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Review Article

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Integrating economics into fisheries science and advice: progress, needs, and future opportunities

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While the science supporting fisheries management has generally been dominated by the natural sciences, there has been a growing recognition that managing fisheries essentially means managing economic systems. Indeed, over the past seven decades, economic ideas and insights have increasingly come to play a role in fisheries management and policy. As an illustration of this, the International Council for the Exploration of the Sea (ICES) has been actively seeking to expand the scope of its scientific expertise beyond natural sciences [another inter-governmental marine science organization which has done this over the same period is the North Pacific Marine Science organization (PICES)]. In particular, the recently created ICES Working Group on Economics set out to review current work and key future needs relating to economic research and management advice on marine capture fisheries. This article presents the results of this review and addresses how economic research can be incorporated into the science of ICES to provide integrated perspectives on fisheries systems that can contribute to the provision of advice in support of policy development and management decision-making for sustainable uses of living marine resources.

Keywords: applied fisheries economics, interdisciplinary fisheries science, management decision support, policy advice.

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Introduction

Over the past seven decades, economic ideas and insights have increasingly come to play a role in fisheries management and policy. Central to the early development of this literature, Gordon (1954) and Scott (1955) laid the foundations of the economic rationale for fisheries management by contrasting resource extraction under open access with optimal management aimed at maximizing economic yield. Clark and Munro (1975) also studied fisheries management as a capital theory problem, allowing economists to use a diversity of well-developed analytical tools to evaluate the efficient intertemporal use of fishery resources. Extending the discrete choice random utility model developed by (McFadden, 1974), (Eales and Wilen, 1986) and later (Holland and Sutinen, 2000) demonstrated the capacity to predict location choices in commercial fisheries. Location choice models have also been applied to the study of recreational fisheries (Bockstael and Opaluch, 1983; Bockstael *et al.*, 1989; McConnell *et al.*, 1995). For an extensive review of applied location choice models, see Girardin *et al.* (2017). Key to these and other contributions has been the increasing availability of economic data and the ability of economics to grapple with the identification of incentives driving fisher behaviour, as well as the evaluation of the costs and benefits associated with policy interventions.

In many instances, economic analyses have actively informed policy design (Wilen, 2000; Anderson, 2015), although scholars have noted that the full potential for contributions of fisheries economics to policy has yet to be realized (Hanna, 2011; Knapp, 2012). Underlying fisheries economics contributions is the recognition that how different policy options interact with stakeholders' incentives impacts the likelihood of achieving management objectives. For example, early economic studies of fisheries management under an industry-wide total allowable catch (TAC) provided an understanding of harvesters' incentives to further engage in capital investment (so-called "capital stuffing"), with the resulting race to fish and dissipation of profit (Homans and Wilen, 1997). Other studies emphasized the incentives for input substitution in input-managed fisheries, questioning the usefulness of such controls in practice (Dupont, 1991). Many fisheries policy innovations were introduced in light of these economic insights, in particular the various approaches for allocating harvest rights to different user groups (Shotton, 2001; OECD, 2006). The work of (Christy, 1973) was instrumental to the introduction of Individual Transferable Quotas (ITQs), which has become a widespread tool for fisheries management. In such management regimes, rather than setting industry-wide catch limits only, the regulator allocates individual catch shares with the intent that these will provide fishermen with more secure rights to fish, thereby limiting perverse incentives (Costello *et al.*, 2008).

Given that efficient allocation of scarce resources is central to economics (Samuelson *et al.*, 2019), assessing trade-offs is consubstantial to the discipline. Indeed, trade-off analysis is embedded in how economists quantify economic value. As a measure of value, economists typically use differences in net benefits from a policy intervention compared to no policy, or differences in net benefits with and without a shock to the system such as an ecological disturbance or an industrial accident (e.g. an oil spill). In supporting fisheries management, application of economic analysis has largely focused on informing decisions on how to best allocate limited resources such as time, capital, and fish stocks to attain the highest net benefits to society (see e.g. Dichmont *et al.*, 2010; Pereau *et al.*, 2012; Guillen *et al.*, 2013). Economic analysis has also paid attention to costs in fisheries, both fixed and variable, and how these can help understand the development of the industry and the influence of policy (e.g. Sala *et al.*, 2018).

In setting the general principles that allow understanding of incentives and trade-offs, early fisheries economics work was largely normative and theoretical (Wilen, 2000). Research over the past three decades has seen a strong development of empirical research, with increasing availability of empirical information and computing power (Andersen, 2013), as well as the recruitment of economists working in national marine laboratories. A number of complex bio-economic methods and models have also recently been developed and implemented for different fisheries around the world (see Nielsen *et al.*, 2018a for a review and Thébaud *et al.*, 2014 for a discussion of key challenges). In contrast to earlier economic literature focusing on stylized biological models, the population dynamics in these models are of similar complexity to stock assessment models currently used in fishery advice. As a result, this new literature has significantly contributed to bridging the gap between ecological and economic perspectives on fishery systems (Doyen *et al.*, 2013; Nielsen *et al.*, 2018a). For example, in Australia, where the policy objective is set to achieve maximum economic yield (MEY) in commercial fisheries, bio-economic models are used on a regular basis to support management decisions (Dichmont *et al.*, 2010; Pascoe *et al.*, 2014; Pascoe *et al.*, 2016). In the northeast US Gulf of Maine, bio-economic models of recreational fisher behaviour are used to set annual management specifications for Atlantic cod (*Gadus morhua*) and Atlantic haddock (*Melanogrammus aeglefinus*) stocks (Lee *et al.*, 2017). Indeed, the application of fisheries economics has been able to rely on a growing diversity of economic models and data, including the collection of cost and earnings data for commercial fishing operations (Thunberg *et al.*, 2015; STECF, 2020; Werner *et al.*, 2020). Other techniques enable economists to assess the welfare changes associated with policy interventions on non-market ecosystem services (ES), such as surveys of willingness to pay for the conservation of marine protected species that interact with fisheries (Wallmo and Lew, 2012).

While the science supporting fisheries management has generally been dominated by the natural sciences, there has been a growing recognition among natural scientists (Hilborn, 2007) that managing fisheries means managing economic and social systems (Charles, 2005). Indeed, international guidelines have increasingly highlighted the need to account for ecological, economic, and social goals in managing fisheries for sustainability as part of ecosystem-based fisheries management (Pikitch *et al.*, 2004). This resulted in the explicit inclusion of socio-economic considerations in fisheries policies around the world as well as in scientific advice, leading, for example, to initial discussions on incorporating fisheries economics into the work of the International Council for the Exploration of the Sea (ICES) as far back as 1971 (ICES, 2003). It is only in recent years, however, that efforts by ICES have materialized to expand the scope of scientific expertise to incorporate contributions from the social sciences. According to its current strategic plan (ICES. 2021. Strategic Plan. 18 pp. http://doi.org/10.17895/ices.pub.7460), the vision of ICES is "to be a world-leading marine science organization, meeting societal needs for impartial evidence on the state and sustainable use of our seas and oceans". Based on this vision, ICES defines its mission as advancing and sharing scientific understanding of marine ecosystems and the services they provide, and using this knowledge to generate state-of-the-art advice for meeting conservation, management, and sustainability goals. This has led ICES to broaden its scientific priorities (ICES, 2019: Strategic Plan, pp. 18–19, https://issuu.com/icesdk/docs/ices_stategic_plan_2019_web), which now include elucidating the present and future states of not only natural but also social systems, placing the understanding of human behaviour, incentives, and values as central to the work of the organization.

