

TOWARDS BEHAVIOURAL MODELS OF FLEET DYNAMICS

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ABSTRACT

Considerable attention has been applied to the development of models explaining how fish stocks change over space and time, from relatively simple stock-recruitment relationships to ecosystem models with a complex food web structure. However, in many case studies fishing effort is assumed to be exogenous and even in dynamic models pre-determined by external factors such as management. An increasing number of operational bio-economic models for the marine environment are including a fleet dynamics component, recognising that fishers respond to changing environmental and economic conditions. These models are based on different assumptions about behaviour. In this review, we examine models of fisher behaviour that are empirically or theoretically developed and tested. In particular, we focus on the range of different economic and social drivers and their relevance to different types of behaviour. We find that economic factors are a dominant driver included in many types of short term behavioural models, although we acknowledge and find that other social factors play a significant role in some types of behaviour. The link between management and economic impacts is reasonably well established, and most bioeconomic models are able to incorporate these feedback systems. Incorporating these other social-dependent behaviours into bioeconomic models, however, is likely to remain a challenge unless links between management and changes in the social drivers are developed.

Keywords: fisher behavior, review, fleet dynamics, bioeconomic models, fishery modelling

INTRODUCTION

An understanding of fleet dynamics and the processes affecting the behaviour of fishers is critical to the successful management of fisheries [1]. The rationale for this as claimed by many authors is that the sustainable management of fish resources is essentially achieved by effectively controlling fishing activities and the associated fishing mortality [e.g. 2, 3]. For policy purposes, effective modelling of marine ecosystems, and the commercially targeted fish populations within these, may only be achieved when complemented by an understanding and ability to model the activity of resource users and their drivers. In the context of fisheries management, arguably more fisheries research investment has been dedicated to stock assessment than to fleet dynamics modelling. Early interest in fishing fleet dynamics in fact developed from the recognition that the fishery-based data used for stock assessment could be strongly influenced by changes in the distribution of fishing effort, so that interpretation of variables such as a change in catch rates required knowledge and understanding of the associated changes in fishing behaviour (see e.g. [4-5] and references therein). Partly as a result of this, and partly due to the development of applied economic and social science research in fisheries, a significant literature on fisher behaviour and fishing fleet dynamics has developed over the past three decades, and quantitative models of fisher behaviour and fishing fleets are available

for a range of fisheries around the world [e.g. 6]. Contributions to this literature originate in human behavioural-based disciplines such as economics, anthropology, sociology, and social psychology; but also derive from the natural sciences [2]. More recently, quantitative modelling has focussed on the effect of policies on resource user behaviour, which determines the effect of management policies on the future state of the biophysical resource.

Broadly defined, fleet dynamics encompasses changes in fishing activity, specifically changes in the allocation of fishing activity across available options both in time and space. Furthermore it encompasses changes in the capacity of fleets, of which both the activity and the investment decisions are a result of the choices made by decision units. The decision units are often called 'fishers' in the literature, but are here understood to include a wider definition. This broad definition is necessary given complexity that exists. That is, the decision units may refer to individual people or fishers (often the skipper of a fishing vessel as a employee of a firm or owner-operator), but also to firms (and fleet managers), organisations such as producer cooperatives or associations, and collectives such as cooperative fishing firms. In the extreme, they can be taken to represent countries cooperating or competing for the harvest of a migratory or straddling fish stock.

The overall aim of this review is to evaluate key drivers which explain and predict fleet dynamics. In pursuing this objective, we (i) outline the relevant theories of behaviour; (ii) review the literature in which theories are applied and tested in empirical applications; (iii) identify the key variables that have measurable and significant explanatory power in these theoretical applications; and (iv) summarise the different techniques or methods used to model fleet dynamics. We apply a vote counting approach to assess the current state of the art in modelling fishing fleet behaviour, identify the most commonly applied approaches and highlight the most significant variables identified in the research that influence and drive behaviour in fishing fleets.

QUALITATIVE RESULTS: THEORIES OF BEHAVIOUR AND THEIR APPLICATION TO FISHERIES

In reviewing the theoretical framework we limit ourselves to the theories identified in the literature and that are relevant to modelling the behaviour of fleets. We divide the behavioural theories into two main groups: theories of individual behaviour, and theories that explain the behaviour of individuals in groups.

