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Future advances in UK marine fisheries policy: Integrated nexus management, technological advance, and shifting public opinion

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ABSTRACT

Having left the European Union, the UK Fisheries Act (hereafter referred to as the Act) provides a framework that may advance sustainable marine resource management. This requires the bias towards social-economic concerns to be recognised, and greater emphasis to be placed on securing the natural capital to support fisheries. A Joint Fisheries Statement (JFS) to be published in 2022 by the UK's devolved fisheries authorities will set out how the objectives of the Act will be achieved. While recognising the value of principles of the Act, this article challenges the current management framework in light of the wider challenges in fisheries practice. It argues for more emphasis on ecological and fisheries regeneration, and maximising societal benefits rather than yields. Three recommendations are provided: (1) an integrated and more holistic *Fisheries-Energy-Environment Nexus* resource management approach would better utilise systems thinking to optimise trade-offs and synergies between competing domains to achieve fisheries, conservation and other environmental goals (*e.g.* delivering the national net zero strategy); (2) the use of best available technologies as is reasonably practicable to monitor compliance and facilitate enforcement should be a regulatory requirement under the JFS; (3) the fisheries and marine conservation science community should work with other stakeholders to change the media narrative, public opinion, and political direction away from a "business-as-usual" model that risks long-term degradation of the marine fisheries resource.

1. Introduction

Efforts to restore and protect degraded marine ecosystems are frequently in direct conflict with traditional fisheries management objectives of maximizing yield and employment and maintaining food security [1]. While attempts to resolve conflict between competing fishing interests have a long history, the conservation of marine species is a much more recent paradigm. For example, proclamations were made at the start of the fifteenth and seventeenth centuries, respectively, to reduce English fishing for cod (*Gadus morhua* L.) in Icelandic waters [2], and Dutch fishing for herring (*Clupea harengus* L.) off the English and Scottish coasts [3]. In comparison, early marine conservation efforts to protect endangered populations from extinction date back only as far as the start of the last century, such as the conventions for the protection and preservation of the fur seals of the North Pacific (1911) and the preservation of the halibut (*Hippoglossus stenolepis* Schmidt) fishery of the Northern Pacific Ocean and Bering Sea (1923) [4]. Today, fisheries management can remain biased towards consideration of the social and economic dimensions, while the ecological foundations on which sustainable exploitation depends may continue to receive less attention, indicating a lack of recognition that marine fisheries are social-ecological systems [5] (Fig. 1). The UK Fisheries Act (hereafter referred to as the Act) provides an opportunity to address this bias by advancing more sustainable fisheries policy and management to meet

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the objectives of both marine conservation and the fishing industry.

Although conflicts between the conservation of marine ecology and fisheries interests are becoming increasingly numerous, dialogue between the respective stakeholders and co-ordination between the appropriate authorities is often lacking [10]. Current management strategies that focus on trade-offs between the two domains frequently fail to achieve optimal outcomes [11], while opportunities for synergies (win-win) between conservation and social-economics goals are missed. In-line with the FAO [12] guidance on sustainable fisheries,[1] to realise better trade-offs and synergies for both sectors there is a need to integrate fisheries and marine conservation science to provide advice to policy makers [13] and highlight the non-financial benefits to fishers, their communities, and wider society [14].

Although marine fisheries are a relatively small contributor to the UK economy, representing approximately 0.12% of economic output in 2016 [15], they garner substantial political and public interest, especially in relation to historic UK-EU agreements. When the UK negotiated to join the European Economic Community (EEC) in 1973, fisheries was a highly controversial issue and one of the last to be settled, with the Common Fisheries Policy (CFP) considered to be one of the most interventionist of policies [16]. For some in the fishing industry, the deal struck represented a betrayal [17,18]. Ever since, fisheries have been a politically sensitive issue, and successive governments have recognised their social-economic and cultural importance in many constituencies. The politicisation of fisheries has reinforced the biased focus on social-economic aspects, rather than ecological ones.

Having left the EU, the management of UK fisheries is no longer governed by the CFP. As a result, the UK is experiencing substantial economic, political, and regulatory transition with associated uncertainty as it develops its own domestic fisheries legislation. The Act, passed by the UK Parliament in November 2020 [19], requires the devolved fisheries policy authorities to publish a Joint Fisheries Statement (JFS) by the end of the current year (2022) outlining the strategies adopted to meet sustainability and other objectives [20]. As a result, the UK has an opportunity to progress to a more sustainable future for marine resources rather than continue "business-as-usual", risking future degradation of commercial fish stocks and marine environments.

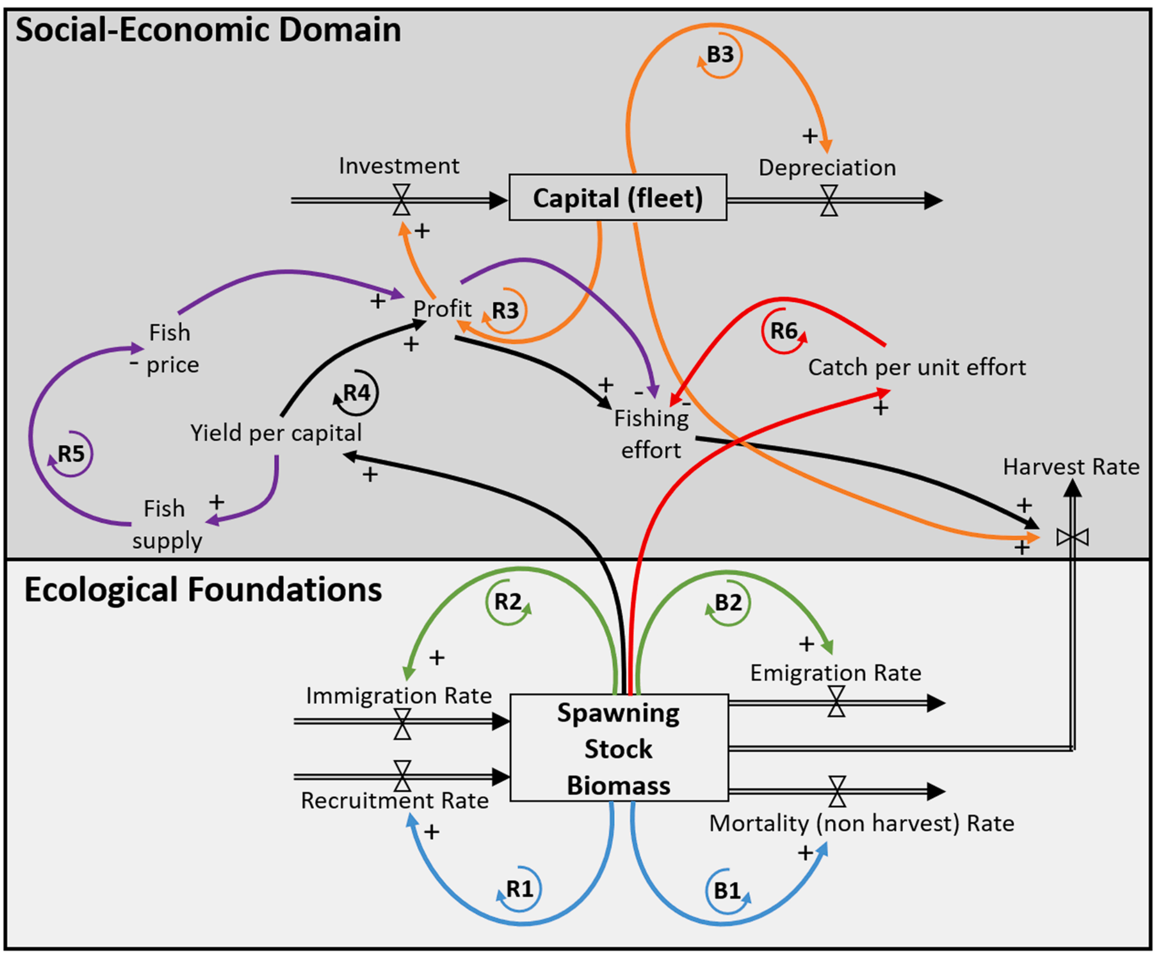

Fig. 1. Marine fisheries are social-ecological systems in which the social-economic domain (dark grey background) is dependent on the ecological foundations (light grey). Stocks and flows and causal loops illustrate potential interactions associated with overfishing of a hypothetical fish population. The spawning stock biomass is influenced by recruitment and mortality *via* a reinforcing (R) and balancing (B) loop, respectively (R1 and B1), and potentially through immigration (R2) and emigration (B2) if there is connectivity between populations (*e.g.* [6] and [7] for plaice). Likewise, the capital of a fishing fleet is influenced by flows of investment (R3) and depreciation (B3). Spawning stock biomass is positively (+) correlated with yield per capital and profits. Increasing yields and profits may result in increased fishing efforts (R4) and investments in the fleet. Alternatively, yield per capital may be positively related to fish supply and negatively (-) correlated with price, driving increased fishing effort if profit ratios decline (R5). As stocks become depleted and the catch per unit effort declines (+ correlation) fishing effort increases (- correlation) as vessel travel greater distances to reach their quota, resulting in increased fuel use as a result (R6) (developed from [8] and [9]).