These priorities have led to a move towards the broadening of the science-base of ICES to fully include social sciences, and to discussions on how to expand upon the conventional information basis largely centred on biological/ecological information to more explicit consideration of the social and economic dimensions associated with policy development and management choices. This inclusion of a marine socio-ecological systems perspective (Link *et al.*, 2017) has led to new initiatives within ICES, including the Strategic Initiative on Human Dimensions (SIHD: https://www.ices.dk/community/groups/Pages/SIHD.aspx) and the initiation of new working groups, including the Working Group on Economics (WGECON). These efforts have been undertaken to promote progress in the integration of economics into ICES science and advice. As one of its first tasks, WGECON (see https://www.ices.dk/community/groups/Pages/WGECON.aspx) set out to review the status and progress made in applying fisheries economics in ICES marine areas to policy topics and research of relevance to fisheries managers.

This article presents the results of this review. Through examination of a selection of key topics of current ICES and global relevance to fisheries science and policy, we illustrate how economic research can provide an improved understanding of the ways in which fisheries develop and respond to change and of the trade-offs associated with alternative scenarios and management strategies. As such, the article addresses the question of how contributions from economic research can be incorporated into the scientific advice of an organization such as ICES, eventually contributing to informing policy development and management decision-making for sustainable uses of living marine resources.

Section 2 presents the review approach, based on consultation with experts in the field and a systematic process of synthesizing and reviewing the state of the art in applied fisheries economics research. Section 3 presents a synthesis of the extent to which existing research is currently used in supporting fisheries policy. We show that a strong body of applied fisheries economics research exists, covering a broad range of topics at the core of fisheries management, but that only some of this work is incorporated in the advice supporting policy implementation. Section 4 identifies the potential for further developments of direct relevance to the science supporting management advice internationally. We conclude by highlighting the key steps that can be taken to support a stronger integration of economics into fisheries science and advice.

Review approach

The review relied mainly on expert assessment drawn from the expertise of WGECON, a group composed of >50 economists and fisheries experts from 16 countries, including European and North American researchers specializing in marine living resource economics. The group met annually from 2018 to 2020 and established an initial list of 12 key contemporaneous commercial fishery management topics central to economic research and analyses that were perceived to be of high relevance to ICES scientific and advisory work.

For each of these topics, the members of the group reviewed both current and future research priorities. The group first considered the research currently conducted and advice provided as part of ICES work and more broadly in fisheries management, including the economic issues relating to the topic that economists have examined, the evaluation methods and tools available, as well as the data available and indicators used. Next, the group assessed key future needs for research and integration into ICES science, including issues and questions that could be documented, evaluation methods and tools that should be developed, data and indicators that needed to be made available, and the associated information flow from research to policy support.

The information collected from group members was first compiled in shorthand format for each topic. Based on these synthetic reports, sub-groups, typically consisting of two moderators and two reviewers, developed revised and elaborated report texts and summary sheets for each topic (see Supplementary Material Section B). The reports and summary sheets were systematically reviewed by at least two other members of the group, leading to revised summary sheets and report text. A final round of revisions was carried out during a final meeting where both moderators and reviewers participated in the process, leading to the material presented in this article.

The identified topics were classified into two broad categories (Table 1). The first category was commercial fisheries management topics, on which ICES science and advice are well established in disciplines other than economics. These topics were ordered from the older, standard topics to the more recent and complex ones. The second category was topics the group perceived to be important to consider for sustainable fisheries yet not commonly included in the standard science supporting advice. These topics were ranked by increasing level of complexity. Table 1 summarizes the topics in both categories and the key research questions addressed under each.

The connections between these different topics were repeatedly and extensively discussed by the group, highlighting the importance of bringing the different topics under each category into integrated approaches in order to inform fisheries management. Figure 1 summarizes the 12 topics considered in the review and illustrates the interconnectedness between them, which is also reflected in the key findings section hereafter.

To complement the work of the expert group, an international survey among fisheries economists was carried out in collaboration with the European Association of Fisheries Economists (EAFE) during 2019. Members of the North American Association of Fisheries Economists (NAAFE) were also invited to respond. The aim of the survey was to evaluate whether the key topics identified by the WGECON experts were indeed representative of the core contributions that fisheries economics can provide to support management advice, and to identify any other topics that should also be included. Survey respondents were asked about key fishery economic topics and were asked to rank the relative importance of each of these topics in terms of research and management advice. The survey was conducted through an online form that was circulated to the EAFE and NAAFE mailing lists. To increase the response rate and discuss preliminary results, a

Table 1. Topics considered in the review.

Topic number	Topic name	Key questions addressed
Well established science and advice topics within ICES to which economics can contribute		
I	TAC setting in output-based management systems	➢ What are the economic implications of alternative TACs? Which TACs enable achieving particular management objectives?
II	Mixed species fisheries management	➢ What are the key economic processes and economic consequences associated with technical interactions in fisheries? How can management measures address these?
III	Area-based and spatial management	➢ What are the economic processes driving the response of fishing fleets to spatially defined management measures, and how does this influence the impacts of these measures?
IV	Adjustment of capacity to resource potential	➢ What is the level of fishing capacity in fisheries, how does it evolve, and how can management strategies assist in aligning capacity to fishing possibilities?
V	Data limited situations (fleets, fish stocks)	➢ How can economic analyses in support of fisheries management be adapted to data-limited situations for both fleets and stocks?
VI	Shared stocks management	➢ How do strategic interactions over the harvesting of shared fish stocks affect the likelihood of developing management agreements, and their effectiveness?
Less established science and advice topics within ICES to which economics can contribute		
VII	Fishing rights allocation	➢ How do access regulations and allocation of fishing rights affect the incentives of fishers and the effectiveness of management measures?
VIII	Sustainability of small-scale fisheries (SSF)	➢ What are the economic specificities of small-scale fishing fleets, and how can these best be incorporated in the evaluation of trade-offs associated with the management of their activities?
IX	Links between catch sector and markets for fish	➢ What is the interplay of seafood markets and the catch sector, and how can these relationships be considered in management advice?
X	Diversification of commercial fishing	➢ What are the economic diversification strategies encountered in fisheries, and how do they affect incentives and responses to management?
XI	Fisheries-aquaculture connections	➢ What are the key market and non-market interactions between aquaculture and fisheries, and how can they be integrated in fisheries management?
XII	Valuation of ecosystem services	➢ How can changes in ecosystem services associated with fisheries and their impacts on marine ecosystems be included in the science supporting ecosystem-based fisheries management?

specific session was organized during the 2019 EAFE Conference in Santiago de Compostela, Spain. Additionally, a presentation of WGECON and the survey were given during the 2019 NAAFE Forum in Halifax, Canada. Additional paper questionnaires were also administered to survey participants during the two conferences.

In total, 36 responses to the survey were collected through fisheries economics networks. Responses confirmed the list of 12 topics but also identified the major additional, cross-cutting theme of climate change impacts that is mobilizing increasing research attention in the profession (other emerging topics such as pollution, regionalization of management, and coastal community studies were mentioned as important topics for future work). Because of its cross-cutting nature, this was not included as a separate topic in the review but rather considered in terms of how research on the 12 topics might assist in addressing the issues arising from climate-related impacts on ecosystems and the economy.

Key findings

The results of the review for the 12 key topics are summarized in this section, highlighting the advances in applied fisheries economic research that are relevant to ICES work. Table 2 provides a qualitative overview of the assessment by WGECON of the degree to which research on these topics has advanced to a stage where the key issues relating to each topic are being addressed, both in research as well as in management advice. This assessment includes the methods, tools, data, and indicators that have been developed and are being used in formal advisory processes at national and/or international levels. In what follows, we provide the main arguments for these assessments for each of the 12 topics, as well as selected key references to the relevant state-of-the-art literature in fisheries economics. For more detailed assessment information and additional references to literature published outside the economics journals on each topic, the reader is referred to Section A of the Supplementary Material.