Explaining individual behaviour

The most common approach to studying fisher decision making is based on micro-economic theory, and the assumption that fishers can be considered as producers or firms. The theory postulates that individual firms act so as to *maximize their profit*, defined as the difference between the revenue obtained from the sale of an output and the costs incurred in obtaining this output, including both the costs of using various inputs in the production process, and the associated opportunity costs. This assumption has been shown to hold empirically [7], although some studies have found that the profit maximisation framework may be more accurate in explaining the collective (or average) behaviour of firms (i.e. the fishing business) than the behaviour of individual fishers [8].

A number of empirical applications have been based on the profit maximisation approach to determine the expected behaviour of fishing firms. In particular, restricted profit functions have been estimated to determine optimal effort levels and targeting behaviour of individual vessels in the short term in response to input and output changes, as well as optimal levels of capital investment in the longer term [9-12]. Similarly, cost functions have been used to estimate how average vessel size may change in the longer term under rights based management systems [13].

In practice, decisions will actually be based on producer expectations of revenues and costs associated with alternative production choices, which may be characterized by variable degrees of uncertainty. Hence, empirical applications have been based on the development of models focusing on how to represent anticipation and its effect on choice. While this has led to a broad range of approaches, many applications encountered in research on fisheries have relied on expected utility theory, and progress in the domain of discrete choice modelling. Approaches have notably been based on Random Utility Models (RUMs) that are well suited to the modelling of decisions that can be defined as discrete choice problems, and which allow incorporation of both monetary and non-monetary attributes of choices, as well as individual characteristics including attitudes towards risk, variability in information levels, or the role of normative and social influences on decision-making. In such models, discrete fisher decisions, underpinned by expected utility maximisation assumptions, can be statistically related to the attributes of the fisher, vessel, and business, as well as the attributes of the alternatives, for instance the location of fishing activity and longer term decisions such as exit and entry decisions). This approach has led to a growing number of applications in the past two decades [14-23].

Foraging theory was first developed in behavioural ecology where it describes the foraging behaviour of organisms [24]. The theory asserts that organisms behave in a manner that maximises their energy intake at minimal energy outlay. In a fisheries context, fishing vessels may be viewed as individual foragers, aiming to optimise gain rates in

the form of short-term net revenue at minimal cost [5, 25]. Hence, the theory is generally consistent with profit maximisation. Foraging theory also provides the foundation for the ideal free distribution (IFD), a theory that predicts the relationship between prey (cf. fish) and predators (cf. fishers) in the environment. IFD and game theory have common ground in that they predict optimal individual resource exploitation decisions (e.g. [26]). IFD assumes that all foragers (fishers) "... *have ideal knowledge of their environment and are free to move between all sites*" ([26] p.178); whereas game theory goes beyond these propositions and models strategic interactions between parties which maximise their optimal resource usage subject to their interaction with other players.

In IFDs the relationship between commercial fishing vessels is firstly based on the resource distribution [26-28]. Inherent in this is the notion that each fisher will choose to go to the location that reflects this resource distribution and thus where they expect to maximise profitability. The equilibrium distribution is where the proportion of foragers matches the proportion of resources present in that location [3]. However, an equal distribution of the catch does not necessarily mean an equal distribution of profits due to the asymmetric nature of fishers and their business characteristics. Despite the very simple human behavioural assumption, the IFD approach provides a starting point for investigating fleet behaviour, by comparing the spatial distribution of resources and that of fishers [29].

Foraging theory also provides a basis for the dynamic state variable modelling approach, which assumes that optimal fishing behaviour can be calculated under the assumption that each individual is a utility maximiser ([30]). The decision-maker's "state" includes any information about its condition that can influence the expected reward from each option. For fishers choosing strategies to maximise profit, the state could include the catch of various species in the hold, the amount of trips, or quota remaining [30-32].