[1] A biologically sustainable fish stock is defined by FAO [12] as a stock of which abundance is at or greater than the level that can produce the maximum sustainable yield (MSY) (see Kemp et al., 2022 this issue for a discussion).

The consultation process as part of the development of the JFS and subsequent Fisheries Management Plans provides an important opportunity for fisheries and marine conservation science communities to work together with other stakeholders, including neighbouring states, to positively shape the future management of fisheries. A draft of the JFS was released for consultation in January 2022 [21].

This paper explores the social-economic factors that underpin the current status of the UK fisheries resource (for a discussion related to the ecological domain see Kemp et al. [22], this issue). While recognising the important principles of the Act and other earlier policies (*e.g.* the Marine and Coastal Access Act [2009] and development of Marine Conservation Zones), such as the ecosystems-based approach, this paper provides further recommendations that we think should be included in the final JFS to advance more sustainable management of marine ecosystems and resilient fish stocks to the benefit of current and future communities. The need to manage marine resources in an integrated and holistic manner by accommodating complexity and systems (Nexus) thinking [23] and the requirement to use available smart technologies to monitor and protect fisheries is articulated. This article also examines the role of stakeholders in influencing the debate and considers how the media discourse, public opinion, and political direction might be shifted to consider fisheries from a more holistic perspective in which environmental regeneration and conservation are recognised as central tenets of future policy.

2. Embracing systems complexity: the fisheries-energy-environment nexus

It is increasingly recognised that a focus on single objectives in a multi-use ocean will result in strong trade-offs rather than optimal solutions [24], indicating a need for holistic approaches that consider multiple sectors [25,26]. As a result, a diverse range of approaches to more sustainable fisheries management have integrated both fisheries and conservation objectives (*e.g.* Marine Protected Areas target conservation goals while providing co-benefits [synergies] for fisheries, [27]; but see [1] for a discussion of conflicts [trade-offs] between biodiversity, climate change, and food security). Many of the frameworks developed, such as ecosystems-based fisheries management [28], and co-management and adaptive management [29] will likely play an important role in advancing UK fisheries policy. However, there is also a need to progress systems thinking (*e.g.* [8,30]) to simultaneously solve multiple sustainability challenges (*e.g.* UN Sustainability Development Goals, [31]) that bridge different domains (*e.g.* net zero Target Amendment to the Climate Change Act [2008], UK Government [32]; food security, see [33]; marine biodiversity, EU Marine Strategy Framework Directive, [34]) [23]. That is, to enhance the sustainability of UK marine fisheries [12] it is important to recognise that they occupy a position within a wider *Food-Energy-Environment Nexus*.

The Act does not explicitly adopt a holistic, integrated management framework, but shows some appreciation of interactions with other sectors through its eight core fisheries objectives, six of which are focused on limiting adverse environmental impacts: sustainability, precautionary, ecosystem, bycatch, scientific evidence and climate change [19]. Indeed, the draft JFS [21] implicitly describes a Nexus approach. For example, it states that ‘alignment and integration of fisheries management with wider marine management mechanisms is essential’ [21]. It also calls on fishery policy authorities to pursue appropriate research and policies to protect, restore and sustainably manage blue carbon habitats as a nature-based solution that can support adaptation and resilience to climate change, alongside benefits for carbon sequestration and biodiversity. The detail of such measures will be critical in practice but at least the JFS provides an opportunity to enact measures that could make an important contribution to wider environmental objectives, such as reducing greenhouse gas emissions in fishing as part of the strategy to achieve net zero by 2050 [32].

There are considerable challenges to enhancing the environmental sustainability of fisheries when viewed more holistically. Globally, today’s fishing fleets are heavily reliant on hydrocarbons (fuel represents up to 60% of the total costs of fishing, [35,36]), and impose a large carbon footprint [37]. In the UK context, one study estimates that the UK marine fisheries emitted 914.4 kilotons of CO_2 between May 2012 and May 2013 [38,39], while producing other harmful atmospheric pollutants (*e.g.* NO_x and SO_2, [38]). Furthermore, the magnitude of carbon and other emissions from fishing has increased globally over the decades, with the small-scale sector (and particularly those that focus on pelagic species, [40]) having lesser impacts in terms of emissions per unit catch than what are considered to be the larger industrial fleet (*e.g.* vessel length range: 16–150 m; capacity range: 185 – 7235 $kW.boat^{-1}$ in [41]). The increasing carbon footprint partly reflects the ever-greater distances travelled in search of a dwindling number of fish [42] (R6 in Fig. 1). Since 1950, this has been achieved through state subsidised fuel ([39,43,44] for UK context) that enables higher fishing effort and capacity and reduces long-term fish production and carbon sequestration in the ocean [45]. This overexploitation threatens the welfare of fishing communities [43,46] because it is increasingly unprofitable (*e.g.* [47]). Small-scale fishers in particular are left in ever greater indebtedness (*e.g.* [48] for UK context) when fuel price is volatile ([49] for UK context) as has become pertinent over recent times (*e.g.* Seafish [50] in relation to the fuel crisis). As such, providing unsustainable support to sectors of the industry that may be overexploiting a primary resource can lead to resource dependency [51], while reducing the resilience of local communities that may be more dependent on the fishing sectors that might employ less environmentally damaging techniques. Therefore, it is important to meet commitments to remove capacity enhancing harmful subsidies [43], such as the fuel tax exemption that preferentially benefits some sectors of the industry [52], while at the same time not disadvantaging others ([22], this issue). Convictions to do so must be maintained, despite conflicting future strategies that may be employed by competing states [53].

Today, the UK fishing fleet continues to represent a large proportion of the total shipping sector when considered as the absolute number of vessels (*e.g.* 2019: 5911 registered fishing vessels, [54], compared to 1177 cargo vessels, [55]). Although the number of fishing vessels has been reduced to just over half registered three-decades ago (1990: 11, 189, [56]), it nevertheless continues to represent an important contributor to the overall UK transport sectors’ greenhouse gas emissions (which itself represents 28% of the UK’s total emissions, 2018 figures, [57]). Some sectors of the fleet are particularly strong contributors. For example, using Automatic Identification Systems (AIS) data to calculate an activity-based estimate of annual fuel consumption, trawlers use nearly 93% of the amount consumed by the total UK fishing fleet (2012–2013 data) [38]. Furthermore, it is suggested that the indirect carbon footprint of bottom trawling and dredging may be increased through the disturbance of marine sediments that store carbon, resulting in the release of aqueous CO_2 [24]. It should be recognised that, as carbon cycle dynamics and interactions between the atmosphere and oceans are complex, there are substantial uncertainties related to the consequences of disturbing marine sediments [58] and that the underpinning assumptions may be incorrect [59]. Nevertheless, reductions in the UK bottom trawl capacity may have the potential to enhance the recovery of those species harvested and enable the regeneration of benthic habitat in areas where they have been damaged and are most sensitive [60], while possibly contributing to climate change mitigation by protecting carbon stocks.