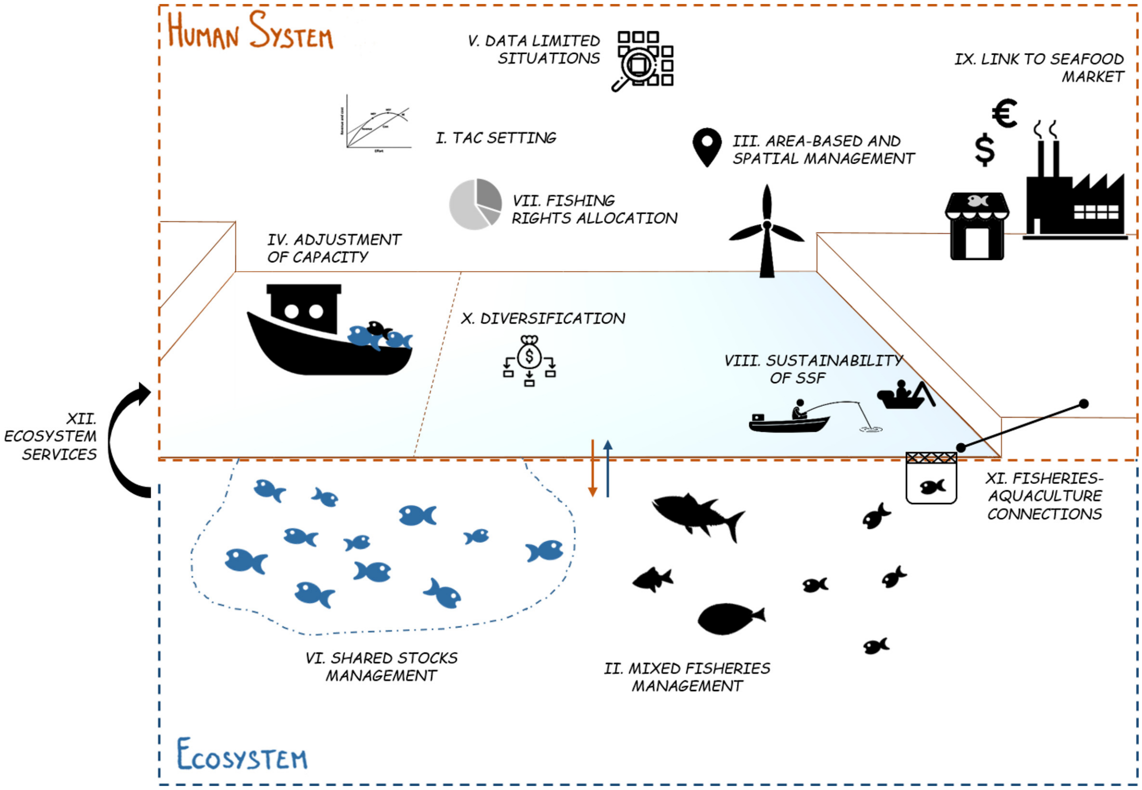

Figure 1. Graphical representation of the topics for science and advice considered in the review. See Table 1 for the identification of questions addressed under each of the topics illustrated.

Table 2. Progress in the availability and use in advice of work on issues, methods, and tools, and data and indicators for each topic, within and outside ICES.

		Issues		Evaluation methods & tools		Data & Indicators	
Topic number	Topic Name	ICES	Outside ICES	ICES	Outside ICES	ICES	Outside ICES
I	TAC setting in output-based management systems	Dark green	Dark green	Medium green	Dark green	Medium green	Dark green
II	Mixed species fisheries management	Dark green	Dark green	Medium green	Dark green	Medium green	Dark green
III	Area-based and spatial management	Dark green	Dark green	Medium green	Medium green	Light green	Light green
IV	Adjustment of capacity to resource potential	Dark green	Dark green	Medium green	Medium green	Medium green	Medium green
V	Data limited situations (fleets, fish stocks)	Dark green	Dark green	Light green	Dark green	Light green	Dark green
VI	Shared stocks management	Dark green	Dark green	Light green	Light green	Light green	Light green
VII	Fishing rights allocation	Dark green	Dark green	Medium green	Medium green	Light green	Light green
VIII	Sustainability of Small-scale fisheries (SSF)	Medium green	Medium green	Light green	Light green	Light green	Light green
IX	Links between catch sector and markets for fish	Medium green	Medium green	Medium green	Medium green	Light green	Light green
X	Diversification of commercial fishing	Light green	Light green	Light green	Light green	Light green	Light green
XI	Fisheries-aquaculture connections	Light green	Light green	Light green	Light green	Light green	Light green
XII	Valuation of ecosystem services	Light green	Light green	Light green	Light green	Light green	Light green

Colour scale indicates the extent to which the research is available and used/applied in the science supporting the advice, according to the views of the expert group. Dark green: used/applied; Medium green: fully available; light green: only partially available. "Within ICES" refers to research that is being conducted within ICES member countries. "Outside ICES" refers to research that is being conducted in countries outside ICES.

Category I: well-established science and advice topics in ICES

Topic I: TAC setting in output-based management systems

Early fisheries economics research largely centred on redirecting attention from the strictly biological focus of fisheries science to consideration of issues such as wealth dissipation, fleet misallocation, or the low income of fishers (Scott, 1989). Efforts thus focused on extending the biological production function and its response to alternative regulatory regimes (Clark and Munro, 1975; Clark, 1980; Scott, 1989). At the same time, output controls such as TAC limits were becoming a common instrument to help sustain fisheries harvests internationally, with strong developments in the science of population dynamics. Earlier economic work studied how TACs can interact with fleet incentives to result in overcapacity and reduced economic returns (Homans and Wilen, 1997). With the growing availability of economic data on fishing activities, a range of applied bio-economic models were developed and are being used to inform management. However, with some notable exceptions (Dichmont *et al.*, 2010; Pascoe *et al.*, 2016), these models have mainly focused on impact assessments, evaluating the economic consequences of alternative TACs set based on biological objectives, either achieving maximum sustainable yield or avoiding unwanted biological outcomes of fishing (see Supplementary Material for references to the large body of literature that has developed in this field in the ICES context). In parallel, significant steps have been made in the bio-economic modelling literature to build directly on the biological models routinely used to inform TAC setting, in particular age- or size-structured models of fish population dynamics (Pascoe and Mardle, 2001; Tahvonen, 2009; Macher *et al.*, 2018; Tahvonen *et al.*, 2018). Given that they largely capture the key dimensions considered in identifying fishing mortality targets in fisheries management advice, we argue that these models can be directly used to examine strategies that consider economic objectives, including MEY (Grafton *et al.*, 2010). With the increased availability of economic data on fishing fleets across ICES regions, these models constitute a strong set of tools for addressing many of the research questions identified under the different topics that follow.