Explaining the behaviour of individuals in groups

As well as theories that explain the behaviour of individuals, there are a number of theories and methods that have been used to predict and explain fishers' choices when the fisher is part of a group. As an example of studies that take a normative stance, the link between social norms and the attitude and behaviour of individuals was first outlined in the Theory of Planned Behaviour [33-35]. The theory suggests that planned behaviour is heavily influenced by social norms as well as the direct benefits to the individual. The combination of social norms and economic incentives has been used to explain compliance behaviour in fisheries [36-38], where the behaviour of each fisher is assumed to rely partially on their perception of how others are behaving, and what behaviour is acceptable in the group. In terms of predicting the behaviour of individuals in a group, here we draw the readers' attention to only two research topics: game theory and network theory. This current review could not do justice to a review of sociology in general (even if fisheries related; see [39] for an extensive comment on the anthropology of fisheries).

Game theory dates back to seminal publications by Von Neumann and Morgenstern [40] and Nash [41-42]. Munro [43] provides the first application of game theory to fisheries. In a fisheries context the focus has been mainly on the magnitude of a production unit's inputs (effort required to maximise net benefits) within a game as will be explained. In game theory this decision is assumed to be driven by rational and strategic behaviour and the interaction between rational and strategically behaving players is the actual game. Players' decisions are bound not only by their own actions but also the actions of others targeting the same stock or fishing at the same area. In other words, players maximise their well-being knowing that others maximise their own. Players can be individual fishers, fleets, regions or countries for example. Applications of game theory in fisheries can be divided into three broad categories: non-cooperative, cooperative and coalition games (see reviews by [44-46]). Non-cooperative games can be used to study situations where players seem to compete for the resource. Cooperative games can be applied in cases where binding agreements between players are possible. In coalition games both features of competition and binding agreements can be combined. The equilibrium or solution of the game is where players do not gain benefit from changing their behaviour, for example the hours they fish, unilaterally (the Nash equilibrium [41]). Non-cooperative games assume that each player maximise its' self interest and cooperative games assume that a group of players have agreed to maximise their common benefits. Intuitively, a player would agree to cooperate if the benefits of cooperation would exceed the benefits from non-cooperation. Non-cooperative game theory has been used to explain why overfishing can be rational [47-48] and results from cooperation have often been contrasted with non-cooperation to show the benefits from cooperation [44, 49]. Non-cooperative and cooperative games also shed light on which management measures would enable stock recovery and whether it is worthwhile for parties to enter co-management relationships with government agencies. [50]. A general finding of coalition games is that cooperation yields surplus. As explained earlier, this surplus could be divided among the players so that it would be beneficial to all players to cooperate [51-55]. However, in most cases full-cooperation cannot be achieved, but partial cooperation can.

Network theory aims to explain the characteristics of a connected system and the behaviour of connected individuals within that system. Network theory draws on graph theory in mathematics, which is used to analyse a collection of connected 'nodes' (agent/individuals) and 'edges' (connections). The connections between individuals in a network can be many things including, for instance, a friendship or a market exchange (e.g. buying and selling fish or licences and/or quota). Information (and the sharing thereof) can also be considered a connection. The connections between actors in a network can be mapped and measured, allowing estimation of different statistical indicators which provide information about the network, the connections, and the actors within it. Social network theory and analysis was made famous by a *small world experiment* by psychologist Stanley Milgram [60] and was further developed by various social scientists [e.g. 61, 62-63]. Social networks play an important role in many social and economic events. It is now well established that social networks exist in fisheries and the associated fishing communities [e.g. 64]. Social networks and friendship networks provide a way of sharing information about location and resource abundance. Information sharing between fishers affects fishing success. Social networks and related information sharing also affects fisher compliance behaviour [64-65], with greater compliance in 'connected' groups. Meuller *et al.* [66] find that successful captains hold central positions in the social network among salmonid fishers in Lake Michigan. Trade networks also exist in markets and over two decades worth of social network analysis has been undertaken in this context [e.g. 67, 68-70]. It may be expected that trade networks, both in the product market as well as the quota market, will also affect fisher decisions, in particular exit and entry decisions, but potentially also compliance decisions.

Synthesis of behavior theories

The general theories that underpin much research into fishery relevant behaviour apply to key groups of variables. These variables operate at different scales, for instance, some apply to individuals while others apply to groups. A classification of how the different theoretical frameworks outlined above relate to the different categories of variables and decision units is illustrated in Figure 1. In reality, the boundaries between the theories are probably less well defined, but the key variables used in the development of models relating to each theory differ. For example, even though utility maximisation is the underlying goal in the game theoretical analysis, game and network theory relate to social variables, since both apply to situations where individual behaviour is affected by other individuals. The next section will shed light on the relative frequency with which the variables contained within each of the category have been included to explain short and long term fisher behaviour.

