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The future of marine fisheries management and conservation in the United Kingdom: Lessons learnt from over 100 years of biased policy

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ABSTRACT

Marine wild-capture fisheries depend on the capacity of the ocean to provide a flow of harvestable resources to sustain the industry. Paradoxically, conventional fishing often undermines these resources by degrading the environment and overexploiting fish stocks. Many UK fisheries have declined for over a century due to a biased focus on their social-economic value and lack of recognition that they are social-ecological systems and need to be managed as such. With the UK's recent transition to an independent coastal state, the Fisheries Act (2020) and associated Joint Fisheries Statement provide an opportunity to correct this. Focusing on the ecological foundations, a more sustainable future for UK fisheries may be achieved by: (1) implementing a conservative quota setting system based on Maximum Sustainable Yield (MSY), defined as that which would occur when the biomass of a population of the target species is at 50% of that estimated at carrying capacity, to set catch limits rather than targets. The biomass of fish stocks should be allowed to regenerate to a minimum of 120% of that which will achieve MSY to provide a buffer against the uncertainty in ecological response to climate change. (2) Fishing capacity should be reduced while redistributing a greater share of the quota to sectors of the fleet that are demonstrably more sustainable; recognising that short term compensation may be required by some to mitigate the impacts of displaced activity until the benefits of stock recovery are realised. (3) Greater restrictions should be applied to ensure the most damaging fishing techniques (*e.g.* bottom trawling and dredging) are prohibited as appropriate in the network of marine protected areas. Protection should be enforced to promote the regeneration of degraded habitats and restoration of fish populations to help achieve the objectives as set out in the Act.

1. Introduction

The UK's wild marine fisheries sector is currently experiencing substantial change due to multiple ecological, economic and political shocks to the system [1]. Since joining the European Economic Community (EEC) in 1973, UK fisheries management has largely been governed by the Common Fisheries Policy (CFP) as well as domestic legislation aligned with the CFP [2,3]. However, when the UK left the European Union (EU) at the end of January 2020, there was a need to replace the CFP with legislation that would fill the legal vacuum left. The UK Parliament passed the Fisheries Act (hereafter referred to as the Act) on the 23 November 2020 [4], with the principal aim to enable full control and legal responsibility of fishing and to establish a Fisheries Framework for future management in UK coastal waters (the exclusive economic zone) [5]. The Fisheries Framework (formally the UK Fisheries Management and Support Framework) includes the Act, retained EU law, the Joint Fisheries Statement (JFS) and Fisheries Management Plans (FMPs). It provides for a joint approach to fisheries management between the devolved administrations, enabling Scotland, Wales and Northern Ireland greater powers to manage their fisheries according to

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Table 1
Objectives as set-out under article 1 of the Fisheries Act 2020 [5].

Objective	Description
Sustainability	(a) fish and aquaculture activities are environmentally sustainable in the long term, and managed so as to achieve economic, social and employment benefits and contribute to the availability of food supplies, and (b) the fishing capacity of fleets is such that fleets are economically viable but do not overexploit marine stocks.
Precautionary	(a) the precautionary approach to fisheries management is applied, and (b) exploitation of marine stocks restores and maintains populations of harvested species above biomass levels capable of producing maximum sustainable yield.
Ecosystem	(a) fish and aquaculture activities are managed using an ecosystem-based approach so as to ensure that their negative impacts on marine ecosystems are minimised and, where possible, reversed, and (b) incidental catches of sensitive species are minimised and, where possible, eliminated.
Scientific evidence	(a) scientific data relevant to the management of fish and aquaculture activities is collected, (b) where appropriate, the fishery policy authorities work together on the collection of, and share, such scientific data, and (c) the management of fish and aquaculture activities is based on the best available scientific advice.
Bycatch	(a) the catching of fish that are below minimum conservation reference size, and other bycatch, is avoided or reduced, (b) catches are recorded and accounted for, and (c) bycatch that is fish is landed, but only where this is appropriate and (in particular) does not create an incentive to catch fish that are below minimum conservation reference size.
Equal access	the access of UK fishing boats to any area within British fishery limits is not affected by – (a) the location of the fishing boat's home port, or (b) any other connection of the fishing boat, or any of its owners, to any place in the United Kingdom.
National benefit	fishing activities of UK fishing boats bring social or economic benefits to the United Kingdom or any part of the United Kingdom.
Climate change	(a) the adverse effect of fish and aquaculture activities on climate change is minimised, and (b) fish and aquaculture activities adapt to climate change.

the specific needs and challenges faced by their industries. The Act outlines the UK fisheries management strategy and requires the achievement of eight fisheries objectives (Table 1), while the JFS is prepared by the UK fisheries policy authorities for the devolved nations to outline the policy strategy for doing so through a statement of the use of the FMPs.

Prior to the UK becoming an independent coastal nation by exiting the EU, many representatives of the capture fishing industry were enthused by the possibility of regaining control of fishing rights that they perceived to have been ceded to the EEC by the UK Government in 1973 to secure access to the single market (*e.g.* [6], based on a survey of skippers of over 12 m boats in northeast Scotland). It was largely for this reason that many fishermen were supportive of the UK leaving the EU during the run-up to the Brexit referendum [7,6,2,3]. However, a return of sovereign control over the management of UK marine fisheries did not halt access to UK waters by EU fishing vessels [2]. Just over a month after the Act received royal assent, the UK passed legislation to implement the UK-EU post-Brexit Trade and Cooperation Agreement (TCA) [8]. As a result, EU vessels are allowed to remain active in UK waters through a foreign vessel licencing scheme and to catch fish within quota allowances set out in the TCA [4]. The TCA provided for a reallocation of quota for fish caught in UK coastal waters so that the UK fleet will eventually obtain one-quarter of the existing EU quota over a five-year transition period, with the majority (15%) transferred in 2021 followed by an annual reduction of the EU share by 2.5% thereafter [8].

After the adjustment period ends in June 2026 annual negotiations between the UK and EU will determine how quota will be set. Theoretically, at this point the UK could exclude all EU vessels from UK waters. However, this seems unlikely, as the EU could respond punitively with retaliatory measures, *e.g.* by preventing the UK fleet access to its waters, through the imposition of tariffs on British fish imports to EU member states, or *via* other actions related to wider trade relationships under the TCA [8]. The UK must therefore work successfully towards a common aim in partnership with other coastal states if more sustainable management of fisheries are to occur in the future, achieving both the objectives of the Act and wider marine conservation goals in line with the UK Marine Strategy Regulations [9].

While the development of new domestic UK fisheries legislation and associated trade agreements represent contemporary challenges of managing open-access resources within the constraints of a wider political landscape, there are many aspects that mirror past threats. Historically, the development of fisheries policy and the surrounding political debates and media interest (see [10]) have primarily revolved around the economic interests of some sectors of the industry (*e.g.* larger-scale offshore and quota owning vessels, [11,2,3]) and associated coastal communities, while policy relating to the management of the resource itself and the environment on which it depends has been of lower priority (*e.g.* [12] in relation to the CFP). Such policy biases are problematic because fisheries are complex social-ecological systems [13], and insufficient consideration of the ecological foundations of the wider marine environment from which the industry benefits risk the long-term future of an important public asset as recognised by Government and as stated in the draft JFS [14]. The track record of focusing on short-term political and economic gains while undervaluing the natural capital benefits that marine ecosystems provide humanity has often led to their degradation (*e.g.* [15]). Therefore, there is a need to manage fisheries for wider societal benefits, rather than just accounting for their commodity value, to achieve broader goals related to resilience to climate change (climate change objective), biodiversity conservation, and sustainable development (sustainability objective). The Act provides an opportunity to adopt more sustainable future management practices to instigate real change. Taking historic policy biases into account, this paper considers the potential for the Act and associated JFS to initiate more sustainable management and conservation to the benefit of future generations of UK fishers and wider society more generally (national benefit objective).

