Who gets to fish for sea bass? Using social, economic, and environmental criteria to determine access to the English sea bass fishery

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Abstract

Transparent, performance-based approaches to allocating fishing opportunities are required for signatories to the Aarhus Convention and the European Union's (EU) Member States via the Common Fisheries Policy. The lack of an operational framework to support this requirement means such a system is seldom explicitly used. Using the English commercial sea bass (*Dicentrarchus labrax*) fishery as a case study, operationalisation of this policy requirement is evaluated using a Multi-Criteria Decision Analysis (MCDA) framework. MCDA is a decision-making tool allowing users to explicitly evaluate complex, potentially conflicting, criteria, enabling wider costs and benefits to be considered. The sea bass fishery was selected as the dramatic stock decline since 2010 has meant difficult policy choices regarding the allocation of scarce fishing opportunities between different user groups. To inform the MCDA, the three main English sea bass fishing methods (nets, hooks, and trawls) are evaluated across thirteen social, economic, and environmental criteria to generate a performance score. Importance weightings for each criterion, developed from 50 surveys of fishers, industry representatives, managers, non-governmental organisations, and the wider public, are used to combine these performance scores generating an overall score for the MCDA. Results show that regardless of stakeholder group questioned, hooks achieve the highest MCDA performance, followed by nets, and then trawls. This suggests that taking a performance-based approach to the allocation of fishing opportunities in the English fishing fleet have a prioritisation by fishing type. MCDA could be used to promote transparency, objectivity and social, environmental and economic sustainability into European and UK fisheries.

Keywords: Fisheries allocation; Fisheries Management; Sea bass; Common Fisheries Policy; Multi-Criteria Decision Analysis; Decision Support.

1 Introduction

Fisheries resources are finite in supply but desired by many users (they are rivalrous). Limited fishing opportunities must therefore be allocated to users with competing demands based on a framework to avoid overexploitation which may result from the divergence between individual and collective interests [1]. In accordance with international obligations [2] to avoid over exploitation of resources, the sustainable management of fish stocks is required. In Europe, the Common Fisheries Policy (CFP, REGULATION (EU) No 1380/2013) [3] and Marine Strategy Framework Directive (MSFD) [4] provide the legislative framework setting out the goal of achieving Maximum Sustainable Yield (MSY) and Good Environmental Status (GES) by 2020 for all commercially exploited fish stocks [5]. Accordingly, allocations of fishing opportunities by the European Commission are, in principle if not in practice, made to EU Member States in line with these objectives for the major shared fisheries [6].

The national distribution of fishing opportunities should follow Article 17 of the CFP which specifies that Member States use “transparent and objective criteria including those of an environmental, social and economic nature [7].” Article 17 requires fleets that deliver best value to society to be given preferential access to fishing opportunities. However, the practical application of this broad policy objective is not specified and the current allocation of fishing opportunities often relies on piecemeal historic decisions. This presents the potential for conflict with the provisions of the United Nations Aarhus Convention which provides the public with rights regarding access to information, public participation and access to justice, in governmental decision-making processes on matters concerning the local, national and transboundary environment with a focus on interactions between the public and public authorities.

When considering fisheries management objectives and developing allocation criteria, a number of studies have examined options for allocation (including criteria and indicators), beyond the widespread ‘historic share’ approach [8,9,10,11]. However, a significant gap remains in the peer-reviewed academic literature with no practical guidance on how to turn potential criteria into the allocation of fishing opportunities.

Using the English sea bass (*Dicentrarchus labrax*) fishery as a case study, multiple-criteria decision analysis (MCDA) is explored as a tool for transparently allocating fishing opportunities in a non-total allowable catch (TAC) operated fishery. Sea bass was exemplified because it is an important commercial and recreational stock [12] that has undergone a severe decline in recent years, following a period of poor recruitment due to adverse environmental conditions (Figure 1) coupled with unchecked expansion of fishing effort and unsustainable catch levels [13]. In brief, the commercial sea bass fishery is split between an offshore fishery on spawning aggregations, mainly using pelagic trawls and drift nets, and an inshore fishery using a variety of gears (fixed nets, rods, and lines) targeting sea bass after spawning and/or juvenile fish [14]. The fishery is mainly exploited by fleets from France, the UK, and the Netherlands with equal landings from the UK and France in 2016, despite France previously catching two thirds of the EU total (see Figure S1) [15]. Since 2015, following steep declines in spawning stock (Figure 1) the European Union (EU) has introduced Emergency Measures, closing the fishery, limiting recreational angling and commercial catches, and increasing the minimum legal landing size [16]. This study does not consider the question of allocation between commercial and recreational take, but the methodology could also be applied between these sectors. A full history of the sea bass fishery is provided in the Supplementary Material.

Continued debate regarding further fishing opportunities amongst Member States, the commercial and recreational sectors, and different fishing gear operators within the commercial sector is expected. With so few fishing opportunities available for sea bass, great care must be made that opportunities maximise social and economic value while minimising environmental damage and several reports on EU fisheries have advocated a criteria-based approach to quota allocation [17,18]. Based on this a set of social, economic and environmental objectives for use in the UK sea bass fishery were developed. While the UK will be leaving the CFP following Brexit (the departure of the UK from the European Union as a result of a referendum held in June 2016) [19], the approach of Article 17 is consistent with the UK Government's Marine Policy Statement of promoting good governance and achieving a sustainable economy [20]. The findings of this study can therefore be used to inform fisheries allocation across the EU and in the UK post-Brexit

2 The English sea bass fishery

2.1 Stock decline

Sea bass is an important commercial and recreational stock [21]. Owing to its popularity on menus and availability to fishers as a non-quota species, increased catches between 2000 and 2010 proved unsustainable and the Northern European stock has undergone a severe decline in recent years (Figure 1) [22] and the Southern stock appears to be following the same trajectory [23].