Topic II: mixed species fisheries management

Models have been applied to the question of managing so-called mixed fisheries, where fleets targeting mixes of species interact through differing levels of contributions to the mortality of given fish stocks in given areas and seasons while also differing in their levels of economic dependency on these stocks (Holland and Sutinen, 2000). This has led to further empirical analysis of the structure of profit functions in fisheries and to a better understanding of observed industry structures and their evolution over time (Squires, 1988; Weninger, 2001). Research has also focused on aggregate fishery-level production relationships to determine the economic importance of bycatch species in a fishery and optimal bycatch rules (Larson *et al.*, 1998). Economic models of bycatch have included incentives that may exist in multi-species fisheries for fishermen to modify their fishing strategies (Birkenbach *et al.*, 2020), as well as responses to TAC and quota allocation decisions for target and bycatch species (Marchal *et al.*, 2011; Holzer and DePiper, 2019). A broad range of simulation methods have been developed for evaluating the sustainability and distributional effects of management strategies pursuing biological targets such as single stock MSY (and associated ranges) or multi-species MSY, as well as economic targets such as single- and multi-fleet MEY and/or social targets such as employment (Voss *et al.*, 2014; Ulrich *et al.*, 2016; Nielsen *et al.*, 2018a). Multi-criteria assessment methods, such as viable control, have been developed to evaluate strategies satisfying a set of ecological, social, and economic constraints (Gourguet *et al.*, 2013; Doyen *et al.*, 2017; Briton *et al.*, 2020). Recent modelling efforts make use of the latest biological and economic knowledge to examine the benefits of strategies aimed at economic multispecies management objectives as well as dealing with variability and uncertainty (Lagarde *et al.*, 2018; Voss *et al.*, 2021). However, while these methods and tools are widely available and have been used to support management in other parts of the world, to date they have not generally been used in management advice at ICES.

Topic III: area-based and spatial management

As the importance of spatial structure in the distribution of fish populations and the need to account for this in designing spatially explicit management measures has become increasingly acknowledged, so has research focused on describing, explaining, and predicting the spatial allocation of fishing activities and their interactions with the spatial dynamics of fish resources (Eales and Wilen, 1986; Sanchirico and Wilen, 1999; Holland and Sutinen, 2000; Smith, 2000; Smith *et al.*, 2009; Dépalle *et al.*, 2021). The analyses have particularly been used to examine the potential bio-economic consequences of spatial management measures such as closed areas and marine protected areas (Hannesson, 1998), with more recent work highlighting the importance of considering economic behaviour in examining the potential benefits of such measures (Smith and Wilen, 2003; Haynie and Layton, 2010; Albers *et al.*, 2020).

In the context of ICES, recent *ad hoc* initiatives have examined balancing spatially resolved environmental and fisheries economics considerations; an example being the risks of habitat degradation and protective measures adopted as part of deep-sea access regulations. However, to date, ICES has not implemented any advice that incorporates economic or social considerations into spatial fisheries management. This contrasts with other regions where studies of the economic consequences of spatial management have been conducted and are being considered by advisory bodies (Bisack and Sutinen, 2006; Abbott and Haynie, 2012).

Topic IV: adjustment of capacity to resource potential

Rights-based fishery management approaches aimed at removing the race-to-fish incentives due to the common-pool nature of marine fish stocks should eliminate the need to manage fishing capacity (Homans and Wilen, 1997). However, the pervasiveness of policies focused on biological and social considerations has led to a need for capacity management and the development of research to support this endeavour (Pascoe, 2007a). Economists have particularly focused on the short-term measurement of fishing capacity using output-based measures of observed production given the technical characteristics of fishing fleets and prevailing conditions in the fishery (Kirkley *et al.*, 2002). While robust methods are now available to carry out such measurements, their use to date to inform policy has remained limited. Instead, input-based definitions of fishing capacity have been predominantly used as part of multi-criteria evaluation approaches such as the EU capacity balance indicator guidelines. These guidelines require an annual evaluation of several bio-economic indicators of excess capacity of EU fleets (https://stecf.jrc.ec.europa.eu/reports/balance), leading to mandatory national plans to address excess capacity. Concurrently, public buyback programmes have often been seen as a preferred capacity reduction instrument, as they are voluntary and compensate industry members for capacity reductions (Pascoe, 2007a). This has led to a large body of work investigating the outcomes of alternative designs for such programmes (Campbell, 1989; Weninger and McConnell, 2000; OECD, 2009; Holzer *et al.*, 2017). Factors influencing capacity, such as capital investment (including fishing rights) ownership (Nostbakken *et al.*, 2011), entry and exit dynamics of fishing capacity in fisheries (Tidd *et al.*, 2011), or technical progress in fisheries (Squires, 1992), have been extensively considered. Underlying these endeavours is research into the implications of governmental support policies for the fishing sector on capacity, fish stocks, and fisher welfare (Clark *et al.*, 2005; Martini and Innes, 2018; Smith, 2019). The impacts on capacity of incentive-based approaches to regulating access to fisheries resources have also rapidly developed (see Topic VII below). Finally, the alternative approach of using bio-economic models to help identify long-term target capacity levels, both in input and output terms, has also made strong advances (see Topics I and II above). The extent to which these different lines of research and sets of analytical tools can effectively inform fisheries policy and management in the ICES area, however, remains limited.

Topic V: data-limited situations

For several species, stocks, fleets, and fisheries, a lack of data limits the ability to develop appropriate fisheries management advice on matters such as limitations on levels of total catch in single or multi-species fisheries, the spatial and seasonal management of fishing, or the designation of spatial restrictions on fishing. With the growing literature on applied economic analyses of fisheries, there has been increasing acknowledgement of the information limitations and uncertainty that need to be explicitly considered in developing tools that can effectively support policy. This led to an early recognition that, even under economic, biological, and implementation uncertainty, an understanding of the likely responses of fishers to regulations could provide useful information, alongside efforts to develop more complete bio-economic approaches (Bockstael and Opaluch, 1983). Related research has considered the implications of uncertainty for the determination of optimal management strategies (Andersen, 1982; Charles and Munro, 1985; Sethi *et al.*, 2005; Gourguet *et al.*, 2014; Tromeur *et al.*, 2021). Studies have also focused on methods to enable economic analyses while explicitly accounting for the limited information available (Pascoe, 2007b; Sanchirico *et al.*, 2008; Pascoe *et al.*, 2014; Gacutan *et al.*, 2019). For user groups such as small-scale and recreational fishing activities, data limitations tend to be particularly acute. A growing body of economic research has been devoted to providing a better understanding of these sectors (Zeller *et al.*, 2006; Schuhbauer and Sumaila, 2016; Abbott *et al.*, 2022).

Topic VI: shared stocks management

A further extension of fisheries economics has dealt with the added complexity associated with managing fisheries that are shared by several states, with potentially conflicting management strategies due to diverging incentives for fish stock preservation, fishing effort costs, or consumer preferences (Munro, 1979). Building on game theory, approaches to eliciting the likely outcomes of international fisheries management have been proposed (Bailey *et al.*, 2010; Hannesson, 2011; Costello and Molina, 2021), with a growing number of empirical applications. Empirical analysis has also shown that the status of fisheries dependent on shared stocks is generally poorer than that of fisheries under single jurisdictions (McWhinnie, 2009). Despite the insights economic research provides into the determinants of international fisheries management, this research has remained largely academic with few actual applications to policy.

Category II: less-established science and advice topics in ICES

Topic VII: fishing rights allocation

Fishing rights, in particular quota allocation, are a key foundation of many fisheries and their management in ICES member countries. In many ways, rights-based management represents the interplay between traditional ICES biological advice and how management bodies implement that advice. Economics can play a key role in helping understand this interplay, especially in relation to the political economy of converting scientific advice into fishing opportunities (Bellanger *et al.*, 2016). Fisheries economic research on fishing rights has focused on both conceptual (Arnason, 1990; Boyce, 2004; Costello and Deacon, 2007) and empirical applications examining the rationalization of commercial fisheries using ITQs (Dupont *et al.*, 2002; Weninger and Waters, 2003; Grainger and Costello, 2016; Birkenbach *et al.*, 2017). Economic research has in fact investigated a broad range of rights-based management approaches (Shotton, 2001; Costello and Kaffine, 2008; Thébaud *et al.*, 2012), including territorial use rights (Wilen *et al.*, 2012). Further extensions of fishing rights research have included allocation between commercial and recreational fisheries in the presence of incompletely defined rights (Holzer and McConnell, 2014) and defining temporal fishing allocations taking into account the finer spatial and temporal scales at which the race to fish may occur (Huang and Smith, 2014). Despite this strong scientific expertise and active research efforts, which are being undertaken in ICES countries on the processes by which fishing rights are allocated among individual fishers, economic analysis of the biological, economic, and social impacts of fishing rights has typically not been included in the research undertaken by ICES or in the advice it produces.