The Act aspires to enhance the sustainability of marine resources and protect ecosystem services while continuing to also focus on economic considerations [16]. Of the eight fisheries objectives set out in the Act, five (sustainability, precautionary, ecosystem, bycatch, and climate change) aim to enable more environmentally sensitive fishing practices if achieved [5]. However, sustainability objectives enacted through legislation should be viewed cautiously; the CFP also set, and in many cases failed to achieve, its own sustainability goals (see Article 2 of CFP; [17]). Objectives in themselves are seldom enough, unless they are measurable, there is a clear "roadmap" on how and when they will be realised against agreed deadlines, effective monitoring, enforcement and control is provided, and the consequences of not meeting them are clearly stated. The Act does not make the objectives legally binding duties; it merely establishes a legal framework to enable the devolved fisheries policy authorities to develop such strategies through the JFS, which is published within two years of the Act being passed [5]. The first JFS and subsequent iterations thereafter must set the agenda for more sustainable management of UK wild marine fisheries going forward. To do this the wider fisheries science and marine conservation community must advise the UK Government and devolved administrations on the actions needed to enable ecosystem regeneration and stock recovery and for the devolved administrations to work constructively together to achieve the national objectives set.

This paper has two main purposes. First, it provides a brief critical review of the current status of the UK wild marine fisheries resource within the context of historic exploitation. Second, focusing on the ecological foundations on which fisheries are based, it explains why it has been challenging to meet earlier management strategies and sustainability goals (*e.g.* EU target to rebuild commercial stocks to sustainable levels by 2020, [18]). We recognise that the Act provides a valuable framework for more sustainable management strategies, and that important approaches that should be adopted to meet its objectives have been dealt with in depth elsewhere (*e.g.* [19] for ecosystems based fisheries management; [20] for precautionary approach; [21] for co-management and adaptive management). Building on these, this paper focuses on developing recommendations related to key areas critical to regeneration in the UK context, namely (1) the rebuilding of fish stocks by the setting of sustainable quota, (2) reducing and redistributing capacity, and (3) protecting marine and coastal ecosystems. Further recommendations related to the social-economic and political dimensions are provided elsewhere [10]. Solution-oriented recommendations are also provided for an evidence-based approach to future UK fisheries management and communication with the aspiration that information and guidance generated will initiate greater engagement between Government and the wider fisheries science community.

2. The recent history and status of UK marine fisheries

As in many other areas of the world, landings of fish into UK ports by the home fleet have declined over several decades; more than 120 years of Government fisheries statistics [22] show evident declines since 1895 [23]. Although several factors contribute to variation in landings, such as natural fluctuations in stock biomass (*e.g.* the gadoid outburst, [24]), changes in landing controls (*e.g.* [25]) and the level of enforcement (*e.g.* [26]), technical measures to increase (*e.g.* [27]) or reduce catch (*e.g.* [25]), and geopolitical settlements (*e.g.* at the end of the "Cod Wars", [28]), the overexploitation of fish stocks due to industrialisation of fishing has undoubtedly played an important role [29]. Focusing on demersal species, those that tend to live on or near the seabed (*e.g.* cod *Gadus morhua* L., haddock *Melanogrammus aeglefinus* L., and plaice *Pleuronectes platessa* L.) and are preferred by the UK consumer, rapid industrialisation and intensification occurred in the early 20th Century until a dramatic reduction in fishing activity during World War I [29]. Thereafter, catches soon recovered and the annual UK landings by British vessels during the 1920 s and 1930 s rapidly increased, reaching its historical maximum at over 600,000 tonnes [22] (Fig. 1 for England and Welsh ports).

In the inter-war years, the predominantly steam powered fishing fleet boomed, with over 30,000 sea fishermen employed in England and Wales in the mid-1930 s, and more than 22,000 in Scotland [22] (Fig. 2). Catches once again declined rapidly during World War II when the fishing fleet was substantially diminished due to acquisition by the admiralty of vessels for war service [30] (Fig. 1). High rates of capture and landings immediately resumed after the end of the war as the industry benefitted from the prior respite and the dividends of a temporary recovery stocks experienced during a period of low exploitation [30]. Furthermore, fishing efficacy was enhanced due to technological advances [31], leading to a dramatic acceleration in the intensity of fishing effort, rationalisation, and specialisation during the 1950 s and 1960 s. Over the past century, the general trend has been for fewer, but bigger vessels (Table 2). This was especially so in the northeast Atlantic fishing grounds (FAO area 27), an area exploited by the majority of the larger-scale UK fleet [32], especially the highly lucrative distant water fleet, largely based out of the ports of Hull, Grimsby and Fleetwood. This sector experienced a dramatic and terminal decline (Fig. 3) as a consequence of the "Cod Wars" that were finally settled in favour of Iceland in 1976 [28]. Total fishing power peaked in 1972 [29], two decades after landings had started to decline. This post-war period of increased effort onboard larger and more efficient vessels, often powered by subsidised diesel [33,34] and capable of travelling greater distances in search of fish, correlates with a continued rapid decline in the numbers of fishers employed in the UK between 1948 and 1970, when there was a fall of 26, 000 (55%) [23]. This decline began much earlier, however, and has been apparent since the start of the last century (Fig. 2) continuing to the present day, partly driven by advances in technology and efficiency as well as a reduction in profits for some sectors. Today, there are less than 6000 fishers (employed full and part-time) registered in England and Wales, and less than 5000 in Scotland (less than 11,000 in UK) (Fig. 2); this compares to over 40,000 and 38,000 (more than 109,000 for the UK), respectively, in 1899 [22]. A reversal of this trend by enabling an increase in employment in the marine fishing sector can only occur if supported by the regeneration of stocks and more sustainable fisheries management practices. To do so would help achieve the national benefit objective as set out in the Act (Table 1).

The northeast Atlantic remains one of the most productive and heavily fished areas, producing on average 41% of the total quantity of fish captured in the whole of the Atlantic Ocean and Mediterranean Sea [35]. However, between 2010 and 2019, the decade immediately prior to Brexit and the COVID-19 pandemic, the annual UK demersal landings by UK vessels continued to decline, averaging around 123,000 tonnes [22]. Since the CFP was formally enacted in 1983, landings have been influenced by the setting of quota referred to as Total Allowable Catches (TACs) at EU level, and that are allocated by the individual member states. Since that point, a greater proportion of fish caught by English and Welsh vessels in UK waters have been landed in mainland Europe [29] where demand for certain species caught is higher. However, the CFP began after a period of UK national fishery decline during the 1950 s, 60 s and 70 s. Today we continue to live with that legacy. From the perspective of enhancing future UK food security [36], a more self-sufficient fishing industry would provide an important contribution

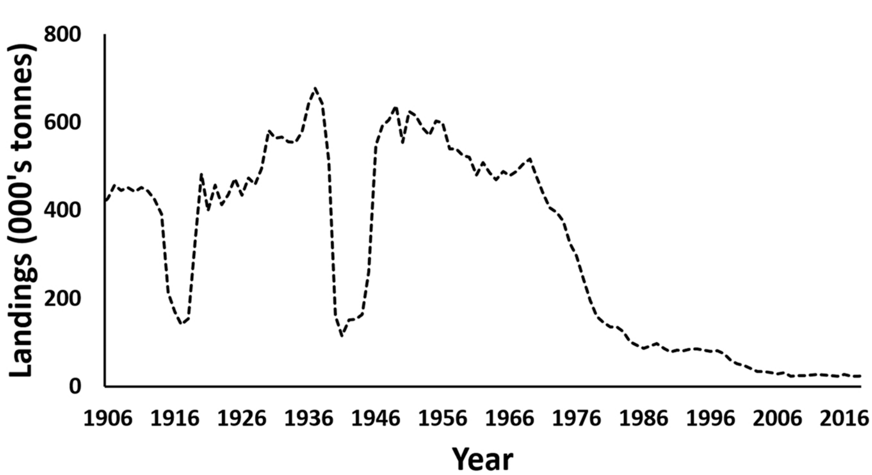

Fig. 1. Total annual landings of demersal fish by the home fleet into English and Welsh ports between 1906 and 2019. Marine fisheries are social-ecological systems and two distinct systemic shocks to the fishing industry in World Wars I and II are clearly apparent, with a rapid return to "business as usual" thereafter as fishers benefitted from greater catches due to a recovery of stock after fishing pressure was reduced. A more insidious long-term shock to the ecological system is apparent due to overfishing after World War II, as the fleet converted to diesel engines and fishing power increased dramatically during the 1960 s to peak in 1972 [29]. Total landings today are lower than they were during the two World Wars.

