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

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8

9 **Abstract**

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

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

30 **1 Introduction**

31 Fisheries resources are finite in supply but desired by many users (they are rivalrous). Limited fishing
32 opportunities must therefore be allocated to users with competing demands based on a framework to
33 avoid overexploitation which may result from the divergence between individual and collective interests
34 [1]. In accordance with international obligations [2] to avoid over exploitation of resources, the
35 sustainable management of fish stocks is required. In Europe, the Common Fisheries Policy (CFP,
36 REGULATION (EU) No 1380/2013) [3] and Marine Strategy Framework Directive (MSFD) [4] provide the
37 legislative framework setting out the goal of achieving Maximum Sustainable Yield (MSY) and Good
38 Environmental Status (GES) by 2020 for all commercially exploited fish stocks [5]. Accordingly, allocations
39 of fishing opportunities by the European Commission are, in principle if not in practice, made to EU
40 Member States in line with these objectives for the major shared fisheries [6].

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

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

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

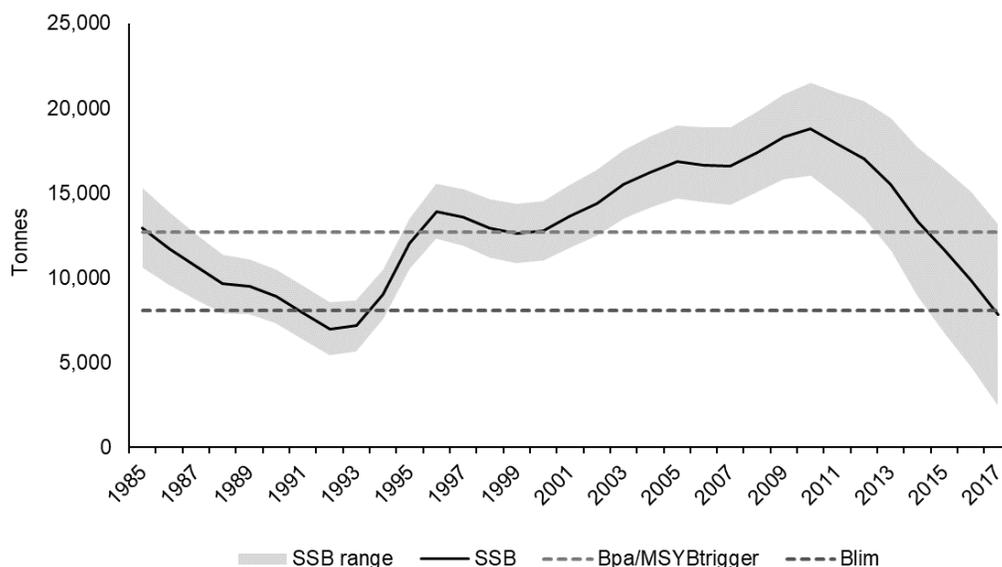
69 methodology could also be applied between these sectors. A full history of the sea bass fishery is
70 provided in the Supplementary Material.

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

82 2 The English sea bass fishery

83 2.1 Stock decline

84 Sea bass is an important commercial and recreational stock [21]. Owing to its popularity on menus and
85 availability to fishers as a non-quota species, increased catches between 2000 and 2010 proved
86 unsustainable and the Northern European stock has undergone a severe decline in recent years (Figure
87 1) [22] and the Southern stock appears to be following the same trajectory [23].



88

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

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

99 2.2 The fishery

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

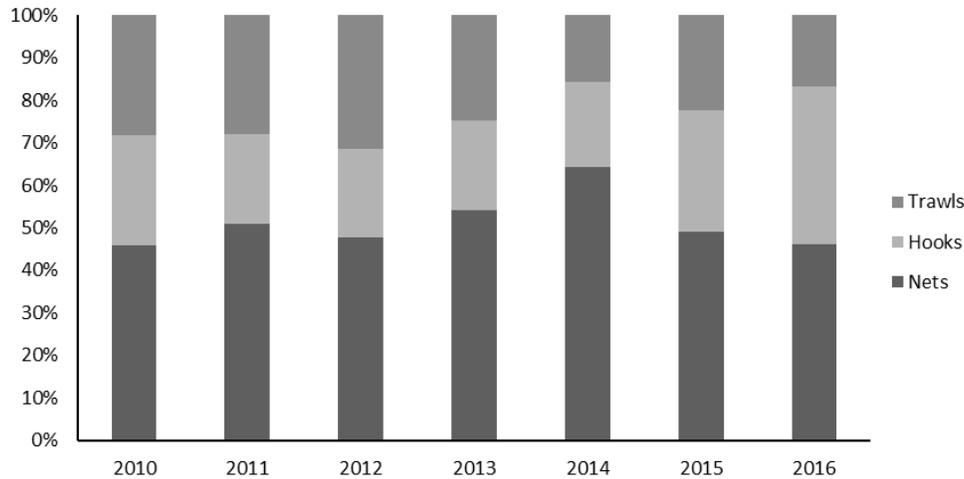
107 UK vessels landed 501 tonnes of sea bass in 2016 with a first sale value of £5 million. Of that volume,
 108 487 tonnes were from English vessels and 61 tonnes were from Welsh vessels [29]. Over 42% of English
 109 landings were from six ports, which are listed in Table 1.