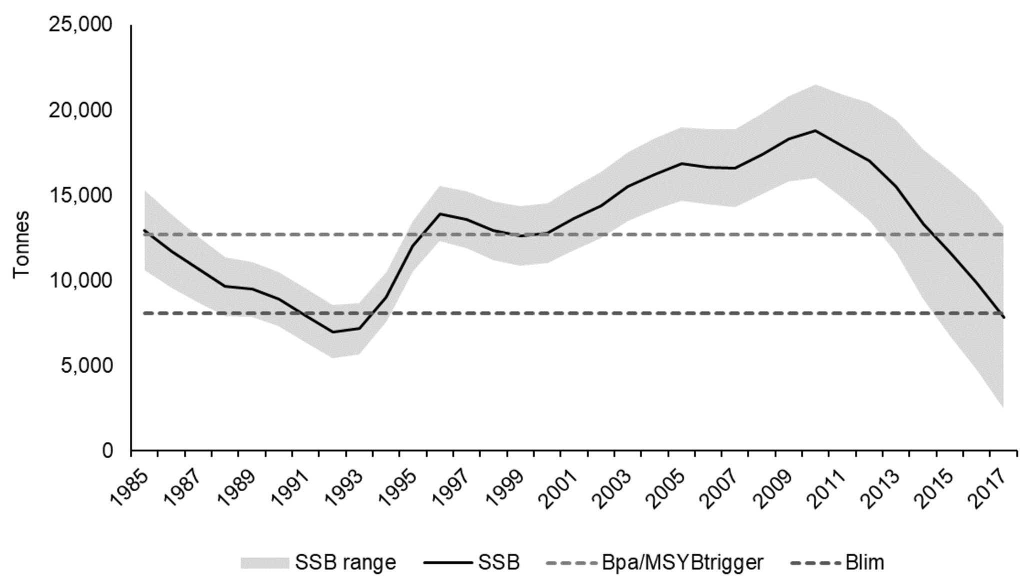

Fig. 1. Spawning stock biomass of the Northern European stock of sea bass (Reconstructed from ICES data [22]). Abbreviations: SSB – spawning stock biomass, Bpa – precautionary reference point for SSB, MSYBtrigger – the lower 95% confidence limits (of SSB) with exploitation at FMSY from long-term simulations, Blim – limit reference point for SSB.

Sea bass grow slowly, do not mature until 4–7 years of age, and have been recorded up to 28 years of age [24]. Juvenile sea bass up to three years of age occupy nursery areas in estuaries whilst adults undertake seasonal migrations from inshore habitats to offshore spawning sites where they are targeted by pelagic trawlers [25]. After spawning, sea bass tend to return to the same coastal sites each year [26]. The combination of slow growth, late maturity, spawning aggregation, and strong site fidelity, increase the vulnerability of sea bass to over-exploitation and localized depletion [27].

2.2 The fishery

France has long been responsible for the majority of sea bass landings since the fishery started at a scale to be recorded. The winter pelagic trawl fishery was conducted only by French vessels with UK vessels excluded by UK-specific regulations due to concerns over cetacean bycatch [28]. Starting in January 2015 the EU introduced Emergency Measures for sea bass (described in Section 2.4), closing the spawning fishery, limiting recreational angling and commercial catches by gear type and area, as well as increasing the minimum legal landing size. In the past few years, the UK share of the fishery has increased as a result of Emergency Measures closed the French offshore fishery.

UK vessels landed 501 tonnes of sea bass in 2016 with a first sale value of £5 million. Of that volume, 487 tonnes were from English vessels and 61 tonnes were from Welsh vessels [29]. Over 42% of English landings were from six ports, which are listed in Table 1.

Table 1. Major ports for the English sea bass fishery (MMO [30]).

Port	Weight (kg)	Value (£)
Weymouth	49,920	562,470
Brixham	41,163	397,003
Plymouth	31,535	359,197
Eastbourne	33,421	325,731
Portsmouth	26,676	245,115
Newhaven	24,127	208,309
England total	487,109	4,502,050

The English sea bass fishery can generally be categorized into three gear types: nets, hooks, and trawls. In 2016, vessels using nets landed 223 tonnes of sea bass (465), vessels using hooks landed 181 tonnes (37%) and vessels using trawls landed 81 tonnes (17%) (Figure 2) [30].

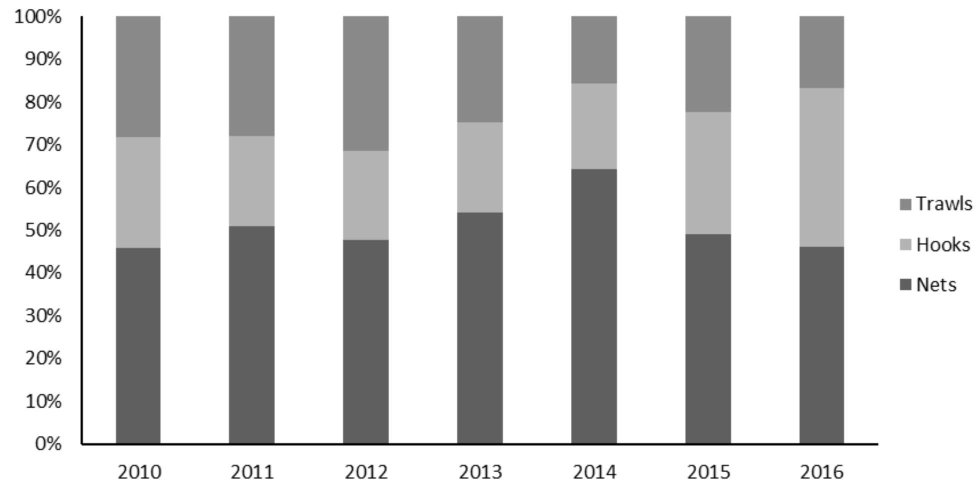

Fig. 2. Composition of English sea bass landings by gear type. (Reconstructed from MMO data [30]).