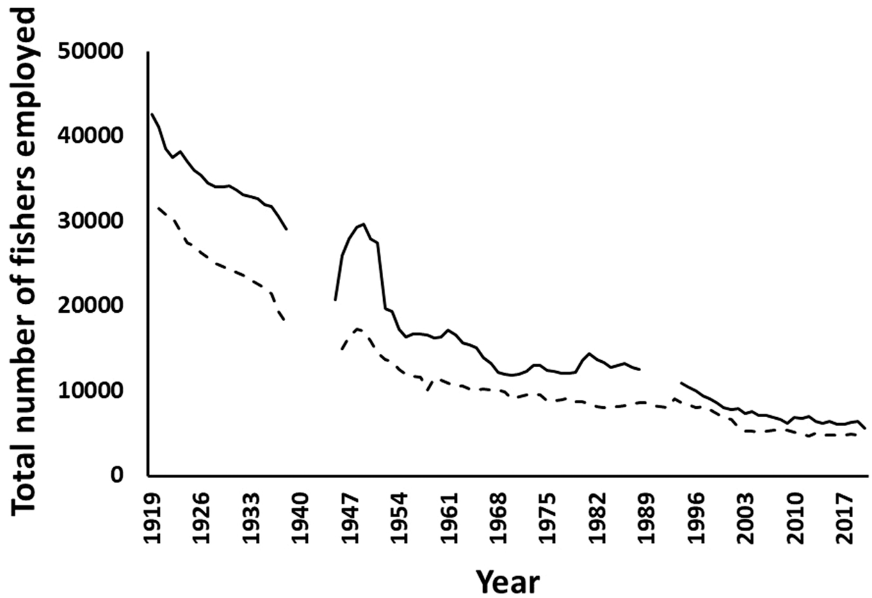

Fig. 2. Total number of marine fishers employed in Great Britain between 1919 and 2020. The solid line represents England and Wales and the dashed line Scotland. Declines commenced prior to the shift to steam power during the interwar period and continued after World War II when the fishing power of the fleet increased. The "Cod Wars" were settled in 1961,'73, and '76, and the UK joined the Common Market in 1973. The data aggregates full-time and part-time employees (source [22]).

Table 2
Number of vessels and gross tonnage for selected years (each decade) from 1908 to 2018 [22]. Due to variation in reporting of fishery statistics, figures may not always be directly comparable between year and country but can be used to indicate general trends. Prior to 1952 values for English and Welsh fishing vessels was supplied by the Registrar General of Shipping and Seamen, but thereafter were collected at the ports by MAFF District Fishery Officers. Similarly, values shifted for English and Welsh vessels in 1966 with the exclusion of those not used at all for commercial fishing in that year, resulting in deviation from previous years. Furthermore, fishing vessels were registered under various Shipping Acts resulting in the registered tonnage figures not being strictly comparable. Information for 1998 is not presented because data for vessels less than 10 m length were excluded. Note that prior to 1996 the tonnage value is GRT (Gross Registered Tonnage) and thereafter it is GT. There is no simple mathematical relationship between GRT and GT, but GT is almost always higher than GRT.

	Number of vessels		Tonnage (GRT - GT)	
Year	England & Wales	Scotland	England & Wales	Scotland
1908	9574	–	191993	–
1918	10032	–	194088	–
1928	7579	6216	179955	88289
1938	6436		171308	–
1948	7009	5297	127693	66634
1958	4828	3174	244264	–
1968	3292	2717	–	–
1978	4146	2618	–	–
1988	5433	2334	66843	72345
1998	–	–	–	–
2008	3670	2213	65580	126794
2018	3569	2083	64224	108407

and help achieve both the sustainability and national benefits objectives (Table 1). To achieve this, however, will require a major shift in societal acceptance of alternative seafood products as well as policy to reverse the degradation of marine ecosystems and reduce current levels of harvest. The Act and JFS provides a means by which this might be achieved if lessons are learnt from history.

The reduction in catches in the northeast Atlantic fishing grounds and associated decline in landings in UK ports at least partly reflects a depletion in fish stocks due to overcapacity and unsustainable practices

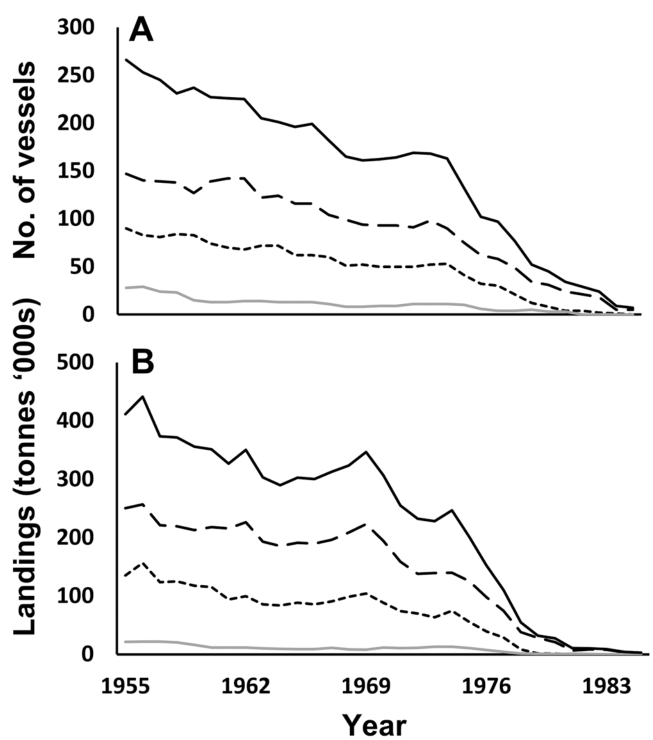

Fig. 3. A. The number of "Distant Water" vessels (over 140 ft [42 m]), and B. the associated landings (tonnes '000 s) for the UK (solid line) and the ports of Hull (long dashed line), Grimsby (short dashed line), and Fleetwood (grey line). In 1960, "Distant waters" were defined as including the Barents Sea and water adjacent to Bear Island, Spitzbergen, Greenland, Iceland, Labrador, Newfoundland, and the waters off the coasts of Norway and Portugal [22]. The 1976 settlement to the "Cod Wars" resulted in the UK acceptance of a 200 nautical mile Icelandic exclusive economic zone, resulting in the demise of the distant water sector in these ports.