In addition to the carbon footprint of fishing, there are also substantial transportation and processing costs driven by an imbalance in what is caught and eaten in the UK. Prior to Brexit, approximately 75% of the fish eaten nationally was imported, while up to 80% of that caught was exported [61], with the majority (67% by value in 2019) of exports destined for the EU [54]. Overall, the UK has been a net importer of fish since the mid-1980s, with a trade deficit of around 348,000 tonnes of fish and related products in 2019, worth £ 1.7bn [54]. Pelagic species represent the greatest proportion (around half in 2019) of the UK catch in terms of weight, with herring and mackerel *Scomber scombrus* L., comprising the largest exports of wild caught fish. The top three imports in weight are tuna, *e.g. Thunnus* spp., cod and salmon; while shrimps and prawns *e.g. Penaeid* spp., salmon and cod are the most valuable categories [54,62]. Interestingly, when considering the nation's favourite, cod, the amount the UK exports (annual average 15,260 tonnes, 2015 – 2019 data, [56]) is almost identical to that caught by the home fleet and landed into UK ports (15,700 tonnes), although the vast majority consumed (110,900 tonnes) is imported, primarily from Iceland [63]. When viewed purely from an energy perspective, the logic of exporting an equivalent volume of fish as that which is caught, while importing the rest, is highly questionable. The explanation relates to differences in consumer demand as imports are predominately from Iceland as frozen at sea fillets that supply the UK's fish-and-chips trade, while exports are sold overseas as a fresh premium product. When considering fisheries more holistically as part of a wider *Food-Energy-Environment Nexus*, taking on board the challenges of a shifting climate (*e.g.* [64]), variability in fuel prices (*e.g.* [49]), geo-politically driven modifications of supply chains ([65,66] in relation to tariffs on Russian whitefish imports in response to the invasion of Ukraine) and declining and moving stocks [67,68], there is a need to consider how to address imbalances that contribute to the unsustainable use of energy and overexploitation of fish.

Wasteful practices in the fisheries and aquaculture processing supply chain illustrate the need for a Nexus-based approach to fisheries management. Of all marine fish caught globally, approximately 35% is either lost or wasted (FAO, 2018) due to an inability to keep the catch fresh, or because fish are discarded as undesirable or too small for market, creating a circle in which fishers catch more fish to compensate for those discarded (another reinforcing causal loop in addition to those illustrated in Fig. 1). Furthermore, despite extensive efforts to replace animal with plant protein (*e.g.* [69,70]), a number of aquaculture systems depend on feed provided by the processing of wild caught forage fish that people could have eaten [71], and generate huge quantities of waste [72]. Forage fish are the crucial link between lower and upper trophic levels in the food web because they transport energy from millimetre-sized plankton to the larger fish eaters [73]. For that reason, they should not be overfished, and when they are fished, preferably used directly for human consumption rather than animal feed to reduce energy lost through a long food chain. Reduction of fish waste overall, while using that which remains to produce biofuels (*e.g.* [74]), may represent a Nexus success, providing it does not generate greater pressure on fish populations through creation of a fish waste market to supply renewable energy needs (*e.g.* [75]).

From a Nexus perspective, sustainable fisheries might be possible if harvest is set at levels that allow stocks to recover using techniques that facilitate the regeneration of sensitive habitats in those areas where they have been damaged, while reducing the carbon footprint of long supply chains. This can be achieved by focusing on the domestic UK market and products with short supply chains (*e.g.*, as opposed to European caught fish shipped to China for processing before returning to the UK for consumption, [76]), with the additional benefit that these are likely to be easier to monitor and less prone to infiltration with illegally caught or mislabelled fish sourced from elsewhere (see [77]). This is not a small challenge, however, as it would require the marketing of the catch of local fishers to drive a change in dietary preference of the wider public, a requirement recognised in the draft JFS with respect to the need for the fisheries policy authorities to promote locally sourced seafood and encourage better consumer awareness to make informed choices related to a more sustainable and healthy diet [21].

If a shift in preference to locally caught fish could be achieved then this would provide a healthy and climate-conscious alternative to other sources of protein, such as red meat that has a considerably larger carbon footprint [40,78,79]. In the UK context, one study indicated that the age and sex adjusted average dietary carbon emissions (kilograms of carbon dioxide equivalents per day) for those who selected to be "fish eaters" (*i.e.* excluded red meat but ate fish) was just over half (54%) of that of those whose diet included a high red meat component ($\geq$ 100 g day^{-1}) [80]. Indeed, compared to industrial[2] fishing, local marine food systems based on "Community Supported Fisheries" can reduce the carbon footprint of seafood distribution by two orders of magnitude, while benefitting conservation through targeting stocks that are in high local abundance [81] and improving the security of local food networks in the face of market shocks (*e.g.* due to COVID-19, [82]).

3. Integrating social-political solutions to challenges of the Fisheries-Environment-Energy Nexus

To solve the challenges of integrated resource exploitation and sustainable long-term management there is a need to develop and combine bottom-up and top-down social-political and technological fixes, while remaining cognisant of potential unintended consequences (*e.g.* fuel consumption and CO_2 emissions are reduced for electric pulse compared to beam trawling, but results in spatial displacement of fishing activity and a shift to a different target species, Turenhout et al. [84]). From an isolated viewpoint of enhancing fisheries sustainability, it is clear that stocks should not be overexploited, and if they are actions should be taken to allow them to regenerate to sustainable levels, wasteful practices should be minimised, and the most damaging techniques (*e.g.* bottom trawling on sensitive rocky reefs, [85]) reduced or stopped. From a wider Nexus perspective, however, there is also a need to decarbonise the fishing industry, while at the same time promoting low-energy and sustainable fisheries (in support of a wider dietary shift that may include more plant protein) to reduce dependency on energy intensive production of red meat [80].

The challenge of achieving a more sustainable *Fisheries-Energy-Environment Nexus* is not straight forward, as some goals might be contradictory, requiring trade-offs and compromise (*e.g.* in employment, profitability, wages and carbon emissions, [86]; and fishing method, [87]). From the UK perspective, an obvious contribution to a solution, although one that is likely challenging to achieve, is to shift dietary preference to more abundant and local species caught using sustainable techniques. For example, if the UK preference could be shifted, even if only partially, from the four main wild capture species (cod, haddock, tuna, and prawns), to species, such as mackerel, herring and langoustine *Nephrops norvegicus* L., there would not only be a reduction of pressure on overexploited stocks, but a decline in the energy costs of capture and transport.

There are precedents in the terrestrial agriculture sector for shifting from industrially produced and globally sourced food systems to those that are based on short, local supply chains (*e.g.* "farm-to-fork"). Some emphasise the social (*e.g.* [88]) and environmental (*e.g.* [89]) benefits of such initiatives [90]; others point to weak supporting evidence [91], and argue that buying globally benefits the world's poorest communities while carbon offsetting can help mitigate the environmental footprint of transportation [92]. Nevertheless, the supply of locally caught sea fish (*e.g.* through Community Supported Fisheries) will reduce the energy costs of harvest, processing and transportation typically associated with longer supply chains without the need for offsetting, the value of which is both empirically and ethically contested (*e.g.* [93,94]). This will also enable the public to access high-quality, nutritious, fresh seafood while supporting local fishing communities and enabling a better capture of

[2] Thurstan et al. [83] describe the industrialization of fishing as accelerating from 1889 to the onset of World War I. Today "industrial fishing" is a rather arbitrary term. In the UK context we define industrial vessels to be larger than the small-scale (< 10 m) fleet, not confined to inshore local coastal waters during their typical fishing activity, and that tend to be corporate owned by large businesses (as opposed to private or family owned, or by small partnerships and co-operatives).

value for coastal fishers [95] that may employ less-damaging techniques, but are frequently marginalised in the policy dialogue [96,97]. This sector may also become more accountable and potentially better governed than others operating in distant regions because there is a stronger drive for sustainability if consumers are more aware of activities taking place in their local marine environment, as evidenced through various case study examples (*e.g.* [98] for non-UK examples; [99] for description of the first community Marine Protected Area designation in the Isle of Arran, Scotland, UK).

If more holistic management of marine resources is to be achieved through a bottom-up societally driven approach, then consumers must be sufficiently informed of the implications of their choices, *e.g.* in relation to which fish to eat. Indeed, one of the aspirations as outlined in the draft JFS is that seafood will be promoted by the national fisheries authorities who will facilitate the development of robust labelling and traceability systems that can support accreditation and are understandable to the consumer [21]. Historically, the Marine Stewardship Council (MSC) was established to develop standards for sustainable fishing and to inform consumers about which fish they can eat with a clear conscience through a certification and ecolabelling scheme [100]. The intention of the MSC was to influence consumer choice, reward sustainable fisheries, minimise impacts on the ecosystem, and develop effective and responsive management. Several studies highlight the credibility of the scheme [101,102], and that MSC certification has led to many improvements in the management of fisheries [103]. However, others remain unconvinced that the approach reduces the decline of stocks overall [104], benefits the wider environment (*e.g.* [105]), or addresses ethical issues, such as labour practices on board vessels (*e.g.* [106]). Others highlight flaws in the assessment protocols [107], or consider the principles to be applied in a too lenient and discretionary manner due to the liberal interpretation by third-party adjudicators [108] with questionable independence [107]. There may also be an imbalance in power between different sectors, as accreditation requires sufficient funding for assessment that may be difficult for indebted small-scale fishers to resource, resulting in their environmental credentials remaining unseen or unrewarded by a market that demands ecolabelling. Furthermore, from the Nexus perspective, ecolabelling schemes may preferentially influence selection of imported products, despite having travelled substantial distances from developing nations, providing contradictory messaging and conflicting choices for the consumer [109].