Topic VIII: sustainability of small-scale fisheries (SSF)

With the global quest for sustainable fisheries, international interest has developed regarding the economic, social, and ecological impacts of small-scale fisheries. The reasons for this interest are manifold. First, while a large fraction of the fisheries management research has historically focused on large-scale fishing activities, relatively less attention has been granted to SSF, despite the fact that these have been shown to represent significant sources of food and employment, as well as important cultural services, in many regions of the world (Zeller *et al.*, 2006; Schuhbauer and Sumaila, 2016). Second, the observed impacts of fisheries management regimes on rural and remote coastal communities that depend on fisheries have also raised growing concerns (Copes and Charles, 2004; Sutherland and Edwards, 2022). Third, SSF tend to operate in areas in high demand for other sectors (e.g. recreational activities, aquaculture, renewable energy, coastal development), which often leads to spatial conflicts. Fourth, a branch of research has developed that emphasizes the potential role of institutional regimes that may help address the common-pool resource problem (Schlager and Ostrom, 1992; Copes and

Charles, 2004). To date, research on the economics of SSF and their management has centred on gaining an understanding of their economic, social, and biological dimensions, as well as their interactions with other activities. Key interactions of interest include other industrial fishing fleets harvesting the same stocks, recreational fisheries pursuing the same stocks or operating on the same grounds, as well as other competing sectors. This line of research has led to an increase in the knowledge base as well as the quantity and quality of SSF data available, even extending to the cultural ecosystem services associated with these fisheries (Ropars-Collet *et al*., 2017; Andersson *et al*., 2021). However, this information has only recently begun to be considered in the work of some ICES working groups, with a focus on the presentation of information on these fisheries and the communities that depend on them in integrated assessments.

Topic IX: links between the catch sector and markets for fish

An important focus of fisheries economics has been concerned with markets for fish. Research has particularly centred on issues such as the expected long-term drop in fish production of open access fisheries with resulting increased prices of fish (Copes, 1970), and on the importance of taking into account the consequences of fisheries management on consumer and producer welfare (Hanemann and Strand, 1993; Lee and Thunberg, 2013; Costello *et al*., 2020). Economic research on market price effects has included the relationship between complementary or substitute species in the markets for fish products (Gordon *et al*., 1993), as well as the influence of price differences on choices of markets and product forms (Asche and Hannesson, 2002). The economic implications of interactions between ex-vessel prices and increasing levels of processing sector concentration (Clark and Munro, 1980) have also been studied. In addition, over the last 20 years, economic studies have considered consumers' preferences for fisheries certification and willingness to pay for ecolabelled seafood (Blomquist *et al*., 2015; Fonner and Sylvia, 2015; Ankamah-Yeboah *et al*., 2020), as well as the effects these consumer-driven schemes have on production systems and/or fishers' behaviour (Roheim *et al*., 2018). However, despite the key role of market processes in understanding the economic responses of fisheries systems to management, this research is not commonly considered in fisheries management advice internationally.

Topic X: diversification of commercial fishing

Two economic drivers for diversification of a firm are lower production costs by diversifying to similar products (economies of scope; Panzar and Willig, 1981) and to reduce risk by focusing on multiple products with unrelated risk profiles in line with modern portfolio theory (Markowitz, 1952). In fisheries, this may involve multiple fishing operations (Bockstael and Opaluch, 1983), such as using multiple gears to target different species (Kasperski and Holland, 2013), as well as expanding the range of activities to other sectors, such as tourism or processing (Nostbakken *et al*., 2011). Diversification has implications for fisheries management since it alters the incentives driving fishing choices or strategies, depending on the opportunity costs of fishing (i.e. earnings in alternative activities). For example, fishers might increase engagement in a specific fishery during periods with low earnings in other fisheries. The regulation of diversified fisheries can also be examined from the perspective of risk management strategies (Sanchirico *et al*., 2008; Gourguet *et al*., 2014). Economic research has used a wide range of mathematical and statistical methods to examine diversification strategies, their impacts on incentives, and the implications for fisheries management (see, e.g. Huang and Smith, 2014; Holland *et al*., 2017). This has been possible due to the availability of data for within-fisheries analyses, regarding, e.g. fishing effort, gear use, catch composition, fish prices, and operating costs. Less analysis of diversification outside the fishing sector has been possible due to the more limited availability of data regarding alternative activities to fishing. To date, despite its importance in understanding the responses of fisheries to management, this research is not regularly incorporated into fisheries management advice internationally.

Topic XI: fisheries-aquaculture connections

The analysis of interactions between wild-capture fisheries and aquaculture has also attracted research interest with respect to the ways in which the development of aquaculture may affect the status of fisheries, both conceptually (Anderson, 1985) and empirically (Asche *et al*., 2001). Control over the biological process and technical development (Anderson, 2002; Asche, 2008) have led to tremendous growth in the productivity of the aquaculture industry, improving its competitiveness relative to wild fisheries (Nielsen *et al*., 2021), for input factors (Ankamah-Yeboah *et al*., 2021), and in the supply chain (Asche and Smith, 2018). Fisheries and aquaculture compete in the same global markets with common price determination processes (Anderson *et al*., 2018); consequently, fishers and fish farmers influence each other's incentives and strategies (Valderrama and Anderson, 2010). Furthermore, the sectors compete for space, and there are biological interactions in the form of genetic contamination, disease, and environmental externalities (Asche *et al*., 2022), which lead to novel management issues (Nielsen, 2012). Additional interactions relate to the fishing sector providing raw materials for aquaculture in the form of feed and seeds for capture-based aquaculture (Naylor *et al*., 2000; Tveterås and Tveterås, 2010). Notably, while research on the social and economic dimensions of aquaculture has steadily developed over the past two decades, leading to the formation of ICES working groups (https://www.ices.dk/community/groups/Pages/WGSEDA.aspx), this work has not yet specifically considered the economic interactions between fisheries and aquaculture.

Topic XII: valuation of ecosystem services

With growing concern for the scale of human impacts on the biosphere, interest has developed in combining ecology and economics to understand the interactions between ecosystems and human systems giving rise to ES (Polasky and Segerson, 2009). Identifying and quantifying the market and non-market services supported by ecosystems that contribute to human well-being has indeed been the focus of growing research efforts over the last 50 years, including in the marine realm (Smith, 1993; Costanza *et al*., 1997; Boyd and Banzhaf, 2007; Bateman *et al*., 2011; Barbier, 2012; Pendleton *et al*., 2016). In this literature, commercial fisheries have been considered both a provider of provisioning and cultural ecosystem services and a sector that may impact other supporting and regulating services provided by marine ecosystems.