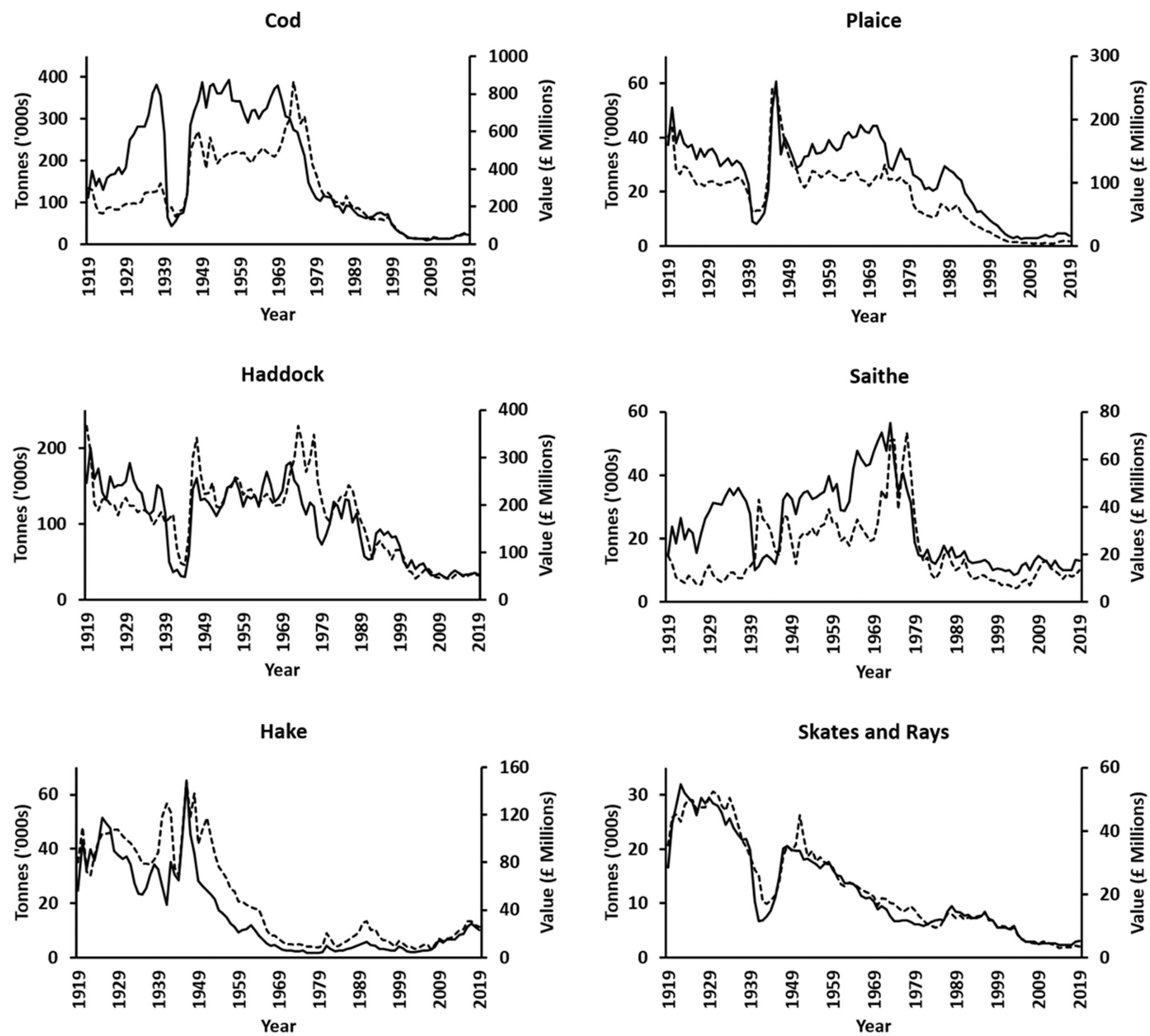

Fig. 4. Declines in tonnage (solid line) and values (dashed line) of demersal fish landed into Great Britain/UK ports by home fishing fleet from 1919 – 2019 for six commercially important species for the UK market. All value data have been converted to the present-day price equivalent using the annual Retail Price Index (RPI). Figures for 1900–1948 are the official estimates from the Office for National Statistics. From 1960 the landing data is for the UK, with the inclusion of Northern Ireland. Prior to this the data is for Great Britain (Source [22]).

[23,29]. Moving away from assessing aggregate landings data for demersal fish, the long-term decline becomes even more apparent when individual species are considered (Fig. 4). The North Sea stock of plaice provides a particularly interesting example that illustrates the complexity associated with stock assessments, policy and influence of temporal scale on perspective. When considered from a short-term viewpoint, reductions in fishing mortality and instigation of recovery plans can be heralded as a fisheries management success (*e.g.* [37]), as evidenced by the recovery of the spawning stocks since 2008. The estimated spawning stock in 2013 surpassed the historic maximum [38] and harvest has been considered sustainable since 2009 [39]. Taking a slightly longer-term view, however, these improvements are set against a backdrop of poor fisheries management during the late 1980 s and early 1990 s when annual quota remained relatively constant despite clear declines in spawning stock biomass (SSB) (Fig. 5). Although fisheries management policy partially explains such decline and recovery, the relative magnitude of its role can be difficult to ascertain, with other external factors exerting an influence. Previous, albeit smaller, peaks and troughs in SSB were evident in the mid-1960 s (*e.g.* [38,40]) and mid-1980 s [38] (Fig. 6). Confounding variables associated with climate change (*e.g.* increasing temperature) and other factors, such as nutrient loading, food availability, and altered predation and larval transport or immigration / emigration patterns (R2 and B2 in Fig. 1, [10]) are also considered to play an important role [41]. Indeed, the International Council for the Exploration of the Sea (ICES) recognises that changes in the spatial distribution of the stock elevate the uncertainty in assessments [38]. The recent recovery may, to some extent at least, reflect spatial stock relocations to deeper areas as indicated by ground fish surveys, while abundance in shallow coastal zones (not regularly monitored in international surveys) appears to have declined

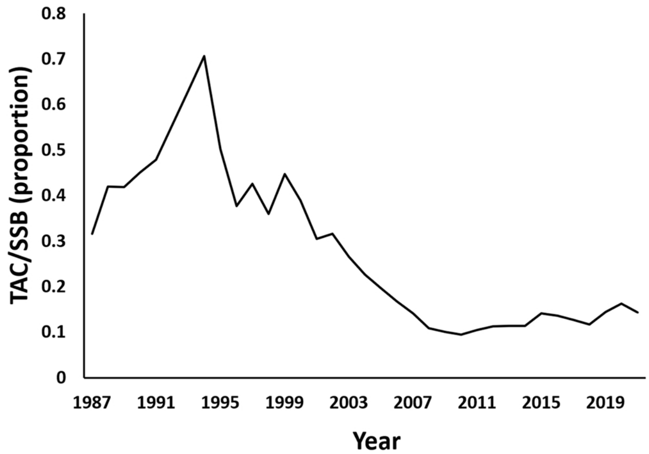

Fig. 5. Annual Total Allowable Catch (TAC) as a proportion of the Spawning Stock Biomass (SSB) for plaice (*Pleuronectes platessa*) in the North Sea (subarea 4) and Skagerrak (subdivision 20). Between 1992 and 1995 the assigned TAC ranged between 50% and 71% of the SSB (data [38]).

[41]. To learn lessons from even longer time frames we depend on catch data; for plaice, landings by home vessels into Great British / UK ports has reduced by nearly an order of magnitude over the past century (Fig. 4).

While the advice of scientists has largely and repeatedly been to reduce catches [46], a large proportion of European stocks continue to be overexploited in terms of fishing mortality and / or biomass [15,47]. Under the CFP several technical measures and regulations were adopted to reverse overexploitation. These included the Fishing Vessels Decommissioning Scheme (*e.g.* [48]); increased trawl cod-end mesh sizes (*e.g.* [49]); implementation of recovery plans (including limits on days at sea; *e.g.* [50]); improved compliance (*e.g.* Vessel Monitoring Systems, [51]; and the Registration of Buyers and Sellers, [52] [Section 2 of article 22]); and the consolidation of quota into fewer operations concentrating on larger vessels (*e.g.* [53]). Nevertheless, despite commitments to reform the CFP to control fishing effort and rebuild commercial stocks to sustainable levels [18], the EU acknowledged that this target was unlikely to be met by the target date of 2020 [54]. While recognising a number of stocks have exhibited some recovery in some areas (*e.g.* northeast Atlantic Ocean and the Baltic Sea), at least in part due to decreased fishing pressure, other stocks and areas have continued to experience overfishing [54]. As of 2018, of the 43 stocks exploited by UK fishers for which data were available, 37% were subject to ongoing overharvest [1]. Focusing on the 28 major stocks in the Greater North Sea, in 2020 only four (two stocks of haddock, hake *Merluccius merluccius*, and western Channel sole *Solea solea*) had sustainable levels of fishing pressure and biomass and six (21%) were of sufficient size to produce maximum sustainable yields (Rainer Froese pers. comm. November 2021 referring to assessment of the ICES [55] advice); in contrast thirteen (48%) out of 27 stocks with suitable data were subject to ongoing overfishing. The reasons for why targets for stock recovery have not been realised in several cases, despite best efforts implemented through the CFP, are many and complex. Explanations include uncertainties in monitoring (*e.g.* stock assessments, variable survey indices, and inaccurate catch data) ([56] for North Sea cod), inconsistent enforcement of regulations that are frequently less restrictive than intended, and risks that technical measures are not accepted by industry if costly [57]. To look forward and develop a more sustainable fisheries policy to benefit the UK marine fishing industry, there is a need to increase the quantity of locally produced fish caught by the UK fleet and landed into UK ports. This would help in the achievement of sustainability, national benefit and climate change objectives as set out in the Act. To do so, however, requires the prior regeneration of stocks that remain depleted.