110 **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

111

112 The English sea bass fishery can generally be categorized into three gear types: nets, hooks, and trawls.
 113 In 2016, vessels using nets landed 223 tonnes of sea bass (46%), vessels using hooks landed 181 tonnes
 114 (37%) and vessels using trawls landed 81 tonnes (17%) (Figure 2) [30].



115

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

117 **2.3 Current management challenges**

118 The recent decline in sea bass has been linked to multiple factors: overfishing of the spawning stock
 119 during winter spawning aggregations, a minimum size that could not guarantee enough sea bass were
 120 reaching spawning size before capture (i.e. recruitment overfishing), and environmental conditions
 121 which had impacted the survival of recent sea bass cohorts leading to poor recruitment. Scientific advice
 122 from the International Council of the Sea (ICES) had not been followed by European fisheries ministers
 123 ever since a precautionary cut in landings by 20% was advised in 2012 [31,32]. The resulting negative
 124 trend of the stock meant urgent action needed to be taken in December 2014 for the 2015 fishing year
 125 [33]. ICES continued to advise more stringent reductions in landings, culminating in the advice for zero
 126 landings (commercial and recreational) for 2017 and 2018 (when applying a precautionary approach
 127 [34,35]).

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

135 **2.4 Recent management measures**

136 To halt this decline in the sea bass stock and try to mitigate the risks of a collapsed fishery, in 2015 the
 137 UK Government requested that the EU instigate a set of Emergency Measures under Article 12 of the
 138 CFP [37]. These initial Emergency Measures [38], implemented between January 2015 and December
 139 2016 include a ban on pelagic trawling during spawning season; an increase in Minimum Conservation
 140 Reference Size from 36 to 42cm and maximum monthly catches by gear type as well as restrictions of 3

141 fish per day per recreational angler [39] (which was reduced to 1 in 2017), closed areas [40] and a closed
142 season during February and March [41].

143 The ICES advice for both 2017 and 2018 fishing opportunities was for zero catch (both commercial and
144 recreational) [42, 43]. This has meant the debate regarding continuation of fishing opportunities
145 amongst Member States, the commercial and recreational sectors, and different fishing gear operators
146 within the commercial sector is ongoing. The 2017 December Council proposed further restrictions for
147 2018, reducing the bycatch allowance for trawls and nets, reducing the hook and line catches to 5
148 tonnes and closing the recreational fishery⁴⁴.

149 **3 The use of criteria in allocating fishing opportunities**

150 **3.1 Guidance from the Common Fisheries Policy**

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

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

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

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

171 Several reports on EU fisheries have advocated a criteria-based approach to quota allocation [50,51]. A
172 2013 report for the EU Parliament suggested a suite of criteria that would interest stakeholders and also
173 have readily available data [52].

174 **3.2 Setting objectives**

175 Setting fisheries management objectives is key to the transparent monitoring of the performance of
176 fisheries. However, objective setting is frequently neglected or inadequate [53]. If stakeholders are not
177 involved, or do not understand the objectives, generating support for management plans will be
178 difficult. According to the Food and Agriculture Organisation, the goals in fisheries management can be
179 split into subsets: biological; ecological; economic and social, which includes political and cultural goals
180 [54]. Incorporating economic, biological, social and environmental objectives into a single framework
181 and including stakeholder views is essential for management success [55].