There are alternative approaches to persuade the public to eat local fish. This includes rebranding of products in association with modified marketing campaigns [110]. There are lots of historic examples: anglerfish *Lophiidae* spp., were advertised as monkfish; pilchards *S. pilchardus* as Cornish sardines; and dogfish and huss *Scyliorhinus stellaris* L., as rock salmon. More recently, the Cornish Fish Producers Organisation announced the rebranding of several products, historically sold mainly to customers in Spain, due to difficulties in exporting fresh food to the continent after Brexit [111]. The British public may now purchase locally sourced products marketed as Cornish king crab (as opposed to spider crab *Maja squinado* Herbst, 85% of which was previously exported) or Cornish sole (as opposed to megrim *Lepidorhombus whiffiagonis* Walbaum, for which 95% was exported).

While educating the public on decisions about food choice, multiple factors (*e.g.* taste, nutrition, price, habit, choice, and ethics and sustainability) interact to create a wide range of possible outcomes (*e.g.* [112,113]). Some may choose to abstain from eating fish entirely (*e.g.* promoted by the Netflix documentary *Seaspiracy* [2021]), and others might select species based on their population status, while many more are governed by alternative factors that, for them, take higher priority (*e.g.* price in the face of a "cost-of-living crisis"). There is a role for bottom-up consumer-led mechanisms to improve fisheries outcomes [114]. It is important to note that they will ultimately prove insufficient without the top-down regulation and/or industry-led governance centred around sustainability if real change is to be initiated.

At a European regional scale, to solve many of the complex challenges associated with enhancing the sustainability of transboundary fisheries in a multi-use ocean, neighbouring coastal states must continue to work closely together to secure optimal social-ecological outcomes. The UK-EU Trade and Cooperation Agreement (TCA) provided an opportunity to redistribute quota so that fishing activity could align better with the decarbonisation agenda of both the UK government and the wider EU. During the negotiations the EU proposed a continuation of allocation based on the principles of historical fishing rights, otherwise known as "relative stability", in which fixed shares of the total allowable catches (TACs) for each fish quota were based on reported landings during a reference period from 1973 to 1978 [115]. The UK negotiation appeared to be based more on the principle of "zonal attachment" that would develop a greater linkage between the fishing fleet and the geographic location of the fish populations over the course of their life history.

There is scope under the Act to adopt the principle of zonal attachment as a tool that can be used to negotiate shares of quota at the international level and that could result in more quota being secured, and so made available for distribution to fleets in the UK. This would enable the home fleet to obtain a greater share of the stock residing within its local waters [116], and improve the economic link between fishing activities and coastal communities as is one of the objectives of the Act [117]. Thus, from a Nexus perspective, zonal attachment has the potential to reduce the carbon footprint and other environmental costs associated with the existing supply chain, especially if consumers are persuaded to buy local and more sustainably sourced fish from sectors of the fleet using less-damaging techniques. This would align with international policy commitments (*e.g.* COP26, [118]) and may also provide a means to prepare for climate driven shifts in the spatial distribution of populations, such as that observed for mackerel in the northeast Atlantic that triggered a dispute between the EU, Norway, Iceland, and the Faroe Islands [119], thus reducing the potential for future conflict between partners.

The final TCA agreement reflects a negotiated compromise in which provisions on allocation appear to be closer to the aspirations of relative stability supported by the EU than those of zonal attachment proposed by the UK [120]. Twenty-five percent of the previous EU quota for fish caught in UK waters will be reallocated to the UK gradually over a five-and-a-half year period. This will be achieved in incremental phases, with a 15% reallocated in year 1 (2021) and a further 2.5% per year thereafter. Scrutiny of the details at a national scale indicate minimal benefits for the small-scale fleet and little realignment with zonal attachment [121]. Instead, large commercial vessels are most likely to benefit. This is because the increase in quota is skewed to only some stocks, largely for pelagic and North Sea species such as Norway pout *Trisopterus esmarkii* Nilsson, horse mackerel *Trachurus trachurus* L., and hake *Merluccius merluccius* L., species that are generally unsuitable for the small-scale sector (Table 1 in [122]). Regarding the increase in value across 56 fish stocks due to gaining EU quota, 41% of it comes from just one mackerel stock (Western), while other populations do not undergo any change at all [121]. Despite the shortcoming of the deal contained in the TCA, there remains scope for changing the distribution of fishing entitlements under the Act. This could be enabled under Section 25, which requires national fisheries authorities to use transparent and objective criteria when distributing fishing opportunities. This means having regard to the fisheries objectives and includes criteria relating to environmental, social and economic factors. This provision could be used to increase access to stocks by small-scale fleets, or vessels that use less environmentally harmful gear or that have a lower carbon footprint.

4. Technological advance: smart fisheries

Historically, technology to exploit fish stocks has advanced more rapidly than regulations to protect them, resulting in some cases in a one-sided race towards ecosystem degradation and stock depletion. For example, the emergence of steam trawlers in the 1880s increased fishing power on average by eight times per vessel [123], and enabled bottom trawling further off-shore, deeper, for longer periods, and with larger, more efficient gear [83]. This trend continued so that at the turn of the millennium a diesel-powered trawler had between 50 and 100 times higher fishing power for cod and plaice *Pleuronectes platessa* L., respectively, than the sail powered vessels they replaced [123]. Today, fishing power is enhanced further by, for example, developing greater fish finding capabilities [124], such as using drones to provide a more efficient and cheaper alternative to commercial manned aircraft to locate high-value species, such as tuna [125].

Advances in computer science, *e.g.* related to “Big data”, “Artificial intelligence” (AI), such as machine learning and computer vision [126], and the “Internet of Things” (IoT) [127], are expanding the distribution and accessibility of data to allow fishers to optimise their activities [126]. For example, information on oceanic conditions (*e.g.* temperature and salinity) gathered by “smart buoys” and stored on cloud servers (*e.g.* NTT Docomo, [128]) has the potential to be interrogated on a fishers smartphone to predict the following day’s catch. In the UK context, the Scottish Inshore Fisheries Integrated Data System (SIFIDS) project, administered by the Scottish Government and conducted in collaboration with industry and academia, provides an example of the development of a sophisticated system that will enable fishermen to collect data to facilitate decision-making in fisheries management and marine planning [129]. Initiatives have included pilot schemes to trial low-cost tracking systems that enable the automation of data collection and sharing while minimising the burden of reporting (*e.g.* [130]); link GPS tracks, gear deployment sensors and catch data to assess fishing intensity and Catch Per Unit Effort; develop a prototype scanning device that automates the determination of size and sex of live brown crabs and lobsters onboard vessels while at sea [131]; advance low-cost, non-invasive techniques to identify scallop grounds, deployed from an inshore fishing vessel; and create methods to combine socio-economic data with fishing drivers to inform policy and business planning.

Even actions to enhance fisheries sustainability, *e.g.* by reducing carbon footprints, may have unintended consequences by increasing fishing power that could threaten stocks if they are poorly managed. For example, by transitioning to alternative fuels, such as hydrogen, or by using solar electricity, the relationship between fishing activity and the cost of hydrocarbon-based fuel (such as red diesel) will be disconnected, enabling future vessels to operate more efficiently and increasing the potential for unsustainable exploitation if robust management systems are not employed and compliance enforced. Japan has invested in shifting to renewable energy in fishing activities for over a decade (*e.g.* [132]), and representatives of the motor industry (*e.g.* Toyota & Hyundai) are now building fishing boats driven by hydrogen fuel cells [133]. Elsewhere, others are advancing alternative forms of energy to power vessels, including solar (*e.g.* [134]) and hybrid energy configurations (*e.g.* [135,136]). Without adopting a precautionary Nexus based approach, the next generation of fleet may enhance fishing power and capacity in a way that could imperil wild fish populations and the fisheries and other societal benefits which depend on them, while at the same time claiming green credentials when viewed from the perspective of the decarbonisation agenda.

