Network Process (ANP), and Analytical Hierarchy Process (AHP) belong to this category.

On the other hand, the MODM methods are mostly used when the decision problem is a continuous variable and therefore the alternatives are not predetermined. In these cases, the objective function(s) is optimised while satisfying a set of constraints. MODM methods are classified into mathematical programming models (e.g. Linear Programming, Mixed Integer Linear Programming, Goal Programming, etc.) and heuristic algorithms (Genetic Algorithm, Simulated Annealing, etc.).

In the aforementioned approaches, if the decision maker aims to resolve uncertainties or ambiguities related to criteria, they can apply the fuzzy technique. Fuzzy set theory, initially proposed by Zadeh is applied to objectively address the ambiguities in judgement and resolve the uncertainties in an MCDM problem [25, 26].

MCDM approaches also range from analyst-led (non-participatory) methods to those involving multi-actors within the discussion (participatory MCDA). If the analysis is carried out via the analyst(s), a technocratic approach is adopted and the judgments are provided by the analyst(s) and sensitivity analysis can be performed to provide several scenarios showing how changes in the criteria could yield different outcomes.

However, in participatory methods different actors/stakeholders are involved at selected stages of process (e.g. validating the criteria, weighting the criteria) and adopt a collaborative approach to the decision problem [27]. In these multi-stakeholder approaches, the diversity of interests and positions in the target system are considered and reflected in the criteria development to increase the likelihood of implementation and acceptance of the suggested measures [28]. In the MCDM literature, participation often refers to involving different stakeholders in a community (e.g. fisheries) within the process of developing the decision-making model. Hence participatory and multi-criteria decision-making methodologies has gained popularity in agriculture, including fisheries due to their effectiveness in informing community decision making. Therefore, to reduce conflicts and increase transparency in decision making process, participation of stakeholders and coastal resource users is critical in enhancing scientific information, to develop acceptable solutions [28]. Different preference elicitation methods including AHP and discrete choice experiments are available for stakeholders' preference elicitation. Firstly, the use of a value measurement model reduces the risk of dominant participants influencing deliberations. secondly, the consistency of recommendations is improved through the use of criteria scores and weights. Finally, the results are easily communicated with the public enhancing transparency of recommendation. However, these methods may pose the risk that certain stakeholders dominate deliberations particularly in the context of unbalanced power relationship [29, 30].

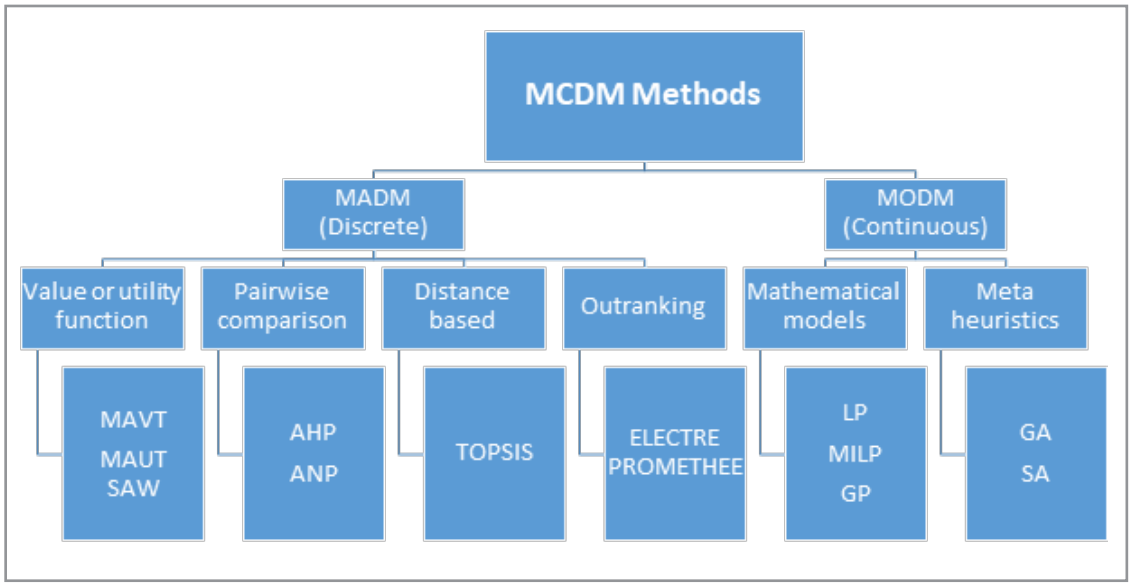

Figure 2: MCDM Classification and Examples of Each Method [31]

Decision Making Process

The main steps in MCDM are 1) defining the decision problems 1) identifying relevant stakeholders 3) defining the criteria 4) weight assignment 5) defining alternatives 6) ranking alternatives 7) sensitivity analysis [32]. Furthermore, the classification based on the way preferences are included, especially in terms of when the decision maker is involved in the modelling process is important. If modelling of the decision makers' preferences is the starting point of the modelling process, it would be a priori inclusion. However, if the answer of the decision makers to specific questions leads the solution process towards the most preferred alternative, it would be interactive articulation of preferences. Lastly, if only the solutions are presented to the decision makers for evaluation that would be the posterior articulation of preference where the decision makers have not been involved in development of the decision-making model from the initial stages [23].