2.3 Current management challenges

The recent decline in sea bass has been linked to multiple factors: overfishing of the spawning stock during winter spawning aggregations, a minimum size that could not guarantee enough sea bass were reaching spawning size before capture (i.e. recruitment overfishing), and environmental conditions which had impacted the survival of recent sea bass cohorts leading to poor recruitment. Scientific advice from the International Council of the Sea (ICES) had not been followed by European fisheries ministers ever since a precautionary cut in landings by 20% was advised in 2012 [31,32]. The resulting negative trend of the stock meant urgent action needed to be taken in December 2014 for the 2015 fishing year [33]. ICES continued to advise more stringent reductions in landings, culminating in the advice for zero landings (commercial and recreational) for 2017 and 2018 (when applying a precautionary approach [34,35]).

Sea bass does not have a total allowable catch (TAC). Resistance to catch limits largely emerge from a disagreement between Member States on the appropriate reference period to use to calculate relative shares [36]. This absence of total catch limits has led to increased pressure on the stock in the last decade, especially from fishers without quota holdings for TAC species. Small-scale fishers in particular have difficulties acquiring quota holdings and can either exit the fishery or focus their fishing effort on non-TAC species (such as sea bass). Many have opted for the latter and the cumulative impact has led to a rapid and alarming decline of stock biomass.

2.4 Recent management measures

To halt this decline in the sea bass stock and try to mitigate the risks of a collapsed fishery, in 2015 the UK Government requested that the EU instigate a set of Emergency Measures under Article 12 of the CFP [37]. These initial Emergency Measures [38], implemented between January 2015 and December 2016 include a ban on pelagic trawling during spawning season; an increase in Minimum Conservation Reference Size from 36 to 42cm and maximum monthly catches by gear type as well as restrictions of 3 fish per day per recreational angler [39] (which was reduced to 1 in 2017), closed areas [40] and a closed season during February and March [41].

The ICES advice for both 2017 and 2018 fishing opportunities was for zero catch (both commercial and recreational) [42, 43]. This has meant the debate regarding continuation of fishing opportunities amongst Member States, the commercial and recreational sectors, and different fishing gear operators within the commercial sector is ongoing. The 2017 December Council proposed further restrictions for 2018, reducing the bycatch allowance for trawls and nets, reducing the hook and line catches to 5 tonnes and closing the recreational fishery[44].

3 The use of criteria in allocating fishing opportunities

3.1 Guidance from the Common Fisheries Policy

While the setting of many fishing limits in the EU is made through negotiations of the Council of Ministers, the allocation of these fishing opportunities is largely the responsibility of each Member State. Article 17 of the CFP does provide some guidance on how these allocations should be considered:

> "When allocating the fishing opportunities available to them, as referred to in Article 16, Member States shall use transparent and objective criteria including those of an environmental, social and economic nature. The criteria to be used may include, inter alia, the impact of fishing on the environment, the history of compliance, the contribution to the local economy and historic catch levels. Within the fishing opportunities allocated to them, Member States shall endeavour to provide incentives to fishing vessels deploying selective fishing gear or using fishing techniques with reduced environmental impact, such as reduced energy consumption or habitat damage" [45].

Article 17 therefore requires fleets that deliver best value to society to be given preferential access to fishing opportunities and develops a set of transparent and objective criteria. These criteria include a mixture of economic, environmental and social indicators, which focus on selectivity, resource dependency and wider environmental impact.

The dire situation of the sea bass stocks creates a unique context to put a detailed criteria-based allocation framework (maximising social and economic value while minimising environmental damage) into action. MCDA as a decision-making tool has previously been used to look at fisheries sustainability indicators [46], trade-off analysis in fisheries management decisions [47], and fishing gear impacts [48], however few have applied it to allocation of opportunities [49].

Several reports on EU fisheries have advocated a criteria-based approach to quota allocation [50,51]. A 2013 report for the EU Parliament suggested a suite of criteria that would interest stakeholders and also have readily available data [52].

3.2 Setting objectives

Setting fisheries management objectives is key to the transparent monitoring of the performance of fisheries. However, objective setting is frequently neglected or inadequate [53]. If stakeholders are not involved, or do not understand the objectives, generating support for management plans will be difficult. According to the Food and Agriculture Organisation, the goals in fisheries management can be split into subsets: biological; ecological; economic and social, which includes political and cultural goals [54]. Incorporating economic, biological, social and environmental objectives into a single framework and including stakeholder views is essential for management success [55].

The UK Government has its own vision, outlined in *Fisheries 2027 - Vision Statement,* that also emphasises the economic, social and environmental dimensions of fisheries:

> "Government's role is to manage this asset on behalf of society and to get the most benefits for today's citizens and future generations. The few in society who catch fish are responsible for doing so efficiently. This means getting the best possible economic and social benefits from fishing for the least environmental cost – including safeguarding stocks for the future. It is the role of processors and retailers in the supply chain to act sustainably, and the consumer's role is to choose sustainably" [56].

There is a particular emphasis on moving beyond fleet economics and capturing benefits to coastal communities, wider society, and future generations. The statement commits to managing fisheries for the "long-term benefits for the whole of society" and determining access to certain fishing types "even if in some cases that is not the most economically efficient way of harvesting the resource" as "wider economic, social and environmental benefits of small-scale fishing can outweigh the comparative inefficiency in harvesting the resource." [57]

Based on Article 17 of the CFP and this clear statement of vision from the UK government, a set of social, economic and environmental objectives for use in the English sea bass fishery were developed.