Rather than developing more efficient techniques to find and harvest fish, today’s challenge is to employ technologies to promote environmentally sensitive and less wasteful methods of capture, while monitoring and reporting catches in real time relative to targets set and changes in stock status. To facilitate stock regeneration, a move forward will entail reversing long-term trends of increasing efficiency and capacity [124], *e.g.* by simultaneously increasing mesh size and reducing the dimension of fishing nets used while deploying them less frequently and for shorter periods. Even with such efforts, however, there is a need to use cutting-edge technologies to help advance more precise stock management and enforcement programmes.

Advances in computer science are changing the methods of monitoring and managing traditional supply chains. At one end of the scale, fishers are installing webcams on board their boats and using social media platforms to market their catches online (*e.g.* for UK examples see [137-139]), thus directly matching supply and demand and potentially reducing waste. At the other end, Big Data and the IoT allows the generation and use of large amounts of information in a more effective and integrated way, including supply chain management of fish products, as part of new “Smart Fisheries Management” (SFM) systems. The IoT comprises a network of billions of devices, such as those embedded within sensors and software that connect, collect and communicate the large quantities of near-real time georeferenced data generated (*e.g.* [126]). These data can be used to advance dynamic and flexible approaches to SFM at appropriate scales, *e.g.* to adjust catch targets, reassign quota, and close fisheries in response to information on stock status, harvest, and market price. For example, commercially available networks of linked wireless sensors installed on fishing gear provide data on fleet effort while at sea, such as counts of winch revolutions, winch direction, and date and time that nets are submerged and hauled (*e.g.* [140]). This information can be transferred *via* Vessel Tracking and Monitoring solutions to terrestrial databases to help coordinate more sustainable management (*e.g.* [140]).

At the consumer end of the supply chain, those purchasing fish are increasingly aided in their decision making through technology. Smartphone apps, such as “The Good Fish Guide”, provide information on specific stocks, indicating which should be avoided (red tags), preferred (green) and eaten only occasionally (amber) [141]. At the same time, supermarket stores are using smart technology to enhance inventory management and advertising. Sensor and camera networks, for example, can signal the need to replenish shelves, monitor the temperature of freezers, and record the behaviours of customers as they search for the best prices [142]. Smart shelves have electronic visual displays that can grab the attention of the shopper [143] and update the prices across the entire store within minutes, while providing additional information (*e.g.* nutritional value) and personalised advertising to the consumer. Cameras integrated with image recognition systems monitor customer-object interactions (*e.g.* [144]), potentially identifying age group and gender of the consumer as they pass a shelf, enabling the display of special offers based on the probability of product preference. This is further informed by the sensors on the shelves interacting with smartphone apps, highlighting deals on products based on purchasing history and preference (*e.g.* [145]), and potentially environmental consciousness.

As the UK is one of the global leaders in high-tech computer science, including in Big Data, AI and IoT (*e.g.* [146]), it is well placed to adopt sophisticated approaches to SFM. This includes in monitoring and enforcing compliance with regulations and identifying illegal fishing and environmentally damaging activities. For example, by integrating increasingly accessible and accurate satellite imagery data with machine learning it is possible to identify and track vessels to monitor compliance and detect illegal fishing activity (*e.g.* [147,148]). This can advance fisheries enforcement, while helping industry comply with regulations developed to enhance sustainability of the supply chain, *e.g.* by identifying and acting against non-compliant vessels (such as those that fish in MPAs or otherwise illegally) when forming purchasing decisions. Information provided by remote sensing can be further reinforced by that gained from onboard Remote Electronic Monitoring (REM) systems (*e.g.* continuous digital camera recording, Global Positioning Systems, Global Navigation Satellite Systems, AIS and Vessel Monitoring Systems) to improve cost-efficiency, increase representative coverage of the fleet, and enhance the registration of fishing activity and location [149]. These enhance the collection of data [126] for electronic reporting and documenting schemes that track the location and amount of fish caught against quota.

The use of REM for regulatory enforcement and data collection was raised and debated as part of an amendment to the Fisheries Bill as it passed through Parliament. While the value of REM was recognised, it was argued that a flexible framework was required, rather than restrictive regulation [150]. This highlighted an unwillingness by the Government to impose technology on the fishing industry, arguing instead that is it better to collaborate with the sector than impose constraints [150]. Indeed, this reflects a trend in institutional responses over recent decades in which an emphasis on legislation regulating fisheries in sovereign territorial waters has shifted towards "soft" governance, *e.g.* relying on voluntary codes of conduct as has been proposed for management of trawling [151], market incentives and partnerships between fishers and governments [152]. While there is undoubtedly value in working in collaboration with stakeholders in developing future fisheries management and conservation policy, and novel approaches can be adopted to improve the efficacy of voluntary codes of conduct (*e.g.* see [153] in relation to the use of "nudges"), relying purely on voluntary measures alone rarely bring about substantial improvement in environmental outcomes [154] unless as part of a SMART regulatory system [155]. The amendment was ultimately defeated, and a regulatory requirement for REM was excluded from the Act, although its value has been positively reiterated in the draft JFS as an element that should be further explored by the fisheries policy authorities where appropriate. In the context of an urgent need to reverse the degradation of a primary resource, we argue that voluntary actions to protect marine fisheries should be further reinforced by a regulatory framework that requires adoption of best available technology where reasonably practicable (rather than where appropriate). At the same time, further work is needed to better understand the impediments to uptake including the concerns of fishers related to intrusion of privacy, liability and costs [149]. The draft JFS is open to innovation in sourcing and using data, and its commitment to fostering collaborative approaches is to be welcomed [21]. This is important because a top-down imposition of reporting and monitoring requirements without bottom-up buy-in can lead to conflicts [156].

5. The public, political and media dimensions in advancing sustainable fisheries policy

While UK marine fisheries are a public asset ([157]; draft JFS), recent debate on their future is prejudiced towards the short-term interests of the fishing industry, more specifically the quota owning large vessel sector [158]. This biased perspective was highlighted by the politicised media coverage of the UK-EU negotiations over a post-Brexit trade deal during a period in which fisheries became particularly newsworthy (Fig. 2). The narrative focused on the social-economic system and largely ignored the ecological domain that provides its foundations. In an analysis of the media coverage (Fig. 2), the articles discuss UK fisheries almost entirely within the context of trade deals, with issues such as gaining a "fairer share" of quota, regaining "control" of UK waters, and "sovereignty", being the primary concerns. Similar issues were prioritised by the fishing industry during stakeholder engagement workshops in the year after the Brexit referendum [18]. Conversely, media commentary on the regeneration of stocks and the conservation of imperilled populations was largely absent. In the wider public debate, there appears to be a lack of interest in, and awareness and acknowledgement of, the long-term decline and some recent recoveries of fish populations on which the UK fishers depend ([22,159],), or the threat to their habitat of damaging fishing practices. Considering that public support for environmental policies is influenced, to some extent at least, by the amount of media coverage [160], its content, the framing of the message, and the source of information provided [161], the creation of a more sustainable fishing industry depends on the engagement of wider society in a more holistic and balanced discussion. This includes introducing the public, and the politicians that represent them, to the concept of fisheries as a social-ecological system so that more informed and nuanced opinions influence the political agenda and societal behaviours, such as which food to eat. Before attempting to reframe the debate there is a need to consider why current discussions on sustainable fisheries might not be high on the agenda and identify barriers to engagement needed to facilitate environmental awareness.

Environmental knowledge is an essential antecedent of awareness in the shift towards meaningful pro-environmental behaviour and policy change [162]. High-profile environmental issues that garner media attention and awareness and that lead to public support and political action include climate change [163], biodiversity loss (see [164] and [165] for comparisons with climate change) and, more recently, plastic pollution of the oceans [166]. In comparison, current attention on the overexploitation by some UK marine fisheries, or indeed global fisheries, appears to be limited. Without direct public engagement, this topic will remain unfamiliar to large sections of society ambivalent to the complexities of sustainable resource management, while more simplistic messages on sovereignty and fairer shares are easier to understand and appeal to nationalistic sentiments. Furthermore, indicators of resource vulnerability are difficult to discern, as the public are generally unlikely to observe *in situ* shifts in fish abundance or damage caused to marine habitats beneath the waves. Indirect or secondary indicators are also less easy to identify, as trips to local fish markets are increasingly a thing of the past, while the provenance of produce displayed on supermarket shelves might be difficult to ascertain, and in some cases intentionally fraudulent [167].