Literature Search Results

A growing problem and concern in sustainable fisheries management is addressing several objectives and involving numerous stakeholders for which international institutions recommend switching from monospecies, and single criterion management approaches toward ecosystems-based approaches [33]. For example, in the case of demersal fisheries, Caddy and Seijo suggest that for protecting juveniles, in spite of having quotas, capacity control and technical measures, the top down management has been ineffective to prevent stock depletion especially of the older spawners which often support recruitment in demersal stocks [34]. Therefore, the basic unpredictability of fisheries at the system level should be considered and a greater range of performance indicators to be included into the decisional framework. However, the implementation of such multidimensional approaches could be difficult and environmental and socio-economic impact receive less attention. In Europe, which is one of the largest suppliers of fish, holistic multi-species management has replaced species management which could consider the views and interests of different stakeholders and trade-offs. Therefore, in the Marine Strategy directive, the common fisheries policy and the maritime spatial planning directive, the EU has accepted the ecosystem-based fisheries management [35].

It is suggested that the scientific advice has to involve stakeholders from consultation to stronger collaboration and it has to move from mainly biological towards integrating socio-economic aspects [36]. For example, due to their exclusion in the decision-making process, the fishers in Europe were critical of existing management regimes and suggest they can develop more effective systems themselves [37]. In a recent survey of 20 stakeholders in the UK's Scottish Fisheries, the three key objectives in sustainable management of fisheries in term of importance were controlling over exploitation of stocks, increase in the transparency and simplicity of policy measures and inclusive governance [38]. Therefore, building trust between policy makers and fisheries through transparent measures and inclusive and collaborative governance is increasingly important for commercial fisheries to operate effectively [38]. In the remainder of this section, we aim to answer the proposed research questions on the type of methods, criteria groups, regions and species that have been considered in the literature.

Application of MCDM Methods

Based on this review, the Analytical Hierarchy Process (AHP) method has been identified as one of the most popular participatory MCDM methods for involving multiple stakeholders [39, 35, 40-49, 16, 14, 50, 51]. One of the advantages of the AHP is that it provides a framework for decision making which is able to analyse appropriate fishery management scenarios. Furthermore, it allows managers to incorporate and consolidate expert judgments and may include interest group preferences [15]. The incorporation of value judgement in the process also gives decision makers the opportunity to explicitly state their preferences with respect to identified objectives [15]. However, the major disadvantage of the method, such as complicated pairwise comparison, and rank reversal problems should be considered. Goal Programming methods have also been applied in a number of studies in which the decision maker has set predefined targets and objectives, e.g. reaching a specific fishing mortality rate (FMSY) or quota allocation [52, 53]. Other participatory MCDM methods including combination with GIS and expert elicitation methods (Wattage et al. 2005), fuzzy MCDM (Romeo,2019), and PROMOTHEE have also been applied in the literature [54-57].

Composition of Stakeholders

Different groups of stakeholders are conservationists, fishermen, middlemen, processors, vessel operators, environmental NGOs, industrial organisations, policy makers, scientists, academics, and the general public. The number and composition of stakeholders in the studies vary significantly with studies reporting results of over 1300 surveys from stakeholders and fishermen to studies reporting results based on only twelve stakeholders and studies in which the number and composition of stakeholders is not clearly stated [43, 35, 49]. The involvement of stakeholders in the study design are mostly interactive articulation of preference and decision makers' answers to specific questions, (e.g. determining the weight of decision-making criteria) guiding the solution process towards the most preferred alternatives. In terms of data collection, different methods have been used including approaches such as Delphi method, interviews (face to face, telephone interviews), online and/or paper form surveys [58, 40]. For example, in a study by Bray et al. on prioritising the management policies for the future of Marine Scalefish fishery in Australia the surveys consisting AHP questionnaires were posted to over 500 fishers, delivered in five industry workshops, sent via email to 200 fishers and also followed up by interviews to complement the survey data and deepen the analysis. In a study by Williams et al. 50 stakeholders of the English seabass fishery were surveyed including industry representatives, fishers, management, NGO and non-expert citizens followed up by quayside and telephone interviews [59]. In a larger study by Kimani et al. which analysed the opportunities and limitations in marine small-scale fisheries value chain in Kenya, a total of 403 respondent were interviewed consisting of 73 middleman, 108 processors and 222 boat captains [39]. In their study the stakeholders were asked about their purposes in engaging in fisheries activities and stakeholders' response revolved around improvement of income and economic wellbeing. Hence, the goal of the AHP was achieving higher financial performance, based on which criteria related to opportunities for improvement and constraints preventing the attainment of this goal was developed.

Number of Criteria

The number of criteria also varies greatly in the studies, with the lower level criteria not exceeding 21 sub-criteria and the most often used criteria are socio-economic, environmental, biological, political/governance. The relative importance given to different criteria usually differ depending on the stakeholder group, while environmental and ecological criteria are prioritised by NGOs and conservation groups, the fishermen usually prioritise yields and employment over criteria such as habitat damage.