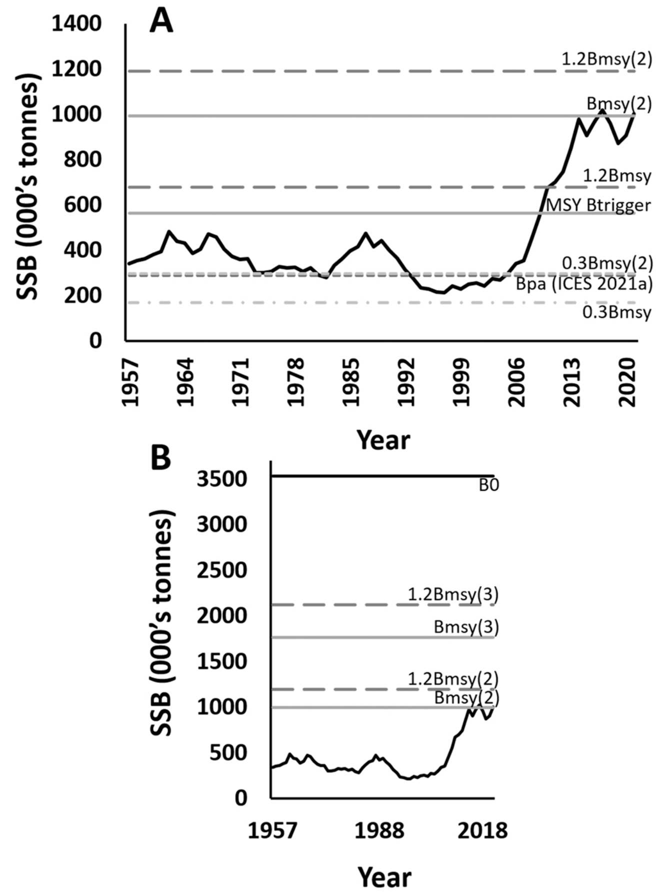

Fig. 6. Spawning stock biomass (SSB) for plaice (*Pleuronectes platessa*) in the North Sea (subarea 4) and Skagerrak (subdivision 20). Values oscillated between the late 1950 s and late 1990 s with an increase in number since the mid-2000 s (data - [38]). (A) MSY $B_{trigger}$ or $2B_{pa}$ is sometimes used as a proxy for B_{msy} (in Table 4 of [38]) with values illustrated based on the 2017 benchmark report [42]. B_{pa} (Table 4, [38]) is the current precautionary reference point for SSB [42], below which a stock may be considered to be outside safe biological limits. These reference points are substantially lower than those estimated by the ICES Workshop on ICES reference points (WKREF1) [43], *e.g.* as illustrated by B_{msy} [7]. When viewed from this perspective, the current stock is close to B_{msy}, and values in the 1960 s that were considered to represent high levels of abundance at the time [40] would represent an overexploited stock. Using this value, $1.2B_{msy}$ [7] would represent a more precautionary approach. (B) Using the Schaefer [44] model in which B_{msy} is set at 50% of B0 the precautionary approach would use the higher baseline B_{msy} [45] to allow stocks to recover to a sustainable threshold of $1.2B_{msy}$ [45]. If biomass declines to the 0.3 of B_{msy} [45] the fishery would be closed.

3. Rebuilding UK fish stocks

3.1. Setting quota based on principles of sustainability

Quotas are a form of output control intended to prevent overexploitation of stocks by regulating fishing activity. They directly limit the amounts of fish or shellfish removed, *e.g.* typically by setting a catch limit in terms of tonnage or the number of fish of a specific species in a certain area over time (*e.g.* TACs) [58]. The quota set can then be shared across different stakeholders. The EU started introducing landing limits for some species in the mid-1970 s [29]. These were eventually formalised as the TACs under the European Council Regulation (EEC No 170/83) adopted in 1983 as part of the development of the CFP [59]. TACs are required under international law [60] for harvested fish stocks, and the system of setting them for individual stocks among member states provided the basis for management measures employed by the EU.

Until Brexit, this was the system by which the UK share of the TAC and resulting UK fishing quotas were agreed. Under the CFP, TACs are agreed annually for most stocks, and every two years for deep-sea species, by the Council of fisheries ministers having considered scientific advice on stock status provided by advisory bodies, such as ICES [61]. Each EU member state receives a share of the specific species TAC in the form of a national quota; a fixed percentage based on historical catch levels defined as the principle of "Relative Stability", a concept incorporated into the 1983 regulation [61]. This situation is somewhat complicated by the potential for EU countries to exchange quotas with other EU member states, and for individual boats that are wholly or partly owned by EU nationals or companies to be registered as a British fishing vessel able to fish against UK quotas, while typically landing their catch in foreign ports.

The EU Council of Fisheries Ministers have a poor track record of heeding the scientific advice provided by ICES. Under the CFP, quotas were routinely set at levels higher than those advised as safe by scientists, although the discrepancy has reduced over recent years [62]. Between 2001 and 2019, the average amount by which TACs exceeded scientific advice declined from 39% to 10%, with on average around 6 out of every 10 TACs exceeding the advice over this period [63]. During the negotiations for the 2019 northeast Atlantic TACs, the UK agreed the highest absolute total tonnage of TAC set above the scientific advice and were second for the highest percentage (24%) of TAC in excess of maximum recommended levels [64]. Under the CFP, the UK has struggled to transition to more sustainable fisheries management, despite its commitment to reduce fishing effort to regenerate commercial stocks by 2020 [18].

The assigning of TACs must be based on some "reference point"; a target or a limit defined to prevent overexploitation [1]. Maximum Sustainable Yield (MSY) is widely accepted as a reference point for the purpose of setting targets and will continue to play a key role under the Act [16]. Indeed, an aspiration set out in the draft JFS [14] is to achieve the precautionary objective by restoring and maintaining populations of harvested species above biomass capable of producing MSY. MSY is the highest theoretical equilibrium yield catch that can be continuously taken from a stock under existing environmental conditions without affecting the reproduction process ([65], and the definition used in the Act).

In the 1950 s, surplus production models (*e.g.* [44]) were used to provide a catch-based management approach in which MSY was estimated to occur when the biomass of a population (B_{MSY}) reaches half of its maximum (B0), *i.e.* that which would be expected to occur at its unfished level (the carrying capacity). However, other models suggest lower biomass values equating to MSY ([66,67]). Consequently, there is uncertainty as to where B_{MSY} falls and targets have often been set for much lower values of B_{MSY}, such as 40% or 25% of B0 [68]. Setting lower B_{MSY} targets results in higher estimates of fishing pressure to produce MSY, and thus higher yields, at least in the short term. However, the application of values of B_{MSY} that are much lower than those predicted by the Schaefer [44] model may explain, at least partially, why many stocks, including those in UK waters, declined and some currently remain in critical conditions in which their biomass is much lower than values of B_{MSY} calculated by ICES [1,69]. As such, the use of the lower values of B_{MSY} may increase the risk of failure to achieve the precautionary objective as required under the Act, resulting in further long-term unsustainable management practices.

Compared to the alternatives, the adoption of the Schaefer [44] model provides a relatively straightforward approach to help achieve the objectives of the Act and one that is likely to be palatable for policy makers and the industry in setting quota. We acknowledge, however, that the concept of MSY may be criticised as a single-species concept [69], and thus contradict the principles of ecosystem-based fisheries management (*e.g.* [70]), also a prominent feature of the Act and JFS. Appropriate values of MSY are predicated on realistic estimates of carrying capacity, and the calculation of B0 that accounts for "existing environmental conditions" is not a simple matter in the face of random environmental shifts and complex multi-species trophic dynamics [71]. For example, trophically linked stocks will be unable to produce MSY simultaneously; for populations of target predatory species to reach B_{msy} the forage fish on which they depend must be fished at lower levels than those that will produce MSY (*e.g.* [70,72]) and therefore more conservative limits might be set for them. The continued development of modelling techniques that better estimate carrying capacity over appropriate time frames for multiple species in a community should remain a central focus of fisheries research to help achieve the ecosystem objective set out in the Act.