Economic assessment of ES is usually applied in the context of ecosystem-based approaches to fisheries management (EBFM) and in support of the management of competing interests in the exploitation of marine resources. Approaches range from the measurement of the economic contribution of ecosystem functions and services through applied natural capital accounting to the integration of biological processes and functions into economic models to examine the consequences of alternative development and management patterns for fisheries. While wide-ranging internationally, comparable datasets of the monetary or non-monetary value of ES across countries do not currently exist, but initiatives to progress these data are under way as part of broader initiatives to establish reporting standards on the blue economy (Jolliffe *et al*., 2021). Research on the understanding and valuation of ecosystem services is currently being pursued in several ICES working groups. However, to date, this work has not been incorporated into the fisheries science and advice of the organization.

Discussion: future perspectives

Our review conveys that a large body of applied fisheries economics research has developed, especially over the past three decades, which provides information of direct relevance to various dimensions of fisheries management advice. Beyond this assessment of existing research in applied fisheries economics, the group also identified the potential for further developments of direct relevance to the science supporting management advice internationally. These are discussed below, keeping to the list of key topics that structured the review but reorganizing them into three key areas for future research and emphasizing their relevance to future developments in ICES work. These key areas are the provision of ecological-economic advice, assisting with the identification of fishing capacity targets and capacity adjustment strategies, and informing policy in relation to key interactions determining the responses of fisheries systems to management.

Providing ecological-economic advice

Models and data are now largely available to evaluate the socio-economic impacts of TAC setting by taking into account the possibilities for fishers to adjust to TAC constraints through changes in fishing strategies and fishing capacities at producer, industry, or country levels. Such an impact assessment can also address effects on markets (e.g. price responses to changed landings), uncertainties in the management system (e.g. the use of precautionary buffers), or issues of compliance. In addition to these impact assessments, we believe that existing models and data could be used to carry out ex-ante evaluations of TAC strategies to achieve bio-economic objectives such as MEY in single species fisheries, as is already routinely the case in Australia (Pascoe *et al*., 2016). These assessments can also incorporate social goals associated with alternative management options, as has been demonstrated in applied coviability analyses (Briton *et al*., 2020).

Extending such analyses to the optimization of mixed-fisheries systems could also provide a broader perspective on the fishery-wide benefits associated with TAC strategies that may involve reducing single-species TACs below what would generate maximum single-species returns or yields. Standardized data, robust and validated economic methods, and integrated models allowing for the study of critical problems in mixed fisheries are available to evaluate mixed fisheries management options (Nielsen *et al*., 2018a). However, methods to track and assess the dynamic interactions that occur in mixed fisheries in response to management interventions require more research. Assessing the full impacts of mixed-fisheries management strategies requires better capturing fisher behaviour regarding the choices of gear, effort levels, and allocation of effort between areas and seasons (Hutton *et al*., 2004; Dépalle *et al*., 2021), as well as other vessel adaptations and resulting changes in fishing efficiency (van Putten *et al*., 2012). Ex-post evaluations of management measures can also be used to complement ex-ante approaches and test realized outcomes against ex-ante predictions, thus helping better understand the actual industry responses to economic incentives and alternative regulatory obligations. This could inform the evaluation of alternative approaches to distributing catch across stocks and years as part of long-term management plans seeking to address issues of bycatch and discards (such as under the landing obligation in the EU). Developing methods and tools enabling stakeholder engagement in such evaluations (see, e.g. Macher *et al*., 2018) is also likely to strengthen the uptake of evaluation results as part of adaptive management decision-making processes.

Support for the development, maintenance, and uptake of models and data seems essential to progress in this area of bio-economic advice. Standardized data collection protocols are required regarding fishing effort and landings, as well as economic data, using common dimensions regarding key fishery, fleet, and vessel characteristics. In general, the availability of information at the individual-vessel level will be preferable, as this allows data to be aggregated at any scale required. Indeed, individual-based models have been increasingly developed and applied in mixed fisheries management advice (Nielsen *et al*., 2018a), although this demands complex and very data demanding methods.

Contributing to the development of approaches to deal with data-limited situations

While bio-economic models have been developed and applied to a range of fisheries around the world, it seems unrealistic to expect that the data-rich approach of developing full analytical models for the many data-poor fish stocks will ever be possible (indeed, the cost of data collection and model development to achieve this may exceed the additional value derived from the information produced by these models). Hence, there is a need to explore new approaches that can both capture the total economic activity of the fleets (i.e. include information relating to the revenues and costs associated with the catch of all stocks) and link this to the best available understanding of the biological status of the stocks. Fisheries biologists have developed a range of data-poor methods for fisheries assessments, based on the life history characteristics of the fish caught or on catch and effort data. Similar approaches can be carried out with respect to bio-economic assessments, and initial efforts have shown that limited information on the revenues and costs associated with fishing may be used to identify reference points for the management of fisheries that take into account economic objectives (Pascoe *et al*., 2014). With these first results in mind, economists could contribute to the efforts devoted to addressing data-limited fisheries assessments, which usually start with a meta-analysis aimed at integrating the knowledge from existing reports and data sets that may help decrease the uncertainty arising from limited data. Such knowledge can also be used to set priors in Bayesian statistical approaches, allowing to carry out value-of-information analysis and identifying the variables having an impact on the ranking of decision options and thus needing to be estimated more precisely. Further uncertainties due to data-limited situations can be described using risk assessment frameworks such as the pedigree matrix or probability-based harvest control rules (Goti-Aralucea, 2019). Lastly, research is also needed on how to deal with and effectively communicate uncertainty and stochasticity in assessments and advice, both in fisheries economics and in the broader field of fisheries science.

Analysing trade-offs associated with area-based and spatial management

Spatially resolved economic analysis of fisheries focuses on associating fishing stakeholders at the vessel, fleet, and community levels to chosen fishing areas and quantifying the importance of these areas in terms of catch rates and profitability. Based on behavioural change scenarios, the economic consequences of spatial restrictions on fishing on the re-allocation of effort in space and time and to métiers can be estimated (Blau and Green, 2015). Such preliminary analyses provide the economic information needed for trade-off analyses as well as reducing the potential for surprises in the outcomes (Wilen *et al.*, 2002). Research in ICES could incorporate existing models to assess the past performance of spatial management to project possible paths for alternative futures, as well as the fleets likely to be impacted by a proposal. This would enable impact assessment of changes in fishing pressure on the biological and ecosystem components with effects propagating to the economics of the fishery. While ICES hosts many data sets that could help condition such impact assessment models, a major obstacle would still be the limited data collection or resolution of data collected on certain variables (e.g. catch), which currently does not fit the spatial and time resolutions that matter to stakeholders and policymakers.

Increasingly, the above spatial fisheries management considerations need to be cast in the context of broader marine spatial planning aimed at allocating ocean space from an ecosystem-based management perspective (Katsanevakis *et al.*, 2011). This includes both conflicts between fisheries and other maritime activities and the potential for co-locating activities. The benefits of co-locating uses such as wind farms with fisheries have begun to be investigated (Stelzenmüller *et al.*, 2021), but very few practical examples exist. More scientific effort should be put into elucidating the possible ecological-economic effects of reserving space to windfarms, from local to overall effects on marine biodiversity and fishing opportunities (e.g. Bastardie *et al.*, 2014). While relative economic returns have only rarely been considered before introducing spatial management measures, integrating measures of economic benefits into existing ecological models would allow assessment of how these benefits may be distributed across ICES regions and among beneficiaries such as local communities, the tourism sector, or different fishing vessels. Such assessments should consider whether compensation should be considered in the course of implementing the measures as well as the timespan over which the benefits accrue and uncertainty regarding the outcomes of the spatial measures (e.g. including climate change effects). Such integrated understanding could provide new knowledge on hotly debated topics to inform policymakers' decisions. Examples of this could include case studies documenting the possible fishing effort displacement in response to the implementation of conservation areas (e.g. in the EU, Natura 2000 designated areas) that might require costly short-run adaptation of fishing strategies balanced with possible long-term benefits from improved productivity of the exploited ecosystem (e.g. Bastardie *et al.*, 2020). Another example would be the evaluation of large-scale exclusion scenarios such as those associated with "Brexit" that would lead to excluding the EU fleet from the UK Economic Exclusive Zone (Dépalle *et al.*, 2020).