Management Measures

MCDM methods allows the decision makers to prioritise and select the most suitable management strategy with respect to their objectives. The main proposed management scenarios in the studies under consideration are summarised as following, for each measure a short description is provided:

- **Quota allocation (Individual transferable catch quota):** ITQ have often been used as a policy measure for improvement in stock recovery in overexploited fisheries [60]. The implementation of ITQs involve allocating shares or portions of total Allowable Catch Quota (TAC) to individual fishers, vessels, or any community, which may have an interest in the fisheries. This approach aims to increase fisher's involvement in allocation of shares and enables the fisheries to adjust to changing economic and biological conditions which does not require further actions by managers to reduce fishing efforts [61].
- **Effort Control:** effort control strategies consist of measure such as restrictions in vessel size, change in gear types, limited entry (limitation of new licences), and seasonal closures. Effort control may be execrated to reduce overexploitation and increase the sustainability of fisheries.
- **Restriction (or ease) in Subsidies Provided to Fisheries:** Subsidies are defined as financial support provided by the government to an industry. For fisheries, subsidies could be divided in three categories of beneficial, capacity enhancing and ambiguous. Beneficial subsides could be considered investments in the promotion of fisheries, and capacity enhancing subsidies encourage increase in fishing capacity. Ambiguous subsidies have the potential to lead to either sustainable management or overexploitation of fisheries [62].

- **Open Access:** Open access fisheries are unregulated and accessible to rival fleet from any country and the government has limited means and interest in regulating and controlling the amount or type of effort made to catch fish. Open access could serve as a baseline measure and may be used to assess the merits of alternative management approaches and fishing regulations [63].
- **Marine Protected Areas (MPA):** MPAs are defined as sea areas exclusively dedicated to protecting and maintaining the biological diversity. In these areas the associated cultural and natural resources are considered and management in enforced through legal or other effective means [64].
- **Status Quo:** Maintaining the existing state of affairs with respect to the management strategies. Mixed approaches including a number of strategies applied simultaneously

The main objectives across sectors and different stakeholders are identified as:

- Increase in economic yield (profit)
- Increase in value of all landing
- Increase in local employment
- Improved governance and regulatory stability
- Reductions in fishing mortality to a specific target
- Minimising discards and bycatch
- Minimising environmental impact

Regions and Species

Figure 3 shows the distribution of studies based on the species and regions. The regions are categorised as Europe-North Sea (including English Channel), Europe-other (including Atlantic and Mediterranean), USA, Australia, Asia, Africa. The species categorisations are defined as multi-species (including multiple different species types), demersal (including multiple demersal fish species), Pelagic (including multiple pelagic fish species), monotype species (including only one type of species), other (aquaculture, small scale fisheries, invasive fish species).

Europe, in particular The North Sea has been identified as the region with the highest number of studies focused on participatory MCDM (41%), followed by Africa (17%), USA (12%), Australia (10%) and Asia (10%). Furthermore, monospecies fisheries management has the highest share of the studies (32%) followed by multispecies (32%), demersal (14.5%), other (14.5%) and pelagic (7%). The high number of studies in the North Sea could be explained given that the North Sea fisheries system is a dominant component for the EU's ecosystem-based fisheries management regime and contains many different species, fishing fleets and multi-level governance settings [65].

On the other hand, the Mediterranean fisheries are characterised by visible signs of overexploitation of the main fish stocks, significant alteration to marine ecosystems, and low economic performance [13, 66]. As a result of this low economic performance a 45% decrease in fishing units has occurred in 2018 for the EU Mediterranean states. The main features of Mediterranean fisheries is relatively small vessels, multiple landing sites, multispecies catches with low catch per unit of effort and relatively high prices [66]. In Europe, the Mediterranean fisheries are underfunded and have lower levels of scientific stock assessment information incorporated in the fishery management plans in comparison to the North Sea region.

African countries (With the second highest share of studies) are also showing increase application of MCDM methods for sustainable management of fisheries. Marine fisheries and aquaculture are developing rapidly in Africa and they are playing an important role in food security, wealth creation and reducing poverty [67].

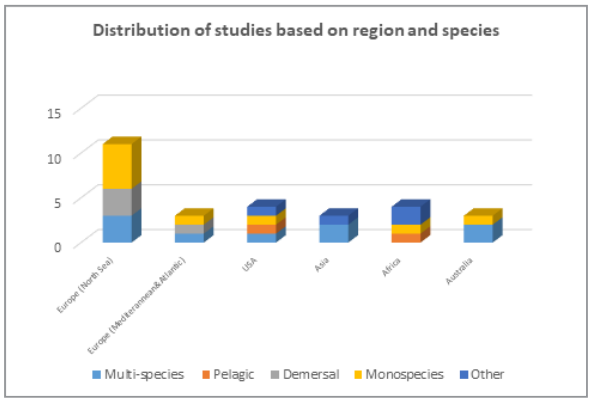

Figure 3: Distribution of studies based on region and species

Table 2: Summarises the methods, Criteria Groups, type of Species and Case Study Regions related to the Studies in this Survey

Author	Year	Method	Criteria group	No. participants	Regions	Species
Leung et al. [51]	1998	AHP	Biological, economic, political, social	34	Hawaii	Pelagic
Mardle et al. [53]	2000	Goal programming	Profit, quota share, employment, discard	Not specified	North Sea	Demersal