The concept of MSY remains an important principle in global multilateral fishing law, including UNCLOS [60], and is mandated under the UN Sustainable Development Goal 14 to conserve and sustainably use the oceans, seas and marine resources [73]. Likewise, MSY is a central tenet of the Act and actions to maintain or restore stocks to a level capable of producing MSY will be encompassed within the JFS and delivered through the FMPs [16]. Based on the perception that fishers are unlikely to reject quota systems (*e.g.* Fixed Quota Allocation, [74]) in which they have invested for many years, MSY will likely continue to play an important role in the management of UK marine fish stocks for some time to come.

3.2. Promoting sustainability within the concept of MSY

An analysis of global fisheries management systems indicate that those managed to sustain MSY over the long-term may threaten the future of food security and make little economic sense, while at best enabling only a slow recovery of stocks [75]. Regenerating degraded stocks to levels that are higher than those required to generate MSY would help populations become sufficiently large and diverse as to be more resilient to climate change (*e.g.* [76]) and other environmental challenges; as well as inevitable future economic shocks (such as those experienced as a result of Brexit and the COVID-19 pandemic, [1,77]). It would also recognise the need to advance the definition of more sustainable catch targets and limits, such as outlined under the UN Fish Stocks Agreement and the FAO's Code of Conduct for Responsible Fisheries. It is proposed that this can be achieved within the existing framework that sets quota based on the concept of MSY but requires refocusing so that MSY is employed to define absolute limits, rather than targets [1,69].

Starting with an aim to rebuild degraded fish populations and the wider marine environment to safeguard the sustainability of future fisheries, it is recognised that this must be achieved during an era in which the impacts of climate change are uncertain (the precautionary and climate change objectives). While developing broadscale understanding of how physical, chemical and ecological processes are likely to alter, the fine-resolution details of these changes, such as shifts in sea surface temperatures and acidity and the spatial redistribution of populations, remains difficult to predict. As such, it is recommended that the UK follows the examples set by others fisheries management systems, such as that adopted in Australia [78], by using more precautionary levels of MSY. Elaborating on Kemp et al. [1], we propose that catch targets and quota be set to maintain biomass at least at 120% of that which is estimated to achieve MSY ($1.2 \times B_{MSY}$), with B_{MSY} set at the more precautionary 50% B0, while the limit be set at 30% of MSY ($B_{LIM} = 0.3 \times B_{MSY}$). Once the threshold is achieved, if stocks decline to below $1.2 \times B_{MSY}$, quota should be reduced in a linear fashion until the $1.2 \times B_{MSY}$ is recovered. If B_{LIM} is reached then the fisheries should be closed. Likewise, if stocks are already below $1.2 \times B_{MSY}$ (but assuming they are higher than the limit) using the Schaefer [44] model, then appropriate precautionary quota should be set to facilitate recovery in a timely manner (*e.g.* over the 6 year life-span of a JFS). By reducing yield and effort, this approach will build stock biomass and so not only help promote ecosystem regeneration and meet conservation objectives, but also enhance the profits of fishers. In essence, this will be achieved by moving closer to a Maximum Economic Yield (MEY) model in which the difference between total revenues and the total costs of fishing is greatest [75,78], potentially contributing to the 'national benefit' objective set out in the Act. However, rather than adopting a MEY model *per se*, which prioritises economic (rather than conservation) goals, adopting the rule of 1.2 × B_{MSY} would place ecological considerations at the foundation of fisheries management while realising economic co-benefits.

Using the North Sea (subarea 4) and Skagerrak (subdivision 20) plaice stock, previously discussed in relation to the recent recovery in SSB, as an example, we can illustrate the shift in process required to adopt a more precautionary approach. Currently, ICES do not report either B0 or B_{msy} in their advice (*e.g.* [38]), instead reporting MSY $B_{trigger}$ as a proxy (in this case similar to 2 × B_{pa}, Fig. 6a) to define stock status (Table 4 in [38]) based on the last benchmark created in 2017 [42] (Raphaël Girardin, Chair of Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak, pers. comm.). Using 1.2 × MSY $B_{trigger}$ (1.2B_{msy} in Fig. 6a) as the precautionary reference point, then the current SSB would appear to be in a healthy state and a case could be made for the success of fisheries management strategies employed. Alternatively, if B_{msy} is based on an age-structured assessment following current ICES advice rules, then the ratio B_{msy}/B0 is 0.28 (B_{msy}[2], Figs. 6a and 6b) [43]. Taking this value, the current SSB is approximately at B_{msy}, and further improvements of SSB would be required to reach the precautionary threshold of 1.2 × B_{msy}[2] (Fig. 6a). However, the current framework used to estimate this value of B_{msy} lacks consideration of some important biological principles (*e.g.* the age-structured assessment often does not include a stock recruitment relationship, which is estimated externally to spawning biomass and recruitment estimates). ICES are currently working on introducing consistent biological principles within the framework through Workshops on ICES reference points (WKREF1 and WKREF2, [43], Henning Winker, Chair of the WKREF1, pers. comm.). Acknowledging the substantial degree of uncertainty associated with how stocks will respond to a changing climate and oceanic conditions, *e.g.* in relation to both abundance and spatial redistribution, and in line with the precautionary objective as set out in the Act, we propose the adoption of a precautionary approach based on the Schaefer [44] model (MSY – 50% B0) in which SSB should be allowed to recover to 1.2 × B_{msy}. Based on this value, the current SSB for North sea plaice is not quite at 50% of B0 (B_{msy}[3] in Fig. 6b) and someway off from where it needs to be to reach this precautionary threshold (1.2 B_{msy}[3] in Fig. 6b) to futureproof a stock facing a high degree of uncertainty. If this strategy was adopted, the increase in TAC adopted since approximately 2010 [38] would have been considered premature and restoration measures would have remained in place until the threshold target was reached.

The implementation of our recommendation will help stocks recover to levels that are much higher than those that can produce MSY to improve UK resilience in the face of predicted future global food insecurity [79] and climate change. On the face of it, this approach should be relatively straight forward, as it is not only based on evidence of its efficacy through experiences gained elsewhere (*e.g.* [75]), but also on the maintenance of the existing MSY framework. Our recommendation also aligns with the proposals outlined in the draft JFS [14] related to the use of MSY to help achieve the precautionary objective (Table 1). Nevertheless, implementation will require strong agreement, commitment and involvement among politicians, scientists, economists, fisheries managers and regulators, the fishing and processing industries, and the general public who will, at least in the short term, have to recognise the need to catch and consume less fish and perhaps be prepared to pay higher prices for them. This approach should be adopted relatively rapidly so that progress towards the stated biomass limits might be achieved within a time frame that enables stocks to enhance their resilience to the impacts of a shifting climate [80]. Clear targets should be set by the fisheries policy authorities as to when these limits should be achieved, and the JFS could provide a mechanism to assign milestones against which progress can be monitored, as under the Act the JFS must be reviewed at least once every six years, although it may be amended or replaced at any time.