QUANTITATIVE RESULTS

A total of 132ⁱ publications of fishery relevant behaviour were identified in the review, ranging in date from 1979 to 2010. We identified five main types of behavioural analyses in our review: location choice, discarding, compliance, entry/exit and strategic. Most (around 70 percent) of the research has been on Atlantic (including the Baltic, North Sea and the Mediterranean) fisheries (Table 1) and around half of the research was undertaken on demersal species. The reviewed literature most commonly focused on trawl fisheries (58% of the total). The following analysis focuses on the 32 articles that applied statistical methods, thereby excluding strategic behavior since the modeling approach underlying game theory does not allow us to quantify the explanatory variables of strategic behavior.

Location Choice

Perhaps unsurprisingly, profits most often explain short term drivers of fisher behaviour (28 of the 32 publications) and have significant explanatory power with respect to effort allocation [71-80] (Table 2). Catch rates, returns and profits are closely related concepts.ⁱⁱ Fishers will tend to go where fish are abundant and catch rates are expected to be high, provided the costs of reaching these areas are not substantially high. High catch rates means that less effort is required to catch the fish, ultimately resulting in higher profitability [e.g. 82, 83]. As the actual profit of fishing in an area is unknown, measures of expected catch rates, revenues and distance travelled (representing costs) provide proxy indicators of expected profit in each location. Profit is an important decision making variable but is constrained not only by key resource characteristics such as the level of harvestable biomass [e.g. 84, 85], but also by a number of economic variables.

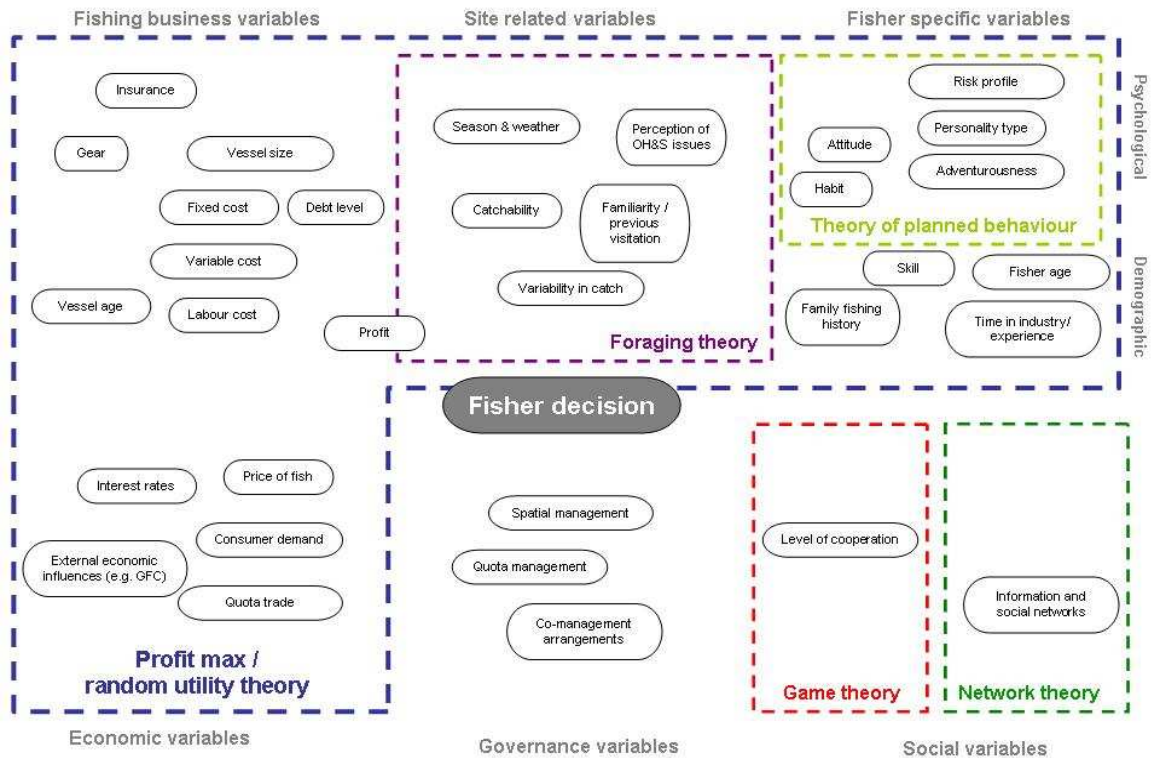


Figure 1: Schematic indication of the variables and categories in relation to behavioural theories.