4 Methods

4.1 Multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) is a decision-making tool that allows users to explicitly evaluate complex, and potentially conflicting, criteria, allowing wider costs and benefits to be taken into account. MCDA has been used in many fields including health [58], energy [59], development [60] and finance [61] and enables managers to establish and communicate defined social, economic, and environmental goals. Given the potential value of MCDA, and its previous application in fisheries and other marine management contexts [62, 63, 64, 65, 66], it was selected as a potentially suitable tool to enact the Article 17 requirements of the reformed CFP. Furthermore, since the decision of the UK to exit the EU, this examination of the technique has value when considering how the UK might allocate resources when no longer a member of EU.

Using the English sea bass fishery to test the potential of MCDA for the allocation of fishing opportunities, information on gear performance was combined with criteria weights derived from a survey of stakeholders to display the trade-offs between different gears and criteria. A MCDA utility score is generated for each gear through weighted summation and then converted to a score out of 100 by dividing by the maximum possible result.

$$MCDA_g = \frac{\sum P_{c,g} W_c}{\sum P_m W_c} \quad \text{(Equation 1)}$$

Where P is the performance score for each criterion, W is the weighting applied, g is a gear category, c is the criteria, and m is the maximum performance score of 5. This weighted approach to performance aggregation is a commonly used approach in MCDA. Critically, it assumes that criteria are independent and that they can be traded off against each other [67].

4.2 Criteria by which to determine best value to society, according to Article 17 of the CFP

Building on the objectives outlined in the UK Government's Fisheries 2027 vision document, thirteen criteria and indicators were chosen to operationalise the requirement for environmental, social, and economic criteria under Article 17 of the CFP (Table 2).

Table 2. Criteria for the allocation of sea bass fishing opportunities under Article 17 of the CFP.

Criteria	Description	Indicator
Profits	Profits are important to generate economic activity while minimising costs and ensure a financially sustainable industry.	£/kg landed weight
Employment	Fishing creates jobs by providing a viable economic opportunity. Often these jobs are created in marginal coastal communities with high unemployment.	jobs/kg landed weight
Greenhouse gas emissions	Fuel use from fishing generates greenhouse gas emissions which contribute to climate change.	kgs of CO_2/kg landed weight
Subsidies	The fishing industry receives subsidies in different forms. This masks true performance and deprives governments of funds for other purposes.	£/kg landed weight
Economic value chain	The impact of fishing does not stop when a fish is caught. Economic impacts continue through processing, transport and other secondary industries generating economic activity and employment.	price/kg landed weight
Sea bass discards	Sea bass discards result from undersized fish being caught. Depending on survivability when discarded this can increase fishing mortality.	kgs of sea bass/kg of sea bass landed
Other discards	Discards from other species result from undersized or non-commercial fish being caught. Depending on survivability when discarded this can increase fishing mortality.	kgs of discards/kg landed weight
Spawning season mortality	Fishing during particular seasons and in particular areas can damage a fish stock when it is reproducing. This leads to lower fish populations than would result from the fishing activity itself.	amount of fishing taking place during spawning season
Bycatch	Bycatch is the unintended capture of marine wildlife such as dolphins, birds, turtles or seals. This can damage or kill the captured wildlife.	Risk Assessment for Sourcing Seafood (RASS) score (1 low risk - 5 high risk)
Ecosystem damage	Fishing activity can harm the marine environment and destroy habitats. This can lead to lower populations and a loss of biodiversity.	Risk Assessment for Sourcing Seafood (RASS) score (1 low risk - 5 high risk)
Ghost fishing	Ghost fishing occurs when fishing gear is lost in the water. This entangles fish and causes fishing mortality.	Descriptive from literature
Fleet dependency	Some fishing fleets heavily rely on certain types of fishing for their economic activity. Any policy change should ensure limited impacts where dependency is high.	Percentage of total value from sea bass landings (%)
Port dependency	Some ports heavily rely on certain types of fishing for their economic activity. Any policy change should ensure limited impacts where dependency is high.	Percentage of sea bass landings to sea bass-dependent ports (>£10,000 and >10% of landed value)

4.3 Data sources and availability

Data sources used to parameterise indicators are detailed in Table 3. In most cases the results by criteria are reported directly or are a simple intensity as indicated by the measure. Three criteria (damage to spawning stock, sea bass discarding, and other discarding), however, required the development of indicators to permit estimation using parameters developed for this study, detailed in section 4.4. In many cases the gear assessments are for fishing activity for a particular gear in general, not specifically activity related to fishing for sea bass. This is due to the fact that activity (e.g. fuel use, labour), especially in a mixed fishery cannot be separated by species in a meaningful way. In these instances (e.g. profits, employment, greenhouse gas emissions), the result is expressed for the gear type per kilogram of landed weight for all species.

It is also the case that there is variance within each gear type. In the nets category there is varying performance by drift nets and fixed nets and in the trawls category by otter trawls, mid-waters trawls and beam trawls. As data is not available for each criterion at this level an average has been taken by broad category, weighted by each gear's contribution to the landings total.

4.4 Analysis

There is no commonly used indicator to describe damage to spawning stock, although the relevant components are clear [68]. Consequently, an indicator was developed to describe the likelihood of impact on the stock from fishing carried out during the spawning season:

$$FS_g = \sum LS_{g,s} D_{g,s} \quad \text{(Equation 2)}$$

Where FS is a measure for fishing during the spawning season, g is the gear, s is the season, LS is the percentage of landings, and D is a damage coefficient. The damage coefficient is defined as 1 for high spawning (January-April), 0.5 for medium spawning (May, June, December), 0.25 for low spawning (July, November) and 0 for no spawning (August-October).