4. Reducing and redistributing UK marine fishing capacity

In combination with more appropriate TACs, reducing capacity will help ensure stock regeneration. There are various means by which this may be achieved, but the socio-economic impacts will need to be carefully considered. For example, in response to long-term declines in catch, the Icelandic fishing industry reduced capacity by scrapping boats and closing factories [81]. It also adopted the Individual Transferable Quota (ITQ) system, along with other countries such as Norway, enabling quotas to be sold to the remaining vessels and thus reducing the size of the active fleet [82]. This approach, however, raises questions of equity and who has the right to fish with examples of the small-scale sector being less likely to benefit compared to large-scale fishers (*e.g.* [53] for Finnish herring fisheries). This issue is also of particular concern in the UK fisheries management context (*e.g.* [45]). Although the use of ITQs has been criticised for, among other things, lacking biological realism [83], through reducing overcapacity and specialising on high value markets the financial performance of both the Icelandic [81] and Norwegian [82] fishing industries improved. The advantages and disadvantages of alternative quota management options and the potential to shift from the current Fixed Quota Allocation model to one in which quota trading with the industry becomes increasingly frictionless (*i.e.* closer to a full ITQ system) has been the subject of discussion and debate for some time [84,85]. The UK Government's current position is that it is fair to respect the investments made by industry and hence the current system should remain in place. Going forwards, it is recommended that the effectiveness of methods to reduce capacity should be regularly reviewed and monitored during the post CFP era until a new more sustainable system is embedded.

In addition to shifting the setting of quota to a system based on regenerating stock biomass by reducing capacity (sustainability objective), it is also recommended that the allocation of that quota be redistributed to provide a fairer share, with particular preference to those sectors of the fleet that cause least environmental harm while providing greatest benefit to local fishing communities (national benefit objective). For example, in the UK some sectors of the small-scale fleet that use the least damaging fishing techniques may provide the best opportunity to meet the objectives of the Act, being less constrained by the unsustainable operations of a less efficient large-scale fleet (*e.g.* in relation to: CO_2 emissions and discard; [86] for a global perspective; economic, social and environmental impacts; [87] for the UK's North Sea cod fishery). Nearly 80% of the UK fleet comprise small-scale vessels ($\leq$10 m length) [23,88], a sector that often has a stronger economic link with coastal communities (*e.g.* provide 50% of catching related employment, [89]) than the larger and more industrial vessels, many of which are foreign owned. The New Under Ten Fishermen's Association (NUTFA) that represent this sector (the 'under tens') highlight that despite representing the majority of the UK fleet by number, they receive $<$ 2% of the national fishing quota [89]. Analysis of the results of the fishing quota distribution under the TCA indicates that the small-scale sector is particularly disadvantaged, as the larger gains of quotas agreed tended to be for the species for which the small vessels hold a low share, while those for which the under 10 m vessels hold a greater share tended to be dealt smaller gains if any at all [2,90]. For example, these smaller vessels will obtain only 1% of the additional quota for mackerel (the species for which the largest gain was agreed), while there was no additional quota for cod in the English Channel. While the latter is a small fishery, it is one frequently used to exemplify the perceived unfair share of EU TACs between the UK and France and is of particular importance to the UK under ten fleet who hold nearly 40% of the UK allocation [2,90]. It is important to acknowledge, however, that small-scale fisheries are not devoid of environmental impacts (*e.g.* see

[91] for an example for the Gulf of California). They do not always provide a sustainable solution, as illustrated in relation to many UK inshore crab and lobster stocks that are often assumed to be harvested using more sustainable methods (*e.g.* [92,93]). This would especially be the case if the size of the fleet was allowed to grow unregulated and / or switch to more environmentally impactful fishing methods to compensate for reductions in other areas. It is important that any rebalancing in favour of one particular sector of the fleet to meet the objectives of the Act is monitored for unintended consequences and that appropriate mitigation is planned and enacted where necessary as part of the review process for the JFS.

5. Designating, managing and enforcing protection of Marine Protected Areas (MPAs) and Highly Protected Marine Areas (HPMAs)

The creation of a network of Marine Protected Areas (MPAs) can provide an effective means of facilitating regeneration of marine habitats degraded by harmful fishing practices, such as the use of bottom trawls, and enabling overexploited fish populations to recover [94]. While the main objective of MPAs is to protect and regenerate marine biodiversity, they also consistently provide wider ecological and societal benefits, including in relation to increased fish biomass [95,94,96]. From a fisheries perspective, protecting marine environments also has the potential to be economically cost-effective as fishers may accrue increased profits associated with higher catches in surrounding areas due to larval export and spillover through movement of juveniles and adult fish and shellfish. Evidence for such has built over recent years as indicated by several meta-analyses, although publication bias through a repeated focus on a limited number of case studies (*e.g.* [97]) and a regional bias to tropical zones (*e.g.* [97,98,95]) is apparent. From a European perspective, the spillover effect has been demonstrated for the Mediterranean (*e.g.* [99]; [100] for artisanal fisheries; [101]), although examples for Northern Europe are limited (see Huserbråten et al. [102] for evidence of gene flow due to larval drift of European lobster *Homarus gammarus*). MPAs may provide additional ecological-economic benefits too. The regeneration and protection of ecosystem complexity may have the potential to enhance resilience to climate change and contribute to mitigation of harmful climate change impacts in certain cases [103], in line with the climate change objective. MPAs may also provide a means to enable the economies of local coastal communities to adapt, through the creation of new jobs, *e.g.* in ecotourism [94], in accordance with the national benefits objective set out in the Act. Such diversification is preferable to reinforcing dependency on a degraded resource through supporting an unprofitable industry [104]. Consequently, while spatial and/or temporal fishery closures can effectively help regenerate stocks, or protect key areas such as spawning grounds, MPAs have a much wider remit which includes supporting fishery-focussed measures.

The UK network of 371 MPAs, representing 38% (338,049 km^2) of UK waters [105], represents a positive step towards implementing management to minimise impact from human activities on ecosystem health. Unfortunately, it is acknowledged that the UK marine environment remains in an unhealthy state [106], and several have suggested that the protected status bestowed on MPAs is often misleading due to a lack of appropriate regulation and adequate enforcement [107,108]. For example, rather than affording actual protection to fish populations within their boundaries, a recent analysis showed nearly 60% of the EU's 727 MPAs were commercially trawled at a higher intensity than non-protected areas [109]. As the UK Fisheries Bill progressed through Parliament on its way to becoming law, attempts were made by the House of Lords to incorporate an amendment to strengthen its focus on sustainability, including the banning of large-scale trawlers from fishing in MPAs [110]. Despite a high degree of public support , the amendment was defeated, with voting along partisan lines, when the Bill returned to the House of Commons [111]. Currently, some control of harmful fishing practices could be achieved through existing licence conditions and MPA-specific byelaws, but such controls are likely to remain *ad hoc* until fisheries management plans or further regulations are adopted under the Act. As a result, the JFS is critical to strategic implementation of appropriate controls and for the devolved administrations to develop a more sustainable future for UK fisheries.

While on the one hand the UK MPAs are not maximising their potential due to weak enforcement and failure to enact stronger restrictions on damaging human actions within their boundaries, on the other hand there has been recent consideration of a new stronger designation; that of Highly Protected Marine Areas (HPMAs) [112], otherwise known as no-take MPAs. The concept of HPMAs is based on a recognition that existing MPAs, while playing an important role in marine conservation, do not enable full ecosystem recovery because disturbing and destructive practices may take place within their boundaries [113], even by lower-impact, small-scale fishing techniques (*e.g.* pot fishing for crustaceans; [93]). HPMAs would have a wider remit, with all extractive, destructive and depositional use prohibited, preventing damaging levels of other activities (*e.g.* construction, dredging, direct discharge of sewage and other effluent, dumping, littering and anchoring), other than focusing on fishing alone. The *Benyon Review*, conducted in 2020, considered whether such areas with higher levels of protection could enable a greater recovery of the marine ecosystem and associated services, and so correspond with the aims of the Government "Blue Belt" policies [114], the UK Marine Strategy to reach "Good Environmental Status" [115], the Commonwealth Blue Charter [116], and the UN Sustainable Development Goals [73]. The Review concluded that HPMAs should be incorporated as an essential component of the network of MPAs.

The *Benyon Review* provided 25 recommendations to Government regarding the value and implementation of HPMAs (see [113]), ranging from definitions to the identification, designation, management and protection of appropriate sites. The main points of the report centre around a "whole site approach" taking also migratory species into account, ensuring that various habitats are equally represented, and embedding HPMAs within existing networks for protection. Decisions regarding selection and designation need to recognise that the ecosystem services provided by meaningfully protected habitats are based on sound ecological foundations, and that regeneration of the marine environment and processes must be the principal driver. Principles of ecological importance (naturalness, sensitivity, and potential to recover, and ecosystem services) as the key selection criteria can provide the basis for the realization of subsequent social and economic benefits.