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

184 “Government’s role is to manage this asset on behalf of society and to get the most
185 benefits for today’s citizens and future generations. The few in society who catch
186 fish are responsible for doing so efficiently. This means getting the best possible
187 economic and social benefits from fishing for the least environmental cost –
188 including safeguarding stocks for the future. It is the role of processors and retailers
189 in the supply chain to act sustainably, and the consumer’s role is to choose
190 sustainably” [56].
191

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

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

200 **4 Methods**

201 **4.1 Multi-criteria decision analysis**

202 Multi-criteria decision analysis (MCDA) is a decision-making tool that allows users to explicitly evaluate
203 complex, and potentially conflicting, criteria, allowing wider costs and benefits to be taken into account.
204 MCDA has been used in many fields including health [58], energy [59], development [60] and finance
205 [61] and enables managers to establish and communicate defined social, economic, and environmental
206 goals. Given the potential value of MCDA, and its previous application in fisheries and other marine
207 management contexts [62, 63, 64, 65, 66], it was selected as a potentially suitable tool to enact the
208 Article 17 requirements of the reformed CFP. Furthermore, since the decision of the UK to exit the EU,
209 this examination of the technique has value when considering how the UK might allocate resources
210 when no longer a member of EU.

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

$$216 \quad MCDA_g = \frac{\sum P_{c,g} W_c}{\sum P_m W_c} \quad \text{(Equation 1)}$$

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

221 **4.2 Criteria by which to determine best value to society, according to Article 17 of the CFP**

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

225 **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)

226

227 **4.3 Data sources and availability**

228 Data sources used to parameterise indicators are detailed in Table 3. In most cases the results by criteria
 229 are reported directly or are a simple intensity as indicated by the measure. Three criteria (damage to
 230 spawning stock, sea bass discarding, and other discarding), however, required the development of
 231 indicators to permit estimation using parameters developed for this study, detailed in section 4.4. In

232 many cases the gear assessments are for fishing activity for a particular gear in general, not specifically
233 activity related to fishing for sea bass. This is due to the fact that activity (e.g. fuel use, labour),
234 especially in a mixed fishery cannot be separated by species in a meaningful way. In these instances (e.g.
235 profits, employment, greenhouse gas emissions), the result is expressed for the gear type per kilogram
236 of landed weight for all species.

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

241 **4.4 Analysis**

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

$$245 \quad FS_g = \sum LS_{g,s} D_{g,s} \quad (\text{Equation 2})$$

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

250 The indicator for bass discarding also required the development of new parameters due in part to a
251 policy change that occurred after the measurement. As the minimum landing size was increased from
252 36cm to 42cm, an adjusted discard rate was calculated based on the size composition of landings for
253 each gear (as well as assumptions about avoidance and parameters for survivability). The adjusted bass
254 discard rate can be expressed as:

$$255 \quad ADRB_g = DRB_g 0.5 LM_g M_g \quad (\text{Equation 3})$$

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

$$262 \quad ADR_g = DR_g M_g \quad (\text{Equation 4})$$

263 The results of the 13 criteria for the three major gear types, reported in Table 3, are converted to a 1-5
264 scoring system by dividing performance outcomes into quintiles. This was completed using the
265 performance of all gear types across UK fisheries, although for economic value chain, sea bass discards
266 and other discards, the quintiles are simply a relative scoring of the range for the three major gear types

267 targeting sea bass as these three criteria are specific to the fishery. An approach based only on relative
268 performance would fail to reward improvements unless the major gear types change positions. It would
269 also lose any sense of scale in a two-gear comparison (as all scores would be a 1 or 5). A description of
270 the methodology used for converting performance into a 1-5 scoring system is provided in Table 2 of the
271 Supplementary Material.

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

279 **4.5 Criteria weightings**

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

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

297 **5 Results**

298 **5.1 Gear assessment using criteria**

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

300 Vessels using trawls were the most profitable fleets fishing for sea bass, however they supported the
301 fewest jobs per tonne of sea bass landed, had a lower average price (£6.50-£7 per kg) as well as the

302 highest discard rates, impact on spawning stock mortality, marine mammal bycatch and ecosystem
303 damage.

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

309 Most jobs per kg of sea bass were supported by hook and line fishing. The price per kg was also highest
310 (£9.50 per kg), while also having the lowest discard rates and impact on spawning stock mortality. In
311 terms of their dependence on sea bass, hook and line were the most (15%) dependent on sea bass and
312 landed 55% of their sea bass into sea bass dependent ports. There is also little to no unwanted bycatch.