Leung et al. [68]	2001	MCDM (linear programming)	Employment, income, economic rent	Not specified	Norway	Norwegian cod
Soma [50]	2003	AHP	Economic efficiency, conservation of resource, employment, governance	50	Trinidad and Tobago	Shrimp
Mardle et al. [14]	2004	AHP	Conservation, economic, allocation and awareness issues between stakeholders	31	English Channel	Multi-species
Chiou, et al. [55]	2005	Fuzzy AHP	Business activities, government policy, socio-economic effects	15	Taiwan	Multi-species
Nielsen et al. [49]	2006	AHP	Economic, political, biological	12	Denmark and Norway	Sand eel and Norway pout
Paterson, et al. [56]	2007	MCDM with fuzzy logic	Ecosystem approach	Not specified	South Africa	Pelagic fishery
Utne [48]	2008	AHP	Social, economic, ecological(environmental)	9	Norway	Cod fishing fleet
Pascoe et al. [47]	2009	AHP	Economic, environmental, resource sustainability, externalities	74	Australia	Multi-species
Innes and Pascoe [45]	2010	AHP	Bycatch, Insitu impact	48	Europe	Demersal
Baio [46]	2010	AHP	Endowment, economic, political, institutional	8	Sierra Leone	Small scale
Daneshfard et al. [52]	2011	Goal programming	Economic, environmental, political	Not specified	Persian Gulf	Multi-species
Wadsworth et al. [69]	2014	AHP	Ecosystem health	107	USA	Multi-species
Rossetto et al. [44]	2015	AHP	economic, social, biological conservation, biological production	Not specified	Mediterranean	Demersal
Brookes et al. [43]	2015	AHP	Industry community, local/regional communities, indigenous community	1308	Australia	Multi-species
Ting et al. [42]	2015	AHP	Ecological, economic, social, institutional	21	Taiwan	Aquaculture
Morgan [41]	2017	AHP	Economic, social, administrative, lack of information, lack of opportunities	58	UK	Multi-species
Bray et al. [40]	2018	AHP	Governance, economic, environmental, social	40	South Australia	Scale fish
Williams et al [59]	2018	MCDM	Profit, employment, GHG emission, subsidies, economic value chain, seabass and other species discard, spawning season mortality, bycatch, ecosystem damage, ghost fishing, fleet and port dependency	50	UK	English Seabass
Szalaj et al [54]	2018	MCDM with GIS	Socio-economic, environmental, biological	Not specified	Portugal	European Sardine
Deboni et al. [57]	2018	PROMOTHEE	Environmental, economic, social	Not specified	North Sea	Demersal
Pope et al. [65]	2019	MCDM	Economic, environmental	16	North Sea	Multi-species
Romeo and Marciano	2019	Fuzzy MCDM(-VIKOR)	Economic	34	Mediterranean(South Italy)	Multi-species
Chen et al. [70]	2019	AHP	Environmental quality, waste and energy management, hygiene, vessel and harbour management	24	Asia	Multi-species

Elvarsson et al. [35]	2020	AHP	Environmental, socio-economic, industry	12	Iceland	Cod fisheries
Kimani et al. [39]	2020	AHP	Resources, infrastructure, training, cost, governance, trust, labour	403	Kenya	Small scale fisheries
Robinson et al. [58]	2021	Participatory Decision modelling	Ecological, economic, social	11	Lake Erie, USA	Invasive species

Limitations and Drawbacks of MCDM

Stakeholder engagement is a key feature in fisheries management, however collecting perspectives from diverse groups and reconciling conflicting objectives as well as dealing with subjective biases remains amongst the challenges. Although MCDMs are powerful techniques to tackle many decision-making problems, they are bound to certain limitations. Rosenhead summarises the limitations of traditional MCDM for dealing with complexity of natural resource management as [71]:

- "Comprehensive rationality", i.e. unrealistic presumption that analytical results and computations could replace judgements.
- Prioritising feasible objectives and optimal alternatives which may lead to de-emphasising the creative generation of alternatives.
- Misrepresentation and misunderstandings about the reasons and motivations for public involvement.

Furthermore, each MCDM method may have certain limitations. Rehman and Romero point out that in the MAUT methods, the underlying assumptions may be questionable highlighting the preferential independence assumption as unrealistic [72]. Alternatively, they suggest that non-compensatory methods such as ELECTRE or PROMOTHEE can replace methods based on MAUT. However, these two methods do not provide a clear process to assign criteria weight and inconsistency of judgment may [21]. For the AHP method, although a clear weighting process is defined, the problem of rank reversal, the preference scale and the absence of zero in the scale and potential modelling challenges due to interdependence between criteria and alternatives have been raised as disadvantages of the method [73, 74].

Mendoza and Martins suggest that the limitations of algorithmic and rigid MCDM methods are exacerbated when the planning and decision making is entirely participatory where local communities or individual citizens would like to be actively involved at different stages of planning and management of public resources that are of value to many different stakeholders [23. In order to overcome these limitations a more flexible approach to MCDM application to natural resources management is required. An effective approach should be capable in dealing with challenging and multi-dimension problems involving subjective opinions of stakeholders, unpredictable cause and effect relationships, and with objectives may be conflicting and not accepted by all stakeholders [23].

Discussion and Conclusion

The over exploitation of natural resources such as fisheries may be due to several reasons such as low levels of fishing cost which are exacerbated by subsidies, high fish prices, slow pace of biomass growth and ill-defined governance structures. For achieving consensus and compliance with policy measures for achieving sustainable levels, reducing conflict and distrust, and developing acceptable solutions, involving stakeholders in defining objectives and management choices is critical participation of stakeholders and coastal resource users is crucial in complementing scientific information [18].