One of the principal signals of resource availability is pricing (see R5 in Fig. 1). As the abundance of fish decline due to overexploitation,

Fig. 2. A word cloud generated on 30 December 2020 based on the text obtained from the first 20 articles retrieved from "Google News" using the search term "Fisheries AND Brexit". On this date the UK Parliament voted overwhelmingly to approve the post-Brexit trade deal agreed six days earlier on 24 December 2020. The articles interrogated had been published between one hour and one month prior to the search. The word cloud illustrates the bias in the text (16,666 words) towards consideration of socio-economic elements, with words such as "deal" (198), "quota" (76), "trade" (75), "access" (46), and "control" (13) appearing at much higher frequencies than those related to stock recovery and management, such as "sustainable" (2), "sustainability" (1), "conserving" (1). The words "conservation", "recovery", "restoration", and "regeneration" were not used in any of the articles.

economic theory predicts a negative relationship between price of products and elastic demand [168]; consumer demand and pressure on stocks should reduce as the product becomes more expensive. Increasing prices may influence environmental awareness by providing a signal to the consumer of resource vulnerability. These relationships break down, however, when the global nature of markets prevent transmission of price signals from local fisheries to the consumer [63]. Signals are weakened when declines in local catches are diluted by product substitution from alternative sources, *e.g.* UK imports of cod from Iceland and the Faeroes ensuring a constant supply despite reductions in North Sea contributions from around 50% in 1983 to just above 10% in 2010 [63]. Today the average value of cod landed by British vessels in the UK remains relatively constant despite declines in catch (Fig. 3). Likewise, government interventions, such as subsidies (*e.g.* fuel duty exemption, [169]) or price control, influence the dynamics of supply by modifying

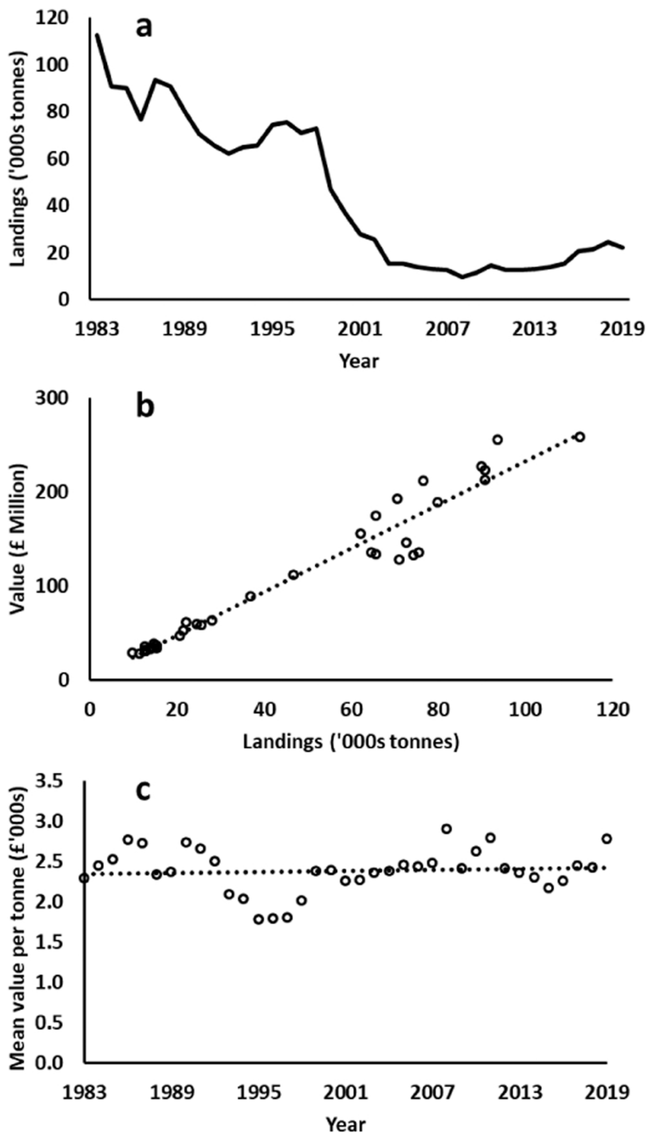

Fig. 3. Despite a declining trend in (a) landings of cod by UK vessels into UK ports between 1983 and 2019 (MMO data), (b) a strong positive linear relationship between landings and value ($y = 2.32x + 0.94$, $R^2 = 0.95$, $F = 655.35$, $p < 0.001$), resulted in (c) a fluctuating but consistent (flat line: $y = 0.002x -2.17$, $R^2 = 0.0081$, $F = 0.29$, $p = 0.60$) mean price (£'000s per tonne). The lack of a price signal to consumers despite falling supply from home waters as a result of imported product are likely to limit cues on stock status. All values have been converted to the present day (2020) price equivalent using the annual Retail Price Index (RPI).

cost structures [170]. This was epitomised by the reduction in the supply of demersal fish during World War II (see Fig. 1, [22,171]). In 1941, landings of the English fleet were only 18% of the pre-war level, and despite an increase in foreign landings, primarily from Iceland, the total British supply was only 40% of that in 1938 [172]. With a reduction in availability of fish, and an increase in the cost of harvest and distribution, the price of many stocks of demersal fish rose rapidly at the start of the war (Fig. 4), leading to the introduction of price control from 1941 onwards [172].

Price signals can be weakened when supply chains become increasingly consolidated and integrated, with large firms or co-operatives of wholesalers, processors, and retailers exerting a downward pressure on prices that the individual fishers are forced to accept [63]. This not only limits signals to the consumer that indicate the potential degraded status of marine resources but threatens the viability of UK fishing communities. This is particularly the case for owners of the smaller vessels who are left to absorb increasing costs through incurring greater debt and risking job security while struggling to recruit crew [49]. Overall, as these factors conspire to dampen the feedback of price signals, the challenge of advancing sustainable fisheries management is impeded. Indeed, even if education and environmental awareness of the status of fish stocks and ecosystems are enacted *via* alternative routes, such as books (*e.g. Four Fish,* [173]), documentaries (*e.g. The End of the Line*, 2009), and public engagement campaigns (*e.g. Hugh Fearnley-Whittingstall's Fish Fight* , 2010), the fact that the availability of affordable fish remains relatively consistent continues to send contradictory signals to the wider public [63].

Even when an "environmentally aware" public are in possession of sufficient knowledge, either provided *via* price signals or other information sources, it is not a given that they will display pro-environmental behaviour, or support those that advocate for doing so. The reasons for a gap between awareness and action are numerous and complex [174]. These include demographics, and external (*e.g.* geography, institutional, economic, and social) and internal (*e.g.* age, motivation, awareness, attitudes) factors, the combinations of which lead to political "predispositions" [175]. There has been considerable examination and empirical evidence collected to quantify the role of different actors in changing public opinion and political direction in relation to a wide range of issues. Particular attention has been directed to understanding the influence of "political" or "intellectual" elites (*e.g.* politicians or academics), the media, and activists and interest groups, all of which have an important role in reframing and shifting the UK fisheries debate.

6. Expert engagement with elites, media and advocates to shift public opinion

The intention to influence public opinion is highlighted in the draft JFS in reference to the fisheries policy authorities' role in improving perception of the fishing industry as a good place to work and promoting positive benefits of eating locally caught seafood as a healthy, low-carbon, and sustainable protein source [21]. Detail on how this will be achieved, however, is lacking, as is recognition for the need to shift public and political awareness, opinion, and support towards a more balanced social-ecological perspective to deliver sustainable fisheries management.