The indicator for bass discarding also required the development of new parameters due in part to a policy change that occurred after the measurement. As the minimum landing size was increased from 36cm to 42cm, an adjusted discard rate was calculated based on the size composition of landings for each gear (as well as assumptions about avoidance and parameters for survivability). The adjusted bass discard rate can be expressed as:

$$ADRB_g = DRB_g 0.5 LM_g M_g \quad \text{(Equation 3)}$$

Where ADRB is an adjusted discard rate of bass, g is the gear, DRB is the recorded discard rate of bass, LM is the current level of landings in the range of the change in minimum landing size, and M is the rate of mortality of discards (90% for trawls, 80% for nets, 20% for hooks – all estimated from previous qualitative descriptions)[69, 70]. The same survivability parameters are used for the indicator of total discards, where ADR is the adjusted discard rate of all species and DR is the recorded discard rate of all species.

$$ADR_g = DR_g M_g \quad \text{(Equation 4)}$$

The results of the 13 criteria for the three major gear types, reported in Table 3, are converted to a 1-5 scoring system by dividing performance outcomes into quintiles. This was completed using the performance of all gear types across UK fisheries, although for economic value chain, sea bass discards and other discards, the quintiles are simply a relative scoring of the range for the three major gear types targeting sea bass as these three criteria are specific to the fishery. An approach based only on relative performance would fail to reward improvements unless the major gear types change positions. It would also lose any sense of scale in a two-gear comparison (as all scores would be a 1 or 5). A description of the methodology used for converting performance into a 1-5 scoring system is provided in Table 2 of the Supplementary Material.

Two sensitivity analyses are also performed. The first sensitivity analysis is an adjustment to the gear assessment for issues with scoring in the gear assessment. The maximum range is found by adding 0.5 to each criterion score up to a maximum of 5 and the minimum range is found by removing 0.5 from each criterion score to a minimum of 1. An additional sensitivity analysis is an adjustment to the criteria weightings to optimise the overall performance of each gear type. These weightings were found by using a solver function to maximise the difference between each gear and the average of the other two gears being compared.

4.5 Criteria weightings

To approach the issue of criteria importance, 50 stakeholders of the English sea bass fishery were surveyed (Annex I of the Supplementary Material). These include 7 industry representatives (large-scale, small-scale, processing), 18 fishers (netters, trawlers, hook and line), 10 people working in management (inshore management, scientific advice), 5 people working for NGOs (conservation, angling), and 10 non-expert citizens. The survey, conducted between January and September 2017, asked these stakeholders to weight the 13 indicators from 1 (low) to 5 (high) for their importance.

The ranking survey was purposefully distributed to a multi-sectoral stakeholder group working on sea bass, and all members of the steering group and their constituents were invited to respond [71,72]. Further quayside and telephone interviews were conducted following suggestions from regulators, managers, scientists and commercial fisheries representatives, for harder to reach stakeholders, to ensure their views were captured [73]. Potential biases may be present as a result of the different survey formats – in the case of regulators, large scale industry representatives and NGO stakeholders, the excel table was easy to complete, however small-scale fishers required an approach which did not require the same level of computer literacy. Therefore the excel table was rephrased as direct questions, referring specifically to sea bass, and the relative importance of that species to the fisher being asked (see Annex 1). These surveys were posted, emailed or asked over the phone to 10 of the fishers and transcribed accordingly into the excel sheet for analysis.

5 Results

5.1 Gear assessment using criteria

The three gear types are compared to each other using the criteria and measures described in Table 3.

Vessels using trawls were the most profitable fleets fishing for sea bass, however they supported the fewest jobs per tonne of sea bass landed, had a lower average price (£6.50-£7 per kg) as well as the highest discard rates, impact on spawning stock mortality, marine mammal bycatch and ecosystem damage.

Vessels using nets performed better on the environmental criteria (except for ghost fishing) than vessels using trawls and have a lower impact on spawning stock mortality, while overall also being dependent on sea bass for 12% of their income. Netters also landed most (52%) of their catch to sea bass dependent ports and provided a higher number of jobs per kg of sea bass than mobile gear, while receiving the lowest subsidy per kg.

Most jobs per kg of sea bass were supported by hook and line fishing. The price per kg was also highest (£9.50 per kg), while also having the lowest discard rates and impact on spawning stock mortality. In terms of their dependence on sea bass, hook and line were the most (15%) dependent on sea bass and landed 55% of their sea bass into sea bass dependent ports. There is also little to no unwanted bycatch.

Table 3. Gear assessment by criteria.

Criteria	Data sources	Measure	Results			Score (1 low - 5 high)		
			Nets	Trawls	Hooks	Nets	Trawls	Hooks
Profits	STECF (2017) The 2017 annual economic report on the EU fishing fleet	£/kg landed weight	0.41	0.43	0.19	5	5	2
Employment	STECF (2017) The 2017 annual economic report on the EU fishing fleet	jobs/kg landed weight	0.04	0.02	0.05	4	2	5
Greenhouse gas emissions	STECF (2017) The 2017 annual economic report on the EU fishing fleet	kg of CO2/kg landed weight	1.46	2.57	2.52	4	2	2
Subsidies	STECF (2017) The 2017 annual economic report on the EU fishing fleet; Borrello et al. (2013) Fuel subsidies in the EU fisheries sector	£/kg landed weight	0.06	0.1	0.1	4	2	2
Economic value chain	MMO (2017) UK and foreign vessels landings by UK port and UK vessels landings abroad	price/kg landed weight	7.4	7.8	9.9	1	1	5
Sea bass discards	ICES (2014) Report of the inter-benchmark protocol for sea bass; Cefas Length distribution of bass discards in the UK trawl fishery	kg of dead bass discards/kg of sea bass landed	0.07	0.23	0	4	1	5
Other discards	Cefas (2014) Discard Atlas of the North Western Waters Demersal Fisheries; Imares (2014) Discard Atlas of North Sea fisheries	kg of dead discards/kg landed weight	0.03	0.11	0	4	1	5
Spawning season mortality	MMO (2017) UK and foreign vessels landings by UK port and UK vessels landings abroad	Percentage of fishing during spawning season	51%	54%	29%	2	2	4
Bycatch	Seafish (2017) Risk Assessment for Sourcing Seafood	RASS score (1 low risk - 5 high risk)	3/5	4/5	1/5	3	2	5
Ecosystem damage	Seafish (2017) Risk Assessment for Sourcing Seafood	RASS score (1 low risk - 5 high risk)	1/5	4/5	1/5	5	2	5
Ghost fishing	IEEP & Poseidon (2005) Ghost fishing by lost fishing gear	Descriptive	Medi um	Low	Very low	2	4	5
Fleet dependency	MMO (2017) UK and foreign vessels landings by UK port and UK vessels landings abroad	Percentage of total value from sea bass landings (%)	12%	1%	15%	4	1	5
Port dependency	MMO (2017) UK and foreign vessels landings by UK port and UK vessels landings abroad	Percentage of sea bass landings to sea bass-dependent ports (>£10,000 and >10% of landed value)	52%	5%	55%	4	1	4
					Total	**46**	**26**	**54**