Table I: Geographic, fishery and gear type split of 132 reviewed papers for five different types of fishery relevant behavior.

Type of fishery relevant behaviour*	Geographic region				Type of fishery			Gear type			
	Atlantic	Pacific	Indian Ocean	Inland	Demersal	Pelagic	Shellfish	Trawl	Line	Net	Pot
Location	22	16			18	10	4	16	8	4	2
Exit/entry	8	1		1	2	6	1	2	1	3	
Compliance	7	1	1	1	3			3	1	2	
Discarding	5				2		3	7			
Strategy	29	1	2		13	16	2	10	4	2	
Total	71	19	3	2	38	32	10	38	14	11	2

Note: totals by region, fishery or gear type do not add up to 132 as information was not available for all reviewed publications.

The variables that most frequently explain location choice behaviour can be loosely grouped into a set of fishing-business related variables, as shown on the top left hand side of Figure 1. However, profit can also be determined by variable, fixed, and labour costs, as well as the price of fish. In their choice of fishing location, fishers will for

example balance higher catch rates with travel time and fuel costs. These variable operating costs may have a strong impact on trip-level profit [71, 74, 78-80, 82, 86-87]. These variables in turn are dependent on, for instance, observable vessel and business characteristics such as vessel size. Vessel size directly impacts on location choice behaviour in that larger boats may have more engine power and are more expensive to run, but they are also more mobile and better equipped to fish during rough weather and can travel to more remote locations [76, 88-89]. Variation in catch is also an important explanatory variable. Variability in catch is different from the actual or past catch [73, 76, 90] or profit, and wealth [72, 91]. Variability can be due to changes in the bio-physical resource characteristics, but can also be related to changes in demand and supply for product [89, 92-93]. The variability in catch is closely related to three other site specific variables that the analysis of the literature revealed to be significant including: time of the year/week/day; the weather; and physical characteristics of the area. In Figure 1 these three site-related variables are shown as ‘season and weather’ which is linked to catch rates and variability in catch.

Table II: recorded presence of variables found to significantly explain relevant behaviour using a mathematical or statistical approach for each reviewed publication.

	Location	Exit/ entry	Com- pliance	Dis- carding	Total
Expected revenue / trip profits	28	3	3	6	40
Distance from/to port, steam time, trip length	15	1	1	4	21
Vessel characteristics / gear type / metier	12		2	2	16
Variation in expected revenue / wealth	9				9
Initial level of wealth	3		4		7
Previous visitation /experience / knowledge / tradition / inertia / state dependence	13	2		1	16
Time of the year/week/day / season	11	1			12
Weather	4				4
Fishing area characteristics (crowding)	3	1			4
Fleetwide expectations / information sharing	7				7
External economic variables (e.g. unemployment rate)	1				1
By-catch species			1	1	2
Level of the fine (punishment)			3		3
Level of enforcement (probability of detection - marginal deterrence)			4		4
Probability of prosecution			2		2
Probability of conviction			2		2
Risk profile/preferences (risk averse & risk seeking)	2	1	2		5
Moral obligation (self interest)			4		4
Legitimacy (bureaucracy)			4		4
Social influence (others cheat)			4		4
Habituation (repeated breaking rules)			2		2

The effect of catch variability on location choice is closely linked to the concepts of risk, the fisher’s perception of risk,ⁱⁱⁱ and expectations moderated by past behaviour. In terms of the utility derived from fishing in an area, variability may be attractive to risk seeking operators, and unattractive to risk averse fishers. The quantitative measure of risk in fisheries models generally takes the form of a typology or risk profile (such as risk averse or risk

seeking) [e.g. 96]. The sign of the coefficient on the variability variable is assumed an indicator of the average risk preference of vessels in the fleet [97-98]. Studies have found that risk averse fishers are less likely to fish in areas where the variability in