The potential direct and indirect social-economic benefits that meaningful and well-managed protected areas (HPMAs and MPAs) can provide are substantial and diverse. They include opportunities for tourism and recreation (*e.g.* surfing, scuba diving and kayaking), culture (*e.g.* conservation of heritage, aesthetic appreciation, identity and spirituality), and scientific research and education, including increasing public awareness of, and engagement with, the marine environment. However, while a shift from extractive to non-extractive use can help improve species conservation and local economic growth, some stakeholders can be disadvantaged [117]. Indeed, the social and economic costs and challenges will likely initially impact the small-scale fisheries and the communities they support the hardest, as they are less able to relocate and the cost of fishing elsewhere will be too high. Over time, however, these fisheries are likely to benefit from increased yields due to the "spillover" and "boundary" effects of increased production and export of fish biomass inside the protected area to neighbouring fished areas close to the boundary *via* active (*e.g.* swimming) or passive (*i.e.* drifting eggs and larvae) mechanisms [97]. Nevertheless, it will be important to engage with and support the small-scale inshore fleet for both socio-economic reasons and because this sector may provide opportunities for meeting sustainability targets in the long-term, particularly if society can be persuaded to shift dietary preferences and "buy more locally caught fish" [1]. As such the Government should acknowledge the challenges of displaced activities and mitigate the impacts of environmental protection measures on small-scale fishing and other marine industries by providing compensation, at least in the short term. In accordance with FAO [118] guidance on developing sustainable fisheries that recognises that livelihoods and well-being of fishers must be considered more explicitly, it is recommended that local stakeholders be actively engaged in developing management objectives from the outset. Co-management can have multiple societal and environmental benefits [21], and stakeholder involvement needs to take place without compromising the overall ethos of the protected area, while accounting for the potential for unforeseen new challenges to arise.

Difficulties in enforcing the protected status of the existing network of MPAs likely reflects a lack of capacity driven by insufficient allocation of funding. Appropriate funding of activities needed to designate and manage MPAs is essential, including enforcement of regulations and the monitoring of long-term effectiveness. This can be complemented by increased collaboration with other sea users and stakeholders, and the use of novel technologies (*e.g.* vessel monitoring). However, while there is a need to fully support a collaborative approach, there remains the risk of an overdependence on voluntary participation by the industry, and a lack of appreciation that such schemes are often insufficient when enacted in isolation (*e.g.* [119]).

It is recommended that the implementation and enforced protection of a resilient network of HPMAs and MPAs must be at the centre of UK fisheries and marine conservation policy. While supporting the development of the HPMAs approach, more and greater protection should be provided to the existing MPA network by developing fishing regulations and management plans where they do not exist, enforcing compliance with regulations that ban the most damaging forms of fishing (*e.g.* [120]), and reducing fishing effort. This would mean banning large-scale bottom trawling and dredging in MPAs designed to protect benthic species and habitats, and large-scale pelagic trawling in MPAs designed to protect more mobile species such as cetaceans. Overall, to avoid potential for the displacement of fishing activity elsewhere, this strategy should be integrated with plans to reduce overall capacity and redistribution of quota to those sectors of the fleet that employ less damaging fishing practices. Government must act quickly and decisively on the recommendations to halt further degradation of marine ecosystems and to use the marine environment and MPA network to support climate, biodiversity and sustainable development goals and help achieve the objectives as set out in the Act.

6. Conclusions

The UK wild marine fisheries sector is currently experiencing substantive legislative and economic upheaval. After leaving the EU, the Fisheries Act (2020) represents the most significant domestic primary fisheries legislation in the UK for nearly 50 years, while the Trade and Cooperation Agreement (TCA) has reallocated quota and imposed new trading rules that have disrupted supply and altered market alignments. This challenges an already fragile and indebted industry (*e.g.* [121]) that tends to not recognise fisheries as social-ecological systems [13]. The UK industry and fish stocks on which British fishers depend declined over the last century so that at the turn of the millennium domestic landings and the status of fish population were lower than those experienced during two World Wars. Since the interwar period, the global human population has nearly quadrupled [122], placing ever greater demands on often degraded resources. Furthermore, increased globalisation of the markets in which the UK offshore fleets now operate has eroded attachment to place and local governance, influencing food security [123]. Fish populations now also face additional ecological threats associated with shifting climate regimes (*e.g.* [124]) and other aspects of global change (*e.g.* potential impacts of microplastics, [125]). Today, several stocks remain below their target biomass levels, while habitats in some areas have been heavily degraded by bottom contacting gears, and fishing communities are deeply unhappy. However, for some stocks we have recently seen some degree of recovery [47], and further improvements may be realised by advancing a more sustainable system of fisheries management. The Act may provide a catalyst for such a turning point if the Joint Fisheries Statement (JFS) is used by the devolved fisheries policy authorities to ignite real change and achieve the objectives set. Nevertheless, based on historic precedent, this is unlikely to be achieved unless the Government is adequately informed by the fisheries science community and recommendations are supported by the public. To accelerate this process, three evidence-based recommendations are provided to help the regeneration of the ecological foundations on which fish populations and the fisheries they support are built. These are:

- **Recommendation 1:** Adapt the existing framework for setting quota to one in which MSY is used to define limits, rather than targets. In line with the precautionary obligation, biomass should be maintained at a minimum of 120% of that which will achieve MSY for most stocks of commercial interest, while the limit should be set at 30% of MSY. If stocks fall to below 1.2 B_{MSY}, which under a precautionary approach B_{MSY} should be considered to be 50% of B0, quota should be reduced linearly until recovery is achieved. If the B_{LIM} threshold is reached the fisheries should be closed. We recognise that a more conservative target may be needed for species of forage fish on which predatory species of commercial interest depend. In accordance with the ecosystem objective, continued research is needed to develop the techniques to better estimate the carrying capacity of trophically linked stocks so that appropriate levels of MSY can be defined for those forage species.
- **Recommendation 2:** Aligning with the sustainability, national benefit and climate change objectives, reduce overall fishing capacity and redistribute a greater share of the quotas to the less environmentally damaging (*e.g.* in relation to carbon emissions) sectors of the fishing fleet including those that use the least damaging practices. This sector should be compensated if disadvantaged, at least in the short-term, until the benefits of stock recovery accrue.
- **Recommendation 3:** To help achieve the sustainability and ecosystem objectives, ensure that existing and any future extensions of the network of MPAs are adequately protected to promote the regeneration of degraded habitats and restoration of fish stocks. The most damaging fishing techniques (*e.g.* large-scale bottom trawling and dredging for benthic species, or pelagic trawling for mobile species) should be prohibited in the MPAs in line with their designation. In accordance with the scientific evidence objective, authorities should be obliged to enforce the protected area status through enforcement programmes supported by sufficient funding and available technologies (*e.g.* satellite remote sensing, vessel monitoring systems).

Further work is needed to advance a more holistic and integrated approach to marine resource management that does not consider fisheries management and marine conservation as mutually exclusive aims. This will require further development of smart technology to enhance sustainability, better protection of marine habitats, and compliance within the supply chain. Furthermore, the stakeholders, including scientists, politicians, media and the wider public, have an important role to play in enabling transition to a more sustainable future for UK fisheries and marine conservation, requiring cooperation to achieve strong governance.

CRediT authorship contribution statement

Paul S. Kemp: Conceptualization, Writing – original draft, Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation. **Gowshika Subbiah:** Formal analysis. **Richard Barnes:** Conceptualization, Writing – review & editing. **Bethan C. O'Leary:** Conceptualization, Writing – review & editing. **Kristina Boerder:**

Writing – review & editing. **Bryce Stewart:** Writing – review & editing. **Chris Williams:** Writing – review & editing.

Data availability

All data supporting this article are openly available from the University of Southampton repository at: https://doi.org/10.5258/SOTON/D2359.

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