Identifying operational fleet capacity targets and capacity adjustment strategies

Having clearly stated long-term objectives that can guide the definition of operational targets in developing fisheries management measures is a necessary requirement for achieving sustainable fisheries. For example, the EU's CFP aims to ensure the exploitation of living marine resources in sustainable economic, environmental, and social conditions by achieving MSY. Efforts to translate this overall objective into operational targets for fishing capacity and to design alternative approaches to achieving such targets could benefit from the accumulated knowledge we find on this issue in the fisheries economics literature. As an intergovernmental organization that brings together broad knowledge from its 20 member countries across the Atlantic, ICES is well suited to provide guidance regarding the approaches and methods that may be best applied to manage fishing capacity in local circumstances.

Development of guidance could include assessing whether the long-standing "balance" indicators in the EU (https://stecf.jrc.ec.europa.eu/reports/balance) adequately address the challenges of adjusting fishing capacity to the production potential of fish stocks. These short-term assessments could be complemented with long-term analyses to help identify economically optimal objectives for fleet structure. Beyond EU countries, a similar assessment of the extent to which policy objectives strike a balance between fishing capacity and fishing opportunities would appear relevant across ICES countries.

Further advice could be provided through overviews of the role factors such as subsidies, nominal limitations on gross tonnage caps, market-based measures, or other factors play in influencing fishing capacity in each country. Additional insights could be gained from comparisons of national action plans for fleet capacity adjustments and assessments of alternative capacity adjustment approaches.

Informing the allocation of fishing rights: key issues and best-practice evaluation methods

In addition to informing capacity management, much more economic insights could be provided regarding the difficult but unavoidable question of how to allocate fishing possibilities to reduce the race-to-fish incentives driving the development of excess capacity. Involving ICES in the coordination of research efforts across its member countries to improve understanding of the alternative allocation approaches and their consequences in terms of management, equity, and sustainability objectives would seem particularly relevant. Such coordinated research efforts would enable providing independent guidelines that could be made available to a broad range of stakeholders within ICES countries on design considerations in fishing rights allocation. Such guidelines could include: (i) structured approaches to the key economic questions to consider; (ii) empirically tested methods and tools to address these questions, and (iii) key data sets and indicators required for the analyses of alternative designs of the allocation of fishing possibilities. A review of national administrative databases holding either quota, fishing rights, swaps, or actual fishing activity data to help build up an evidence base of how rights are effectively distributed could also be undertaken. Methods could then be developed to relate this evidence base to performance measures under alternative management approaches.

Accounting for SFF in sustainability assessments

In determining operational sustainability targets and examining trade-offs associated with alternative management strategies, it is important to account for the ecological impacts, cultural values, and economic significance of SSF. Having a better understanding of the structure of SSF and of their importance to household income alongside that from other sources would enable more comprehensive assessment of the economic consequences of fisheries management on coastal communities (Bueno and Basurto, 2009; Colburn *et al.*, 2016). Studying the synergies and competition between SSF and large-scale fishing along the supply chain would also help improve our understanding of the linkages between fisheries management, markets, and welfare effects.

While a harmonized definition of SSF might seem useful to establish, a "one size fits all" definition of SSF may not be suitable for local management purposes (García-Flórez *et al.*, 2014; Rousseau *et al.*, 2019; Smith and Basurto, 2019). Additionally, research is needed to set boundaries between recreational fishing and SSF. Current definitions may not adequately capture the socio-economic differences between these sectors, such as motivation for fishing. Hence, more research is needed to find the balance between a general definition of support fisheries management advice and the incorporation of the specific characteristics of local SSF.

Meeting these research needs has been hampered by important data gaps. Filling these gaps requires improvements in the information collected (e.g. the distribution of activities within fishing communities, ownership of fishing rights, and income from fishing and other businesses) and the accuracy of data collected by national and international data collection programmes. Higher resolution spatial data regarding SSF is also needed to allow a more robust economic spatial analysis of SSF fishing grounds (Breen *et al.*, 2014; Gacutan *et al.*, 2019). Here also, efforts to engage stakeholders in carrying out the research and developing management advice may facilitate progress.

Informing shared stocks management

A strength of ICES is its ability to coordinate research efforts across its member countries. In this endeavour, ICES can aim to improve the general level of understanding of shared stock management issues and coordinate research across countries to improve the science supporting policy and the development of relevant advice about the impacts of changing established allocation approaches. Our review shows that economics can provide an understanding of both the incentives and other factors at play in shared stock management and the likely outcomes and trade-offs associated with different TAC allocations. In addition, the process for developing TACs and other conservation measures itself warrants further research, as this is key to understanding why certain measures are adopted and others are not. More could also be learned with respect to allocation of fishing possibilities at multiple decision levels (e.g. individual companies, POs, regional authorities, nations) and non-fishing related interests (e.g. processing, fishing rights holders, broader community interests, other industry interests). Improving shared stock allocation processes calls for research in political science, political economics, and applications of public choice theory. The role of additional factors influencing incentives for cooperative management and compliance with management regulations, such as financial support policies for the fisheries sector, should also be taken into account in these analyses.

Including ecological processes in the assessment of shared stock harvest strategies offers promising developments to deal with current and future shifts in stock distributions and the ensuing need for adaptive approaches to allocate quotas (e.g. historic catch shares versus zonal distribution of stocks). Despite improved data availability in many countries, a lack of standardization, compatibility, and sometimes comparability in the types of data collected remains an impediment to better analyses. These difficulties may be related to the potential disincentives for negotiators and the industry in making economic information available when initiating negotiations on conservation objectives and/or access right allocations between parties. Economic analysis can also help assess the potential for long-term harvest strategies to minimize such disincentives, thereby leading to improved data quality.

Informing policy on key interactions determining fisheries responses to management

We find that a large research effort in fisheries economics has been devoted to analysis of how interactions between specific fisheries and other components of fisheries social–ecological systems affect how these systems respond to management. Key interactions to consider include the connections between the catch sector and markets, the diversification of commercial fishing, fisheries-aquaculture interactions, as well as broader interactions between fisheries and the provision of ecosystem services.

Accounting for interactions between the catch sector and markets

Research on implications of different fisheries management options on value chain structure as well as understanding wider market issues and forces has grown rapidly, and must continue. The information produced by such research could be beneficial when considering the regional and global impacts of fisheries management strategies (Mullon *et al.*, 2009; Roheim *et al.*, 2018; Costello *et al.*, 2020; Chávez *et al.*, 2021). Some ICES countries currently estimate the expected economic outcomes associated with agreed quota allocations when these are announced. Economists could provide guidance on such an approach, as well as highlight price effects, supply chain tipping points, and the feedback loops with fishing effort and ensuing fishing mortality. Consumer preference and the effects of labelling schemes are still an active area of research in fisheries economics, and there is a further need to investigate the externalities generated by fisheries and how these effects can be related to markets and consumer demand. Above all, because management can be a driving force for fish prices or market outlets, this linkage should be better documented by fishery science and considered when defining management scenarios. The integration of markets into bioeconomic modelling could help advance fishery science in this domain.