313 **Table 3. Gear assessment by criteria.**

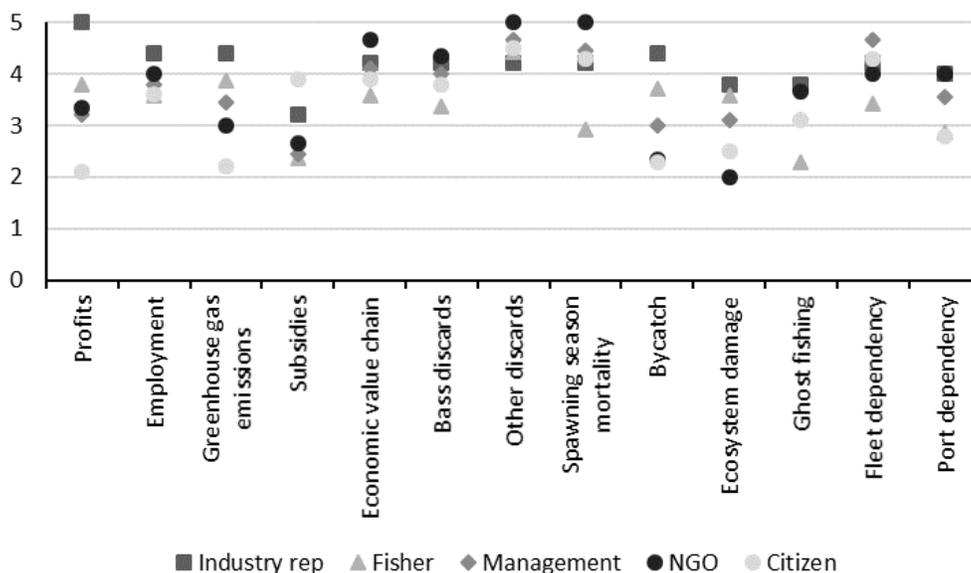
Criteria	Data sources	Measure	Results			Score (1 low - 5 high)		
			Nets	Trawls	Hooks	Nets	Trawls	Hooks
Profits	STECF (2017) The 2017 annual economic report on the EU fishing fleet	£/kg landed weight	0.41	0.43	0.19	5	5	2
Employment	STECF (2017) The 2017 annual economic report on the EU fishing fleet	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	Medium	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