Multiple factors interact to influence public opinion (*e.g.* political debate and media narrative, [176]), and their relative importance can change over time and with context. For example, elite discourse, considered to be one of the most important drivers (*e.g.* [175]), is modified by other interacting influences, such as exposure to different perspectives [177]. The availability of information is another important determinant [178,179], but is often lacking on environmental issues. Even when evidence on which to base informed opinions is available, there is no guarantee that public attitudes and behaviours will be influenced in meaningful ways. Indeed, the role of science can be ambiguous and limited, compared to the influence of elite cues and

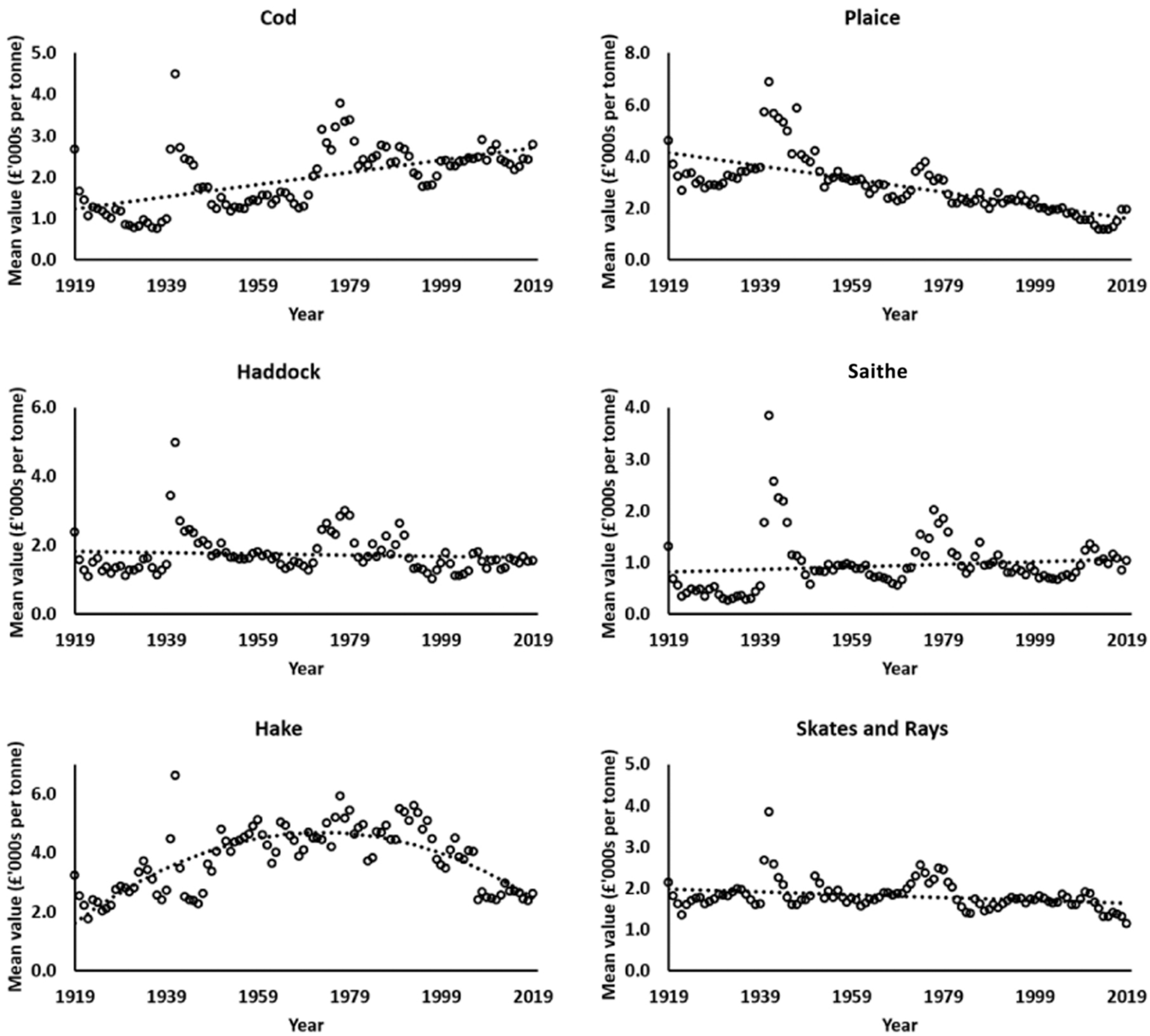

Fig. 4. Variation in mean value (£,000s per tonne) of demersal fish landed into Great Britain/UK ports by home fishing fleet from 1919 – 2019 for six commercially important species. For all species there is a clear spike in mean value at the start of World War II, after which price control was introduced. All values have been converted to the 2020 price equivalent using the annual Retail Price Index (RPI). 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 MMO, 2020).

structural economic factors, *e.g.* in relation to public concern over climate change ([180,181] for the United States). To change public opinion on UK marine fisheries, there is a need to frame the current situation within a historic context while engaging with all parts of the UK fishing industry, science, civil society, political elites and the wider media to shift existing attitudes and reduce the risk of increased polarisation.

Recent consultation and debate on UK fisheries policy have been within the context of leaving the EU. It is known that when there is strong disagreement among the elite, *e.g.* along partisan or ideological lines, the public response becomes increasingly polarised and entrenched; peer reviewed science becomes less influential, while confidence in unsubstantiated opinion increases if it aligns with an existing worldview [182]. Within highly polarised contexts, such as occurred during Brexit, a reduction in the impact of science makes messaging on sustainability more challenging, especially when doubt in its value is reinforced by statements made by the political elite. For example, during the run-up to the Brexit referendum a senior politician, who shortly after took charge of the Government department responsible for fisheries, stated that "I think the people of this country have had enough of experts from organizations with acronyms that say that they know what is best and getting it consistently wrong" [183]. To improve messages on sustainability, the political elites should engage with the science community, as proposed in the draft JFS, who are able to present arguments that may help achieve consensus. If consensus can be attained, common messages tend to be first received by the most politically aware members of society before the wider general public follows [175]. However, the debate must first move away from that traditionally defined by relationships with the EU and party politics, with the support of the elites from all sides won by the weight of scientific evidence. The establishment of the All Party Parliamentary Group [20] on fisheries is a positive move in this direction. Specific opportunities to shape fisheries management policy exist through consultation to inform the JFS and Fisheries Management Plans under the Act, but this should be viewed as part of a wider approach to engaging with other levers of policy, such as mass media.

Mass media plays an important role in the relationship between elite discourse and public opinion (*e.g.* [184]). Such interactions are often complex and difficult to define, changing over time and with context, and the method of study employed [185]. In some cases, the media attempts to influence the political agenda, with varying degrees of success [186]; in others, it forces change through influencing public opinion, and as a consequence, political direction (*e.g.* see [187] in relation to the "*Thalidomide* scandal"). However, the media narrative is predominantly a function of elite cues (*e.g.* climate change, [180,181]; or arguments for war, [188]), and not necessarily an expression of public opinion, although it may be used by the elites to try and influence it. In respect to UK fisheries policy, interactions between media, elites and the public are dynamic and complex. After the TCA was announced, representatives of the fishing industry described what they saw as government betrayal through multiple media outlets (*e.g.* [189]). In response, senior Government ministers defended the deal as a positive outcome for UK fishers (*e.g.* [190]) only to have claims discredited in the public interest by fact-checkers within the UK media (*e.g.* regarding UK fishers share of quota for home waters increasing from half to 58% rather than 66% as claimed, [191]).

Social media has modified the traditional landscape in which information is transferred and debate aired, increasing the speed with which opinion is spread through the wider community. The social media model is by design based on engagement that is most effectively engendered through negative debate elements (outrage, animosity and division) that can result in increased polarisation [192,193]. Platforms such as Twitter are used to establish routes of communication between political elites and the electorate, not only in relation to campaigning, but for fund-raising, and information gathering (*e.g.* [194]), although also to promote misperceptions [195,196]. Social media also gives a voice to those that otherwise might not have a large platform to spread their message more widely, and provides an opportunity to foster greater public participation, mobilisation and information transfer, including in relation to enhancing environmental awareness [197] with examples of both failure and success.

Recent campaigns, using social and/or traditional media, have attempted to change public opinion through a variety of routes. Greenpeace ran a high-profile Facebook and Twitter campaign to raise awareness of their concerns related to perceived exploitation of MPAs by large commercial fishing vessels, culminating in a public petition calling on the Government for a ban [198]. In response, DEFRA defended the position that only those fishing activities that damage MPAs, such as bottom trawling, require management [199]. When an amendment to the Fisheries Bill that included greater protection for MPAs was defeated [200], a frustrated Greenpeace commenced a campaign of direct action by depositing large boulders from vessels in some MPAs to deter fishing activity by snagging nets [201]. This was condemned by the fishing industry, but supported by some celebrities, including Hugh Fearnley-Whittingstall, a TV chef who previously increased public awareness and activated citizens to demand real policy change. Whether this results in shifting the general narrative to influence public opinion, or rather increases potential for ever greater polarisation (*e.g.* between the fishing industry and conservation organisation) and entrenched positions remains open to debate. The latter scenario is certainly unhelpful in generating the partnership working needed as emphasised in the draft JFS.