Notes: Results generated from data described within the identified data sources. Score assigned to each criterion based on quintile boundaries and method presented in Supplementary Material Table 2.

Based on this gear assessment across the 13 criteria, vessels using hooks achieve the highest performance (a score of 54 out of a possible 65 whereas nets scores 46 and trawls 26). These vessels did not universality score higher across all the criteria however and it may be the case that some criteria are more important than others.

5.2 MCDA weighting and scores

Figure 4 shows the results from the stakeholder weighting exercise for each of the 13 criteria. Across stakeholder groups there is a wide range of rank order preferences for each of the criteria. In the most extreme case, profitability was the most important criterion for fishers, whereas this was the least important criterion for citizens. For others, such as employment, there was a high level of consensus regarding rank order preference across stakeholder groups. However, in terms of the actual values to assign for the weightings, there was generally broad agreement across stakeholder groups. Only four indicators (profits, greenhouse gas emissions, spawning season mortality, and bycatch) have a spread of more than two points between the highest and lowest scores. There is, however, a wide spread in the weightings assigned by individual stakeholders in each group (see Supplementary Material Table 1). All criteria have an average weighting of over 2.5, indicating that all criteria were seen to have merit in the analysis.

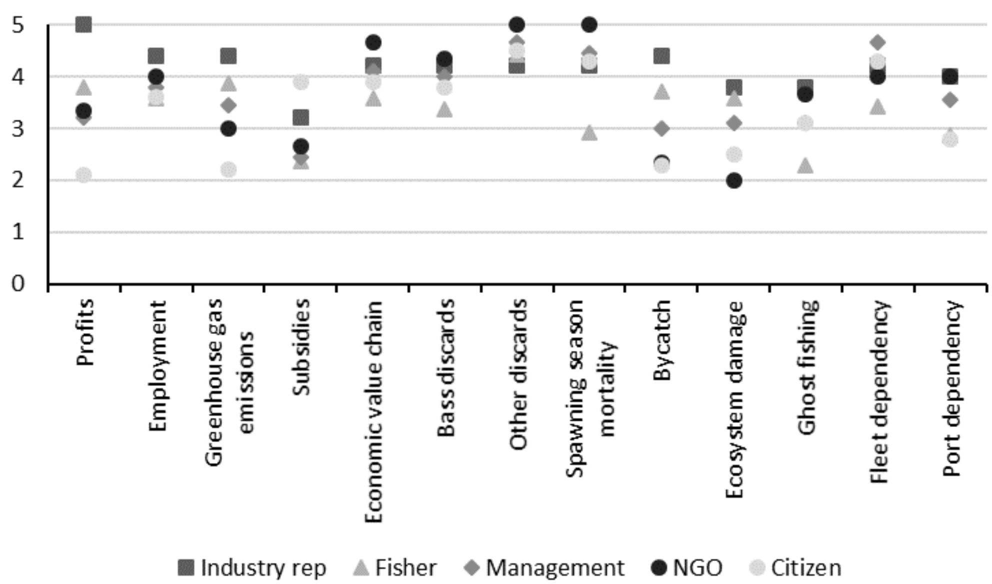

Fig. 3. Criteria weighting by each stakeholder group.

The results of the MCDA, using the gear performance scores and different weighting scenarios are illustrated in Figure 5. There is little difference in the results using the weightings from each stakeholder group. In all cases, gears with hooks have the highest MCDA score, followed by nets, followed by trawls (see Figure 1 in the Supplementary Material).

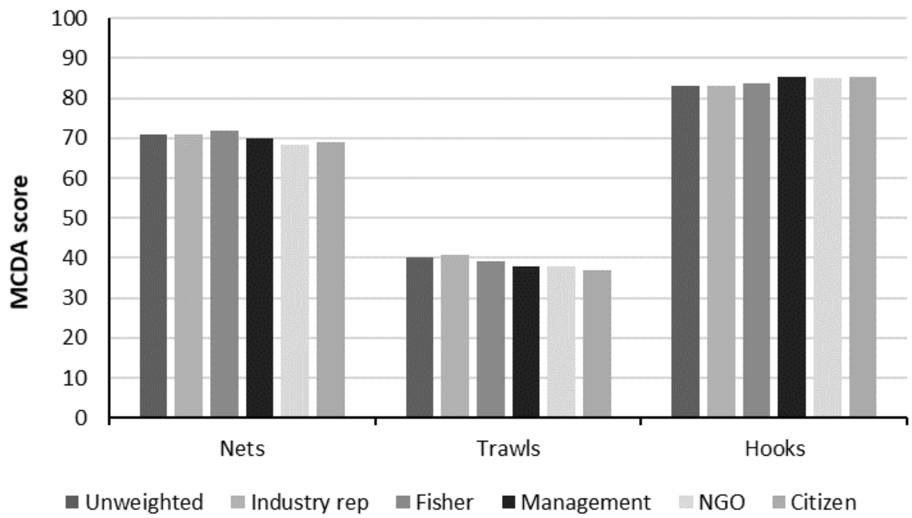

Fig. 4. MCDA scores by gear for each stakeholder group.