This review shows that whilst studies in fisheries management have made progress in integrating a diverse range of criteria in the decision-making framework, there is a paucity of studies on incorporating environmental, particularly climate change and natural variability impacts in the decision-making process. Furthermore, compared to biological aspects, legal and governance criteria have been addressed less frequently in the literature. Improved governance of the sector would greatly enhance the equitable use of this resource particularly in countries where fisheries constitute a large part of the livelihood and economy. In terms of management measures this review suggests that top-down policies based on limiting the catch levels or the effort levels as implemented by the European Common Fisheries Policy are the most conventional management measures for controlling overexploitation. However, such management measures are dependent on accurate stock assessment which are subject to many uncertainties such as environmental variability, inaccurate data and errors in estimation, and inefficient enforcement of quotas leading to illegal unregulated fishing [75].

The findings in this review shows that participatory MCDM techniques, especially pairwise comparison techniques such as AHP have experienced increased application in the period between 1998-2020 and have been applied globally in single species and multi-species fisheries management in particular in the multi-species fisheries management in Europe's North Sea as well as African countries in which marine and aquaculture plays and important role in food security and livelihoods. Application of MCDM techniques in fisheries management helps in formalization of the concepts of goals, objectives and subjective criteria into structured decision framework and provides a useful structure for investigating management scenarios while stakeholders in all levels could be involved in the procedure. Participation of broad range of stakeholders who could provide a diverse perspective of the challenges and solutions, could addresses the challenges regarding scientific uncertainty in assessment advice, and collaborative modelling methods which can incorporate different types of subjective and objective information, as well as fisheries science, would improve ecosystem-based management [76]. This approach may also be applicable to other natural resources

which are common resources in essence yet their utilisation should be managed and governed effectively to avoid overexploitation.

Amongst the major advantages of such methods is the applicability, and relatively easy communication with different groups of stakeholders and continued application of these methods is predicted for reconciling multiple stakeholder's preferences for enhancing the sustainable management of marine resources. Lastly, this study provides a guide for different stakeholders (e.g. managers, fishermen and NGOs) on type of criteria and the management measures that have been used as well as providing information on the type of species and regions that have been considered more in studies therefore highlighting potential gaps and areas of improvement in the literature [77-83].

Limitations and Future Research

This review provides an overview of the applications of participatory MCDM approach for the sustainable management of fisheries. This review does not intend to analyse each individual methodology, rather it aims to show the application of these methods in the field of sustainable fishery management. In this review MCDM methods that consider multiple groups of stakeholders are considered and other multi-objective optimisation methods or bio-economic models are not included in the analysis. With the ever-increasing pressure on fisheries to be sustainable and consider ecosystem and multi-species-based measures, future research may consider the capability of combined methods to incorporate the preference of a network of stakeholders with respect to the management of multispecies fisheries.

Acknowledgements

This research has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No 773713 (PANDORA).

References