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

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

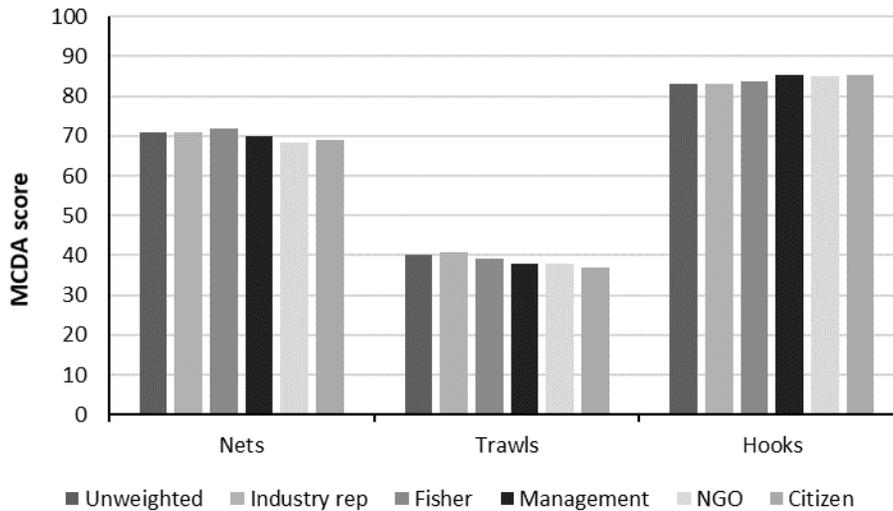
320 5.2 MCDA weighting and scores

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



332
 333 **Fig. 3. Criteria weighting by each stakeholder group.**

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



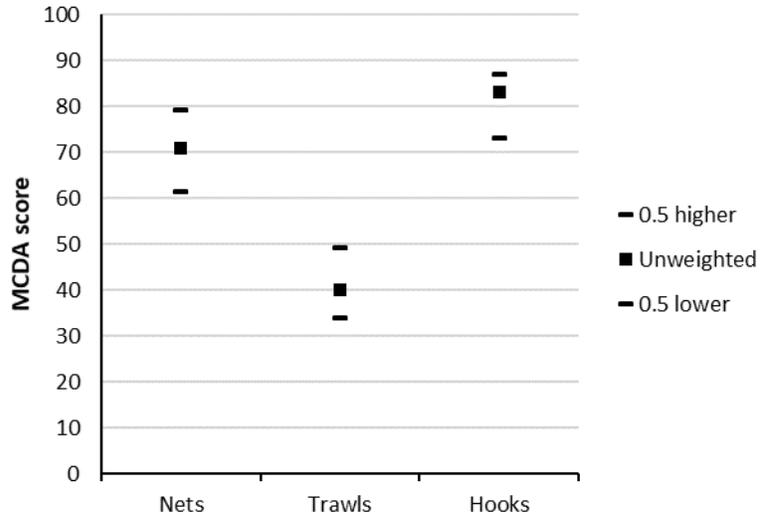
338

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

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

346 **Sensitivity analysis**

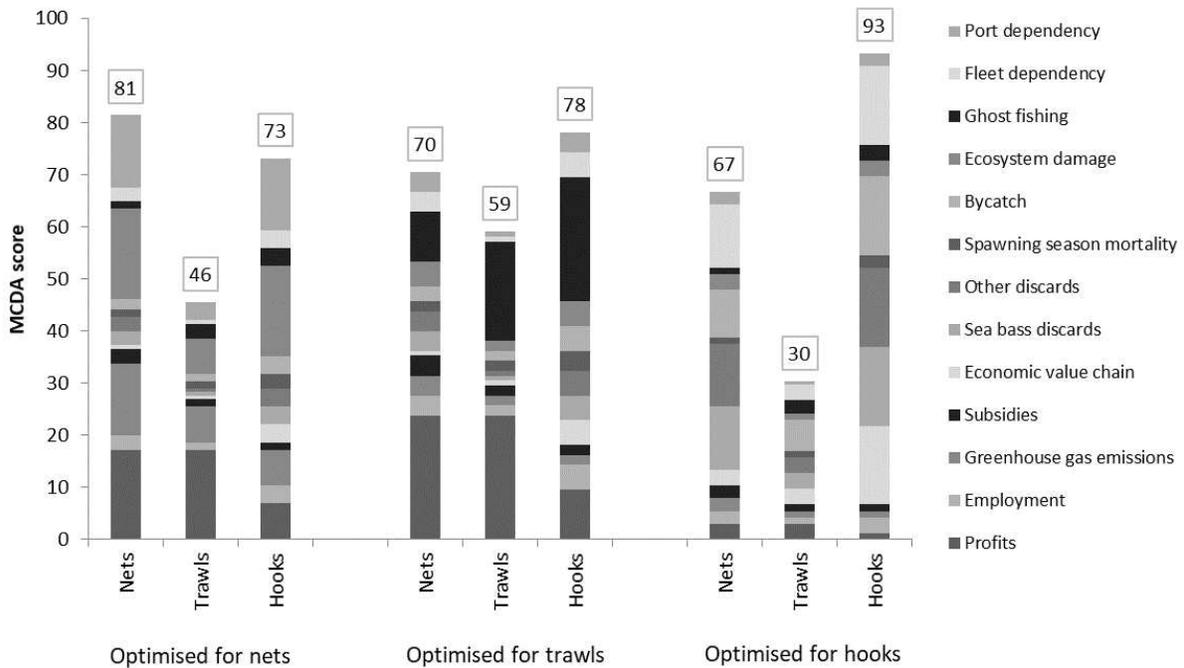
347 The first sensitivity analysis adjusts the gear assessments by half a point in either direction to account
 348 for potential errors in the assessment of performance. The results reveal that if vessels using nets were
 349 frequently underestimated and vessels using hooks were frequently overestimated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



352

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

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



359

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

361 **6 Discussion**

362 **6.1 Relevance of findings**

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

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

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

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

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

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

395 The prospect of ‘Brexit’ and the UK determining its own fisheries policy outside of the CFP does not
396 significantly alter any of these findings, or the value of using MCDA to allocate fishing opportunities
397 throughout the EU. Decisions regarding the allocation of fishing opportunities under Article 17 is already

398 up to individual Member States. Such a framework could, in theory, be applied to the sharing of fishing
399 opportunities between the UK and EU instead of 'relative stability' based on historic fishing, although
400 this is unlikely as the UK and EU Member States may have different agreed objectives for fisheries
401 management. Whatever the outcome of UK EU exit, the requirements the approach to the allocation of
402 fishing opportunities as they relate to national and transboundary decision making mean they must
403 adhere to the principles of the Aarhus Convention; MCDA, as a transparent system of decision making
404 presents one method for achieving this.

405 **6.2 Average versus marginal analysis**

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

415 **6.3 Unavoidable bycatch**

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

428 **7 Conclusion**

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

433 Article 17 of the CFP provides EU Member States with a clear opportunity to allocate (or reallocate)
434 quota and other fishing opportunities in a way that is aligned with the public interest. Under Article 17,

435 Member States shall provide incentives to vessels to use more selective gear or gear with a generally
436 lower environmental impact.

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

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

450

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