The small difference between the MCDA scores by gear for the different stakeholder groups is a reflection of the similar weightings provided by each stakeholder group. Compared to the unweighted gear assessment, the weightings from fishers yield a small preference for vessels using nets, the weightings from industry representatives yield a small preference for vessels using trawls, and the weightings from management, NGOs, and citizens give a small preference for vessels using hooks. In all cases the difference in results are not significant.

Sensitivity analysis

The first sensitivity analysis adjusts the gear assessments by half a point in either direction to account for potential errors in the assessment of performance. The results reveal that if vessels using nets were frequently underestimated and vessels using hooks were frequently overestimated then the overall scores for the two gears may converge. Even under the most extreme changes considered here, the ranking of vessels using trawls against other gear types does not change.

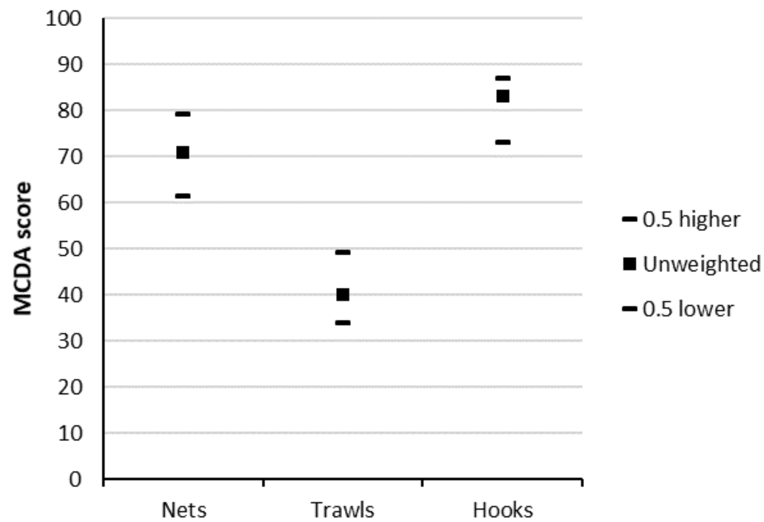

Fig. 5. MCDA score by gear using adjusted assessment scores.

The second sensitivity analysis, using weightings to maximise the relative performance for each gear moves the results much closer together, with vessels using nets ranking above vessels using hooks under some weightings (Figure 6). This contrasts with the actual weightings provided by stakeholder groups (see Supplementary Material Table 1). The results in Figure 6 also illustrate the contribution of each criterion to the overall MCDA score.

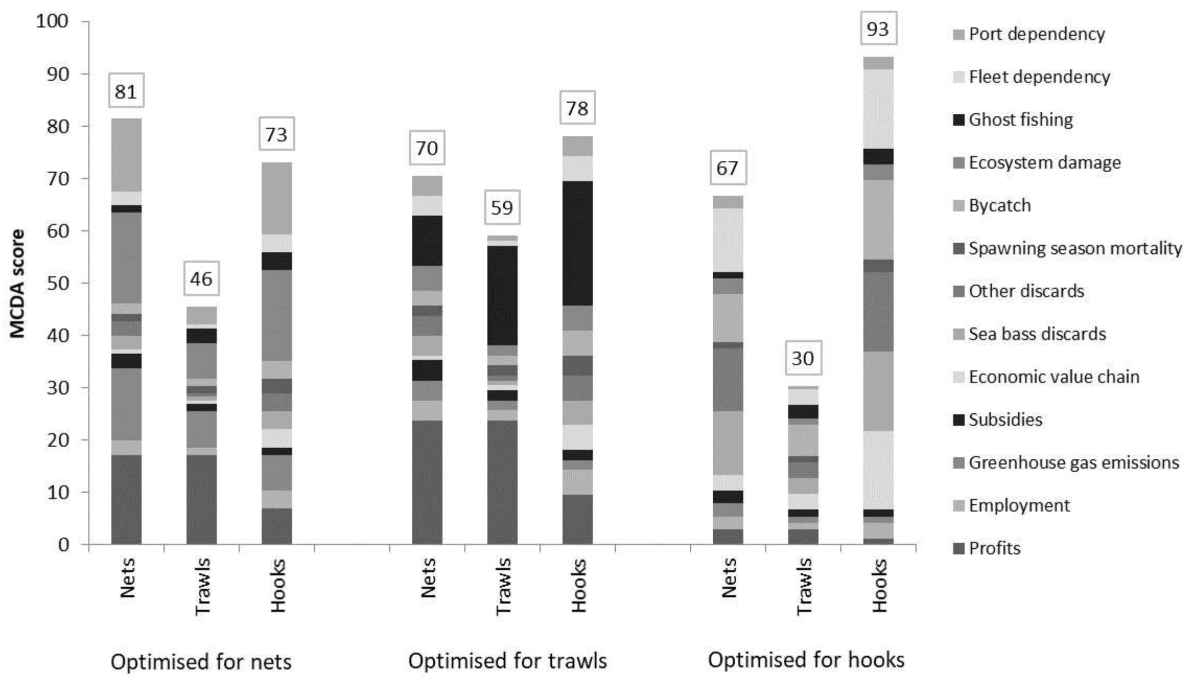

Fig. 6. MCDA score by gear using optimised weightings.