1. Jentoft, S., Bavinck, M., Alonso-Población, E., Child, A., Diegues, A., et al. (2018). Working together in small-scale fisheries: Harnessing collective action for poverty eradication. Maritime Studies, 17(1), 1–12. https://doi.org/10.1007/s40152-018-0083-1
2. Food and Agriculture Organization. (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. FAO.
3. Nieminen, E., Kronbak, L. G., & Lindroos, M. (2016). International agreements in the multispecies Baltic Sea fisheries. Environmental and Resource Economics, 65(1), 109–134. https://doi.org/10.1007/s10640-015-9936-x
4. Charles, A. T. (2002). The precautionary approach and 'burden of proof' challenges in fishery management. Bulletin of Marine Science, 70(2), 683–694.
5. Semitiel-García, M., & Noguera-Méndez, P. (2019). Fishers' participation in small-scale fisheries: A structural analysis of the Cabo de Palos-Islas Hormigas MPA, Spain. Marine Policy, 101, 257–267. https://doi.org/10.1016/j.marpol.2018.10.037
6. Baiju, K. K., Parappurathu, S., Abhilash, S., & Ramachandran, C. (2022). Achieving governance synergies through institutional interactions among non-state and state actors in small-scale marine fisheries in India. Marine Policy, 138, 104990. https://doi.org/10.1016/j.marpol.2022.104990
7. Etiegni, C. A., Irvine, K., & Kooy, M. (2020). Participatory governance in Lake Victoria (Kenya) fisheries: Whose voices are heard? Maritime Studies, 19(4), 489–507. https://doi.org/10.1007/s40152-020-00172-z
8. Macher, C., Bertignac, M., Guyader, O., Frangoudes, K., & Frésard, M. (2018). The role of technical protocols and partnership engagement in developing a decision support framework for fisheries management. Journal of Environmental Management, 223, 503–516. https://doi.org/10.1016/j.jenvman.2018.06.046
9. Herath, G., & Prato, T. (2006). Using multi-criteria decision analysis in natural resource management. Routledge.
10. Aguado, S. H., Segado, I. S., & Pitcher, T. J. (2016). Towards sustainable fisheries: A multi-criteria participatory approach to assessing indicators of sustainable fishing communities: A case study from Cartagena (Spain). Marine Policy, 65, 97–106. https://doi.org/10.1016/j.marpol.2015.12.015
11. Banville, C., Landry, M., Martel, J. M., & Boulaire, C. (1998). A stakeholder approach to MCDA. Systems Research and Behavioral Science, 15(1), 15–32. https://doi.org/10.1002/(SICI)1099-1743(199801/02)15:1<15::AID-SRES181>3.0.CO;2-0
12. Crandall, C. A., Monroe, M., Gianelli, D. J., & Lorenzen, K. (2019). Meaningful action gives satisfaction: Stakeholder perspectives on participation in the management of marine recreational fisheries. Ocean and Coastal Management, 179, 104872. https://doi.org/10.1016/j.ocecoaman.2019.104872
13. Cardinale, M., Colloca, F., Bonanno, A., & Scarcella, G. (2021). The Mediterranean fishery management: A call for shifting the current paradigm from duplication to synergy. Marine Policy, 131, 104612. https://doi.org/10.1016/j.marpol.2021.104612
14. Mardle, S., Pascao, S., & Herrero, I. (2004). Management objective importance in fisheries: An evaluation using the analytic hierarchy process (AHP). Environmental Management, 33(1), 1–11. https://doi.org/10.1007/s00267-003-0023-0
15. Mardle, S., & Pascoe, S. (1999). A review of applications of multiple criteria decision-making techniques to fisheries. Marine Resource Economics, 14(1), 41–63.
16. Leung, P. (2006). Multiple-criteria decision making (MCDM) applications in fishery management. International Journal of Environmental Technology and Management, 6(1–2), 96–110. https://doi.org/10.1504/IJETM.2006.008254
17. Bjørndal, T., Lane, D. E., & Weintraub, A. (2004). Operational research models and the management of fisheries and aquaculture: A review. European Journal of Operational Research, 156(3), 533–540. https://doi.org/10.1016/S0377-2217(03)00102-0
18. Andalecio, M. N. (2010). Multi-criteria decision models for management of tropical coastal fisheries: A review. Agronomy for Sustainable Development, 30(3), 557–580. https://doi.org/10.1051/agro/2009043
19. Díaz-Balteiro, L., Iglesias-Merchán, C., & Romero, C. (2020). The sustainable management of land and fisheries resources using multicriteria techniques: A meta-analysis. Land, 9(11), 380. https://doi.org/10.3390/land9110380
20. Munda, G. (2016). Multiple criteria decision analysis