In another instance, Hugh Fearnley-Whittingstall launched the “Fish Fight” campaign in 2010 to highlight concerns over the practice of discarding over-quota and undersized fish overboard by the crew who were either not allowed to land them, or would have been economically disadvantaged by doing so. The campaign helped lead to reform of the CFP (the ‘landing obligation’) when the discarding of quota species was progressively banned over a five-year period [202]. This development was no doubt strongly influenced by the fact that around 870,000 people from over 195 countries signed the petition [203]. Under some circumstances, it appears that by employing appropriate mechanisms of communication, public opinion can be influenced through a variety of actors (politicians, media, advocates, celebrities), and if informed by the most up-to-date scientific evidence could drive change to achieve a more sustainable future for UK fisheries.

7. Conclusions

Whether viewed within the context of conserving ecological foundations or achieving a socially and economically viable industry, it is apparent that the current status of UK marine fisheries is perceived to be undesirable by many stakeholders. This reflects a historic tendency not to recognise both elements as “two sides of the same coin”. On one hand, and despite recent recovery of some stocks [204], for many the marine environment remains degraded and overexploited. On the other hand, sectors of the fishing industry are highly dissatisfied with the outcome of trade agreements with the EU and many continue to be impacted by reducing profits and increasing indebtedness. There is a need to take a step back and integrate more sustainable resource management with the socio-economic wellbeing of the fishing communities they support. To do so requires a change in media attention, public opinion and education, and political direction if fisheries are to be managed and conserved, using the best available technology, in a more sustainable manner for future generations.

More sustainably managed UK fisheries could increase landings into UK ports of fish captured in the UK Exclusive Economic Zone to source local markets interested in a healthy and sustainable product with a low carbon footprint and a profitable base without subsidies. This vision can only be achieved by allowing the marine ecosystem and fisheries to regenerate and become more resilient. To deliver this, the adoption of a more holistic and wider ranging view of marine resource exploitation and management is recommended. This should consider the interactions between market driven demands and levels and methods of supply, the response of stocks to harvest and the ability of the ecosystem to regenerate, and wider sustainability goals, *e.g.* related to climate change such as the net zero target, biodiversity loss and societal ethics (*e.g.* poverty and gender equality). Adopting a more integrated and holistic *Fisheries-Energy-Environment Nexus* based management approach would promote rational and more informed decisions, enabling trade-offs and synergies between competing domains to be optimised. The UK Government and devolved administrations will play an important role if fishing communities are to be better safeguarded against negative consequences of overexploitation by striking a more equal balance in conserving and exploiting an increasingly resilient resource, using best available technology to enhance sustainability. However, it is unlikely that this will be achieved by voluntary means alone, *e.g.* through industry guidance and codes of practice, in a timeframe that will halt further degradation and promote regeneration. Instead, it is recommended that uptake of best available technology for fisheries monitoring and enforcement be achieved through a combination of collaboration with stakeholders and regulation as part of the JFS.

Considering the complex interactions between the different factors that influence public opinion and environmental awareness, and the current biased media narrative associated with UK marine fisheries policy, we propose that a concerted communication campaign is needed to shift the focus of the debate. This should be driven by the “experts”, *i.e.* representatives of the scientific and fisheries management community (*e.g.* Fisheries Society of the British Isles and the Institute of Fisheries Management) who are equipped with the evidence and ability to articulate the current challenges faced and need for urgent change. This is a particularly important responsibility of fisheries scientists, such as those in government agencies and universities and other institutes that are funded from public sources, and are required to elevate the importance of public and political outreach and engagement (*e.g.* [205]) and demonstrate the impact of their research (*e.g.* [206]). It is recommended that the scientific community work in close collaboration with others, such as environmental lawyers, nongovernmental organisations, conservation and advocacy groups and other stakeholders, including the fishing and seafood industries, to educate politicians and the general public through succinct, clear and consistent messaging needed to shift the societal baselines over the long-term [207]. This may be achieved through a range of actions, including increasing public engagement through films (*e.g. David Attenborough: A Life on Our Planet* [2020] in relation to the global biodiversity crisis) and other media; consumer awareness through marketing and wider public outreach (*e.g.* to shift dietary preference by focusing on buying sustainable and locally sourced fish); information provided by celebrity chefs and activist campaigns

[208,209]; dissemination of the results of scientific research through the traditional press and social media; and political lobbying and engagement. Following the common practices of representatives of the medical profession (*e.g.* [210]), submission of an open letter or petition signed by a large number of the Fisheries Scientists, co-ordinated by the Fisheries Society of the British Isles and Institute of Fisheries Management, would provide a useful first step in changing the current narrative and direction of the debate. In summary, the following recommendations are provided:

- **Recommendation 1**: Adapt the marine resource management approach so that it is better integrated to meet multiple objectives. It is increasingly recognised that a systems approach should be adopted to enhance the sustainable exploitation and management of resources that are integrated and complex in nature [23]. For example, increased exploitation of fisheries may increase job opportunities and profits for some, but may also negatively impact ability to meet targets for energy use (*e.g.* net zero) or the improvement of biodiversity and environmental status; this trilemma may be described as a *Fisheries-Energy-Environment Nexus*. The JFS provides an opportunity to deliver nature-based solutions to support adaptation and resilience to climate change and biodiversity regeneration. For example, approaches such as using MPAs and technical measures to reduce effects of fishing on the marine environment and on stocks of marine carbon should be developed. We support the intentions outlined in the draft JFS and recommend that a more holistic marine resource management-based approach should be further adopted to optimise trade-offs and synergies between competing domains. Aligned with the aim to support the continued development of robust supply chains and a diverse, low emission and modern fleet, we recommend the promotion of a system that better rewards the least damaging sectors when viewed from a wider environmental perspective. This would include better supporting some elements of the local sectors of the fleet that bring product to markets *via* short supply chains and with low carbon emissions; while removing capacity enhancing subsidies. Such actions would help achieve the climate change, sustainability and national benefit objectives.
- **Recommendation 2**: Employ the best available technology to achieve the sustainability, climate change and scientific evidence objectives. The draft JFS highlights the UK's track-record in investing in fisheries science and using new technologies. It also recognises that effective monitoring is a key component of ensuring a well-evidenced, sustainable future for the fishing industry and marine environment. The draft JFS recognises that innovative technological solutions may help realise carbon savings, *e.g.* from engine upgrades (that should not increase fleet capacity beyond sustainable levels), gear choice and green technology, as well as identifying opportunities for vessel emission reductions through alternative fuels. It also acknowledges that technologies may aid future fisheries management that should be evidence led and that there are gaps in current scientific, technical, economic and social data and understanding. It is proposed that such gaps in scientific data should be resolved through a co-ordinated programme of data collection across the fisheries policy authorities that will be delivered through a specific UK Work Plan, in accordance with the Fisheries Framework. We recommend that the JFS should be strengthened and used as an opportunity to more explicitly state the fisheries policy authorities will require the use of best available technologies as is reasonably practicable (as opposed to "where appropriate"). This would include vessel monitoring systems and Remote Electronic Monitoring (REM) for a range of purposes including scientific investigation and to advance sustainable management, *e.g.* in surveillance programmes, monitoring compliance (*e.g.* related to the supply chain) and facilitating enforcement. We agree with the aspirations of the draft JFS that fisheries management measures should be regularly monitored to assess their effectiveness to enable continued improvement of decision making and that information obtained should be made publicly available. We also recommend that the cost of installing technology, *e.g.* in lower impact sectors of the small-scale fleet, might be subsidised by Government (*e.g. via* the UK Seafood Fund and other grants).
- **Recommendation 3**: Achieve multiple objectives through collaboration and partnership working. The draft JFS recognises the need for working in partnership for effective management of marine fisheries due to the devolved nature of UK fisheries and the fact that several stocks are shared with other states. We welcome the proposed partnership working with the scientific community (*e.g.* in relation to the blue carbon evidence base) and recommend that Government works closely with the fisheries and marine conservation science community (*e.g.* Fisheries Society of the British Isles and Institute of Fisheries management) to engage with the wider stakeholders community. In addition to the aspiration that the fisheries policy authorities should seek to improve the general public's perception of the industry as a place to work and prosper, we recommend that efforts be made by Government to change the media narrative, public opinion, and political direction to focus on the regeneration of degraded marine ecosystems on which sustainable fisheries depend. This aligns with FAO [12] guidance on sustainable fisheries that recognises the need to change the narrative and improve communication on fisheries issues and gain political will to strengthen policy frameworks. It also emphasises the recognition in the draft JFS that wild sea fish are a public natural resource.

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. **Kristina Boerder:** Writing – review & editing. **Bethan C. O'Leary:** Conceptualization, Writing – review & editing. **Bryce D. 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/D2358.

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