6 Discussion

6.1 Relevance of findings

This MCDA framework provides a case study in how to apply performance-based allocation of fishing opportunities, using available data in a transparent and objective manner which could serve as a basis for the allocation of fishing opportunities by Member States, in this case England.

Taking a criteria-based approach to fishing opportunities in the English sea bass fishery yields interesting results – both practically and at a broader level. Most directly, it is clear from the results that when taking a broad approach that includes social, economic, and environmental criteria a ranking of performance emerges with vessels using hooks at the top, followed by vessels using nets, and finally vessels using trawls. Interestingly, this ranking is consistent across different weightings applied by stakeholder groups. These findings are significant for decision makers as controversial allocation decisions continue to be made on an annual basis.

At a broader level, the study also shows that it is possible with available data to construct a transparent, objective, and informative framework on which to base decisions on the allocation of fishing opportunities. This performance-based approach to allocating a resource is used in other fields, such as the 'beauty contests' to determine the licensing of mobile networks throughout much of Europe using comparative tender [74,75].

Given that decision makers will continue to have to make controversial decisions regarding allocation of fishing opportunities, it may prove beneficial to political discourse to take an evidence-based approach like the one developed here. Fisheries are rivalrous and therefore any policy or allocation decision is likely to produce winners and losers. MCDA can be used to resolve conflicts in a transparent and objective manner, which can also be tied to wider policy objectives [76].

The MCDA approach taken here (based on multi-attribute utility theory) is one common approach to MCDA but it is not the only one. Other approaches differ in whether and how the weightings are used, as well as how the weightings are obtained. One alternative would be to use pairwise comparisons to identify the importance of each criteria relative to each other. Each MCDA approach has its own advantages and disadvantages [77,78]. One promising possibility to use MCDA in the allocation of fishing opportunities is for all stakeholder groups to complete their weightings in the same setting. While more demanding of resources, this could lead to a better understanding of agreement and conflict between stakeholder groups [79].

Significantly, the least profitable fishing gear (vessels using hooks) in the English sea bass fishery were found to have the highest MCDA score. In this particular instance, utilising market systems to determine the allocation of fishing opportunities would therefore work against wider social, economic, and environmental objectives [80].

The prospect of 'Brexit' and the UK determining its own fisheries policy outside of the CFP does not significantly alter any of these findings, or the value of using MCDA to allocate fishing opportunities throughout the EU. Decisions regarding the allocation of fishing opportunities under Article 17 is already up to individual Member States. Such a framework could, in theory, be applied to the sharing of fishing opportunities between the UK and EU instead of 'relative stability' based on historic fishing, although this is unlikely as the UK and EU Member States may have different agreed objectives for fisheries management. Whatever the outcome of UK EU exit, the requirements the approach to the allocation of fishing opportunities as they relate to national and transboundary decision making mean they must adhere to the principles of the Aarhus Convention; MCDA, as a transparent system of decision making presents one method for achieving this.

6.2 Average versus marginal analysis

This MCDA model uses information on the historic performance of different gear types to illustrate how Article 17 could be applied to UK sea bass fishing. The gear performance per tonne of landing is taken as an average due to the data available. As alternative allocations of sea bass fishing opportunities for different gears would involve a marginal change, with more data it would be important to analyse how one specific tonne could have different impacts. It is possible that the costs and benefits of each additional tonne of quota are non-linear for the fleets. This point is sometimes raised when fishing opportunities for choke species are discussed, although for the time being the landing obligation is not being applied to sea bass in the demersal fisheries landing obligation and so this issue is currently less pressing.

6.3 Unavoidable bycatch

Fisheries resource allocation is a messy problem [81] and all models are tools offering a simplification of reality. For example, the MCDA framework presented does not account for the impacts of, for example, adverse consequences of reducing fishing opportunities to fishing activities which might otherwise continue to contribute to mortality due to the discarding of unavoidable bycatch (sea bass, in this instance). There are therefore conflicts between the commitments of the CFP that seek to incentivise selective gear and eliminate discards, while also accepting that some level of sea bass bycatch is inevitable. This conflict does not however nullify the application of such the MCDA model, but it does require scenario planning and the consequences to be considered and management to address these issues. Solutions have been applied elsewhere to address this conflict, for example the 'cod recovery plan' [82] included provisions for 'real time closures' when discarding threatened the objective of the plan. In light of this complexity, the MCDA results are just one input into resource allocation and fishing opportunities are just one policy tool to address excessive sea bass mortality.

7 Conclusion

The poor state of the sea bass stock has focused attention on the issue of how to ensure that the limited fishing opportunities available are protecting fleets and ports dependent on sea bass, while also providing the right incentives for fishing practices that maximise social and economic outcomes while minimizing environmental damage.

Article 17 of the CFP provides EU Member States with a clear opportunity to allocate (or reallocate) quota and other fishing opportunities in a way that is aligned with the public interest. Under Article 17, Member States shall provide incentives to vessels to use more selective gear or gear with a generally lower environmental impact.

From the results of this study, it is clear that applying performance criteria relevant to Article 17 would enable decision makers to look at the wider social, environmental and economic value of sea bass and allocate any fishing opportunities according to these criteria, thus meeting their legal obligations under the CFP and the UK's Marine Policy Statement.

The research presented here attempts to bridge the gap between theory and practice in the implementation of fisheries policy; this gap is often the reason for policies failing to meet their intended outcomes. Failure in this regard arises because policy implementation in complex dynamic systems such as fisheries management, in the absence of systems for implementation, is particularly challenging. The methods presented here demonstrate a framework for the assessment of the social, economic and environmental criteria on which to base the allocation of fishing opportunities. Such a tool has utility for the agencies and departments charged with implementation of policy as the research indicates how the policy objectives of the reformed CFP, the UK's Marine Policy Statement, and economic resilience in coastal communities may be met through the use of such a technique.

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