and sustainable development. In S. Greco, M. Ehrgott, & J. R. Figueira (Eds.), Multiple criteria decision analysis: State of the art surveys (Vol. 2). Springer. https://doi.org/10.1007/978-1-4939-3094-4_23
21. Velasquez, M., & Hester, P. T. (2013). An analysis of multi-criteria decision-making methods. International Journal of Operations Research, 10(2), 56–66.
22. Hayashi, K. (2000). Multi-criteria analysis for agriculture resource management: A critical survey and future perspectives. European Journal of Operational Research, 122(3), 486–500. https://doi.org/10.1016/S0377-2217(99)00248-7
23. Mendoza, G. A., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. Forest Ecology and Management, 230(1–3), 1–22. https://doi.org/10.1016/j.foreco.2006.03.023
24. Wang, P., Zhu, Z., & Wang, Y. (2016). A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. Information Sciences, 345, 27–45. https://doi.org/10.1016/j.ins.2016.01.084
25. Zadeh, L. A. (1965). Fuzzy sets. Information and Control, 8(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X
26. Hadi-Vencheh, A., & Mokhtarian, M. N. (2011). A new fuzzy MCDM approach based on centroid of fuzzy numbers. Expert Systems with Applications, 38(5), 5226–5230. https://doi.org/10.1016/j.eswa.2010.10.064
27. Chu, C. (2009). Thirty years later: The global growth of ITQs and their influence on stock status in marine fisheries. Fish and Fisheries, 10(2), 217–230. https://doi.org/10.1111/j.1467-2979.2008.00313.x
28. De Marinis, P., & Sali, G. (2020). Participatory analytic hierarchy process for resource allocation in agricultural development projects. Evaluation and Program Planning, 80, 101793. https://doi.org/10.1016/j.evalprogplan.2020.101793
29. Baltussen, R., & Niessen, L. (2006). Priority setting of health interventions: The need for multi-criteria decision analysis. Cost Effectiveness and Resource Allocation, 4(1), 1–9. https://doi.org/10.1186/1478-7547-4-14
30. Baltussen, R., Marsh, K., Thokala, P., & Diaby, V. (2019). Multicriteria decision analysis to support health technology assessment agencies: Benefits, limitations, and the way forward. Value in Health, 22(11), 1283–1288. https://doi.org/10.1016/j.jval.2019.06.014
31. Gebre, S. L., Cattrysse, D., Alemayehu, E., & Van Orshoven, J. (2021). Multi-criteria decision making methods to address rural land allocation problems: A systematic review. International Soil and Water Conservation Research, 9, 490–501.
32. Thompson, B. S., & Friess, D. A. (2019). Stakeholder preferences for payments for ecosystem services (PES) versus other environmental management approaches for mangrove forests. Journal of Environmental Management, 233, 636–648.
33. Lara, M. D., & Martinet, V. (2009). Multi-criteria dynamic decision under uncertainty: A stochastic viability analysis and an application to sustainable fishery management. Mathematical Biosciences, 217, 118–122.
34. Caddy, J. F., & Seijo, J. C. (2005). This is more difficult than we thought! The responsibility of scientists, managers and stakeholders to mitigate the unsustainability of marine fisheries. Philosophical Transactions of the Royal Society B: Biological Sciences, 360, 59–75.
35. Elvarsson, B., Agnarsson, S., Guomundsdottir, S., & Vioarsson, J. (2020). Using multi-criteria analysis to assess impacts of change in ecosystem-based fisheries management: The case of the Icelandic cod. Marine Policy, 116, 103825.
36. Mackinson, S., Wilson, D. C., Galiay, P., & Deas, B. (2011). Engaging stakeholders in fisheries and marine research. Marine Policy, 35, 18–24.
37. Rossiter, T., & Stead, S. (2003). Days at sea: From the fishers' mouths. Marine Policy, 27, 281–288.
38. Akbari, N., Bjorndal, T., Failler, P., Forse, A., & Taylor, M. H. (2022). A multi-criteria framework for the sustainable management of fisheries: A case study of UK's North Sea Scottish fisheries. Environmental Management, 70, 79–96.
39. Kimani, P., Wamukota, A., Manyala, J. O., & Mlewa, C. M. (2020). Analysis of constraints and opportunities in marine small-scale fisheries value chain: A multi-criteria decision approach. Ocean & Coastal Management, 189, 105151.
40. Bray, M. N., Magnusson, A., Bicknell, N., Magnusson, M., & Morison, J. (2018). Adapting to change: Prioritising management for the future of the Marine Scalefish Fishery. Marine Policy, 95, 153–165.
41. Morgan, R. (2017). An investigation of constraints upon fisheries diversification using the analytic hierarchy process (AHP). Marine Policy, 86, 24–30.
42. Ting, K. H., Lin, K. L., Jhan, H. T., Huang, T. J., & Wang, C. M. (2015). Application of a sustainable fisheries development indicator system for Taiwan's aquaculture industry. Aquaculture, 437, 398–407.
43. Brookes, K., Schirmer, J., & Pascoe, S. (2015). Selecting and assessing social objectives for Australian fisheries management. Marine Policy, 53, 111–122.
44. Rossetto, M., Bitetto, I., Spedicato, M. T., & Lembo, G. (2015). Multi-criteria decision making for fisheries management: A case study of Mediterranean demersal fisheries. Marine Policy, 53, 83–93.
45. Innes, J. P., & Pascoe, S. (2010). A multi-criteria assessment of fishing gear impacts in demersal fisheries. Journal of Environmental Management, 91, 932–939.
46. Baio, A. (2010). Show me the way: Inclination towards governance attributes in the artisanal fisheries of Sierra Leone. Fisheries Research, 102, 311–322.
47. Pascoe, S., Bustamante, R., Wilcox, C., & Gibbs, M. (2009). Spatial fisheries management: A framework for multi-objective qualitative assessment. Ocean & Coastal Management, 52, 130–138.
48. Utne, I. B. (2008). Are the smallest fishing vessels the most sustainable? Trade-off analysis of sustainability attributes. Marine Policy, 32, 465–474.
49. Nielsen, J. R., & Mathiesen, C. (2006). Stakeholder preferences for Danish fisheries management of sand eel and Norway pout. Fisheries Research, 77, 92–101.
50. Soma, K. (2003). How to involve stakeholders in fisheries management—A country case study in Trinidad and Tobago. Marine Policy, 27, 47–58.
51. Leung, P., Muraoka, J., Nakamoto, S. T., & Pooley, S. (1998). Evaluating fisheries management options in Hawaii using analytic hierarchy process (AHP). Fisheries Research, 36, 171–183.
52. Daneshfard, C., Zeraatkish, Y., Farahy, M. H., Akbary, S. M., & Morady, M. (2011). The optimal exploitation of fishery resources in Persian Gulf coastal bays. Journal of Food, Agriculture and Environment, 9, 757–761.
53. Mardle, S., Pascoe, S., Tamiz, M., & Jones, D. (2000). Resource allocation in the North Sea demersal fisheries: A goal