This research can rely on existing methods and tools, but researchers and experts from different research communities should be encouraged to share their methods, models, and experiences. Data collected for market and demand analysis must meet data formats that most often do not align with those needed for fisheries science. Therefore, future research in ICES with a focus on the linkages between ecosystem-based fisheries management on the one hand and markets and value chains on the other should contribute to and help design data formats (e.g. regarding ex-vessel production or processing) that enable both dimensions to be explored simultaneously, supported by a strong interaction between research groups and data collecting agencies.

Taking into account diversification of commercial fishing

A better understanding of the impacts of diversification on fishers, coastal communities, and the ecosystem would reduce the risks of biased assessments of the potential impacts of fisheries management in the ICES area. Yet, the economic incentives to diversify and how they affect the success of fisheries management are poorly documented in current research, despite the importance of such diversification strategies in determining the economic risks faced by fishers (Abbott *et al.*, 2023). Briton *et al.* (2021) highlighted the need to better understand the possibilities for fishers to change species mix and thus adjust to changed management or market conditions, taking the example of an Australian fishery. Holland *et al.* (2017) found that fisheries management might restrict individual fishers' ability to reduce income risk through diversification, despite the importance of such diversification in the face of changing productivity and distribution of fish stocks. The role of income sources from outside the fishing sector is even less frequently analysed in economics, although it is well known to be important in many fisheries (Nielsen *et al.*, 2018b; Hoff *et al.*, 2021). Our understanding of alternative sources of income or non-pecuniary aspects such as cultural and job satisfaction would benefit from interdisciplinary work (Holland *et al.*, 2020). Furthering, the economic analysis of diversification will also require the addition of socio-economic data at vessel level, on within-fisheries diversification (e.g. in mixed-fisheries), as well as regarding other sectors towards which fishers can diversify.

Evaluating the implications of fisheries-aquaculture connections

In the context of the Sustainable Development Goals (SDGs), ICES could participate in the elaboration of scenarios for fisheries and aquaculture to achieve SDG goals 14 (life below water), 12 (sustainable consumption and production), and 3 (good health) as seafood is a major source of valuable nutrients for people. The continuous growth in aquaculture and the many links to catch-based fisheries call for more research on the interactions between the two sectors. Possible research questions include how these sectors compete at the fish market and in local communities, and how they can coexist and even potentially benefit from each other. Such studies require geographically disaggregated economic and employment data on fisheries and aquaculture production and markets.

A possible way forward would be to develop an assessment of the competition and impacts of aquaculture development within the value chain as a whole, focusing on specific species as well as broader sets of products and integrating socio-economic as well as environmental management issues. Bio-economic modelling, value chains, and regulatory analyses could be used to address these issues, whereas time series econometrics can provide relevant information related to interactions on markets for wild and farmed fish (Jiménez-Toribio *et al.*, 2007; Bjørndal and Guillen, 2017).

Interactions with the provision of ecosystem services

The push for EBFM is leading to a need to better incorporate the broader interactions between fisheries and the provision of ES into management advice in the future. This includes considering ES when assessing the potential impacts of TACs on fisheries' socio-ecological systems. Such assessments should include the existing understanding of tipping points or thresholds for maintaining ES. Moreover, economic ES assessment could help inform the evaluation of trade-offs associated with marine spatial planning, supporting policymakers in assessing the social welfare outcomes of marine spatial plans.

Providing such advice requires the collection of disaggregated economic data at finer spatial and temporal resolutions, as well as the ability to link this economic data with the other categories of data (e.g. regarding biodiversity, marine habitats, the impacts of fishing and other activities, etc.) used in multidisciplinary frameworks for full ES assessment. Such data gaps could be filled using surveys, which would require some standardization and generalization of the approaches on how to value marine ES.

Conclusion

There has been an increasing demand for fisheries science and management advice to address economic evaluations and analyses. Our review clearly shows that economic research can provide important contributions to ICES science and advice in line with the objectives highlighted in the organization's strategic plan. Moreover, economic insights can contribute to scientific programmes and organizations working towards achieving the UN SDGs relating to the conservation and sustainable use of living marine resources. In many cases, we identify sets of methods and tools that can be used in a broad range of contexts, for which best practice recommendations can be provided as to how they should be used in applied research and management advice. The increased availability of cost and earnings data regarding fishing operations across ICES regions has helped make significant progress in this regard. Continuing efforts and support towards the collection of such data will be key. We also identify a range of other data that can support further applications of economic analyses to the different fisheries management topics considered in our review.

For some key topics, contributing to management advice may involve integrating economic analyses into current practice. For example, while steps have been taken to incorporate economic considerations in the assessment of mixed fishery management options in the European Union, methods and data are available that can directly inform trade-off analyses associated with managing these fisheries. Another example is the incorporation of economic analyses and indicators in the production of social-ecological status assessments such as the ICES Ecosystem, Fisheries, and Aquaculture Overviews. We feel that these overviews would more effectively inform policymakers, managers, and stakeholders by integrating many of the topics listed in our review. Such an endeavour should eventually lead the economic considerations identified in this review to become an integral part of marine science and scientific advice regarding the use and conservation of marine resources in ICES areas as well as other regions of the world.

Future work should focus on demonstrations of the ways in which relevant economic research, methods, tools, and data can be included in fisheries management advice. Applications of such analyses could also inform the ecosystem and fisheries overviews. This has already begun as part of a number of existing working groups in ICES dedicated to the analysis of economic and social dimensions, leading to the expansion of social sciences capabilities as these groups develop and interact with other disciplines on the different topics we identified in developing integrated assessment approaches. Such integrative support tools, knowledge, and advice could be an entry point for engaging stakeholders in holistic assessments of the impacts of fishing sustainably.

These economic analyses can rely on already well-structured research capacity, data, methods, and tools. However, the dedicated inclusion of economics and economists into the ICES strategic plan and its capacity to further grow in the network through the establishment of focused groups such as ICES WGECON is relatively new. Our survey of economists showed that economists have been only marginally involved in ICES activities. One-third of respondents had not participated in ICES conferences and/or symposia in the last five years, while another third had participated only once. Lack of economic topics and time were mentioned as main factors behind low participation levels, a limitation that should be progressively lifted as the presence of fisheries economics in ICES work increases. While the majority of respondents (75%) showed interest in the development of Integrated Ecosystem Assessments, many also said they would increase their participation in ICES activities if funding was available to support their participation. The growth potential is there, especially with the development of activities such as the MSEAS conference (https://www.ices.dk/events/symposia/MSEAS/Pages/MSEAS.aspx), training courses, and cross-cutting meetings such as those recently organized in relation to the interactions between windfarms and commercial fishing (https://www.ices.dk/news-and-events/news-archive/news/Pages/WKSEIOWFC.aspx). Hence, a key challenge for further developing economic contributions to fisheries science and advice remains the ability to support an effective engagement of economists, including early-career ones, in the regular research work of organizations such as ICES. In addition, the engagement of economists in collaborative groups supporting advisory and decision-making processes at multiple scales may also be a key feature that could help mainstream economics into such processes.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contributions

OT, JRN, AM, and HC coordinated the review and the conception of the paper. All authors participated in the identification and development of the review topics. The authors identified as Topic Coordinators in section B of the supplementary material led the initial writing up of the review summaries for each topic. The authors identified as Topic Reviewers reviewed and edited these summaries. OT led the writing of the manuscript. FB, GEB, FD, LG, JH, JI, AM, AnM, ArM, JRN, RN, RR, OT, ET, SV, JV, and SW coordinated the writing up and revisions of sections of the paper relating to the different topics. All authors contributed to editing the manuscript and approved the final draft. OT and BLG led the survey of fisheries economists, and AM helped analyse the results.

Data availability

The review data underlying this article are available in the article and in its online supplementary material. The survey data of fisheries economists will be shared upon reasonable request with the corresponding author.

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