programming approach. Annals of Operations Research, 94, 321–342.
54. Szalaj, D., Wise, L., Rodriguez-Climent, S., Angelico, M. M., & Marques, V. (2018). A GIS-based framework for addressing conflicting objectives in the context of an ecosystem approach to fisheries management: A case study of the Portuguese sardine fishery. ICES Journal of Marine Science, 75, 2070–2087.
55. Chiou, H. K., Tzeng, G. H., & Cheng, D. C. (2005). Evaluating sustainable fishing development strategies using fuzzy MCDM approach. Omega, 33, 223–234.
56. Paterson, B., Jarre, A., Moloney, C. L., Fairweather, T. P., & Van Der Lingen, C. D. (2007). A fuzzy-logic tool for multi-criteria decision making in fisheries: The case of the South African pelagic fishery. Marine and Freshwater Research, 58, 1056–1068.
57. De Boni, A., Roma, R., & Palmisano, G. O. (2018). Fishery policy in the European Union: A multiple criteria approach for assessing sustainable management of coastal development plans in Southern Italy. Ocean & Coastal Management, 163, 11–21.
58. Robinson, K. F., Dufour, M., Jones, M., & Herbst, S. (2021). Using decision analysis to collaboratively respond to invasive species threats: A case study of Lake Erie grass carp (Ctenopharyngodon idella). Journal of Great Lakes Research, 47, 108–119.
59. Williams, C., Carpenter, G., Clark, R., & O'Leary, B. (2018). Who gets to fish for seabass? Using social, and environmental criteria to determine access to the English sea bass fishery. Marine Policy, 95, 199–208.
60. Chu, C. (2009). Thirty years later: The global growth of ITQs and their influence on stock status in marine fisheries. Fish and Fisheries, 10, 217–230.
61. Hoshino, E., Putten, I., Pascoe, S., & Vieira, S. (2020). Individual transferable quotas in achieving multiple objectives of fisheries management. Marine Policy, 113, 103744. https://doi.org/10.1016/j.marpol.2020.103744
62. Sumaila, U. R., Ebrahim, N., Schubauer, A., Skerritt, D., & Li, Y. (2019). Updated estimates and analysis of global fisheries subsidies. Marine Policy, 109, 103695. https://doi.org/10.1016/j.marpol.2019.103695
63. Fuller, K., Kling, D., & Kroetz, N. (2013). Economics and ecology of open-access fisheries. Encyclopaedia of Energy, Natural Resource, and Environmental Economics, 2, 39-49.
64. Hockings, M., & Philips, A. (1999). How well are we doing? Some thoughts on the effectiveness of protected areas. Parks, 9, 5-13.
65. Pope, J. G., Hegland, T. J., Ballesteros, M., Nielsen, K. N., & Rahikainen, M. (2019). Steps to unlocking ecosystem-based fisheries management: Towards displaying the N-dimensional potato. Fisheries Research, 209, 117-128. https://doi.org/10.1016/j.fishres.2018.12.003
66. Maynou, F. (2020). Evolution of fishing capacity in a Mediterranean fishery in the first two decades of the 21st century. Ocean and Coastal Management, 192, 105190. https://doi.org/10.1016/j.ocecoaman.2020.105190
67. FAO. (2020). Assessment of the integration of fisheries and aquaculture in policy development-Framework and application in Africa. FAO, Rome.
68. Leung, P., Heen, K., & Bardarson, H. (2001). Regional economic impacts of fish resources utilization from the Barents Sea: Trade-offs between economic rent, employment, and income. European Journal of Operational Research, 133, 432-446. https://doi.org/10.1016/S0377-2217(00)00322-7
69. Wadsworth, R. M., Criddle, K., & Kruse, G. H. (2014). Incorporating stakeholder input into marine research priorities for the Aleutian Islands. Ocean & Coastal Management, 98, 11-19. https://doi.org/10.1016/j.ocecoaman.2014.05.003
70. Chen, C. L., Chuang, Y. C., & Lee, T. C. (2019). Not out of sight but out of mind: Developing a multi-criteria evaluation structure for green fishery harbors. Marine Policy, 100, 324-331. https://doi.org/10.1016/j.marpol.2018.11.001
71. Rosenhead, J., & Mingers, J. (2001). Rational analysis of a problematic world revisited: Problem structuring methods for complexity, uncertainty and conflict (2nd ed.). John Wiley and Sons.
72. Rehman, T., & Romero, C. (1993). The application of the MCDM paradigm to the management of agricultural systems: Some basic considerations. Agricultural Systems, 41, 239-255. https://doi.org/10.1016/0308-521X(93)90016-4
73. Belton, V., & Gear, A. E. (1983). On a shortcoming of Saaty's method of analytic hierarchies. Omega, 11, 227-230. https://doi.org/10.1016/0305-0483(83)90047-1
74. Barzilai, J. (2005). Measurement and preference function modeling. International Transactions in Operational Research, 12, 173-183. https://doi.org/10.1111/j.1475-3995.2005.00483.x
75. Val, J. B. R. D., Guillotreau, P., & Valle, T. (2019). Fishery management under poorly known dynamics. European Journal of Operational Research, 279, 242-257. https://doi.org/10.1016/j.ejor.2019.05.021
76. Soomai, S. S. (2017). The science-policy interface in fisheries management: Insights about the influence of organizational structure and culture on information pathways. Marine Policy, 81, 53-56. https://doi.org/10.1016/j.marpol.2017.03.017
77. Fleming, A., Ogier, E., Hobday, A. J., & Thomas, L. (2020). Stakeholder trust and holistic fishery sustainability assessments. Marine Policy, 111, 103719. https://doi.org/10.1016/j.marpol.2019.103719
78. Garcia, S. M. (2005). Fishery science and decision-making: Dire straits to sustainability. Bulletin of Marine Science, 76, 171-196.
79. Kempf, A., Mumford, J., Levontin, P., Leach, A., & Hoff, A. (2016). The MSY concept in a multi-objective fisheries environment: Lessons from the North Sea. Marine Policy, 69, 146-158. https://doi.org/10.1016/j.marpol.2016.03.022
80. Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. European Journal of Operational Research, 158, 662-677. https://doi.org/10.1016/S0377-2217(03)00098-4
81. Murphy, R., Harris, B., Estabrooks, A., & Wolf, N. (2020). Capturing stakeholder perspectives through a collaboration with a commercial fishing cooperative. Marine Policy, 117, 103948. https://doi.org/10.1016/j.marpol.2020.103948
82. Potts, T. (2006). A framework for the analysis of sustainability indicator systems in fisheries. Ocean & Coastal Management, 49, 259-280. https://doi.org/10.1016/j.ocecoaman.2005.07.003
83. Sánchez-Lizaso, J. L., Sola, I., Guijarro-García, E., Bellido, J. M., Franquesa, R. (2020). A new management framework for western Mediterranean demersal fisheries. Marine Policy, 112, 103772. https://doi.org/10.1016/j.marpol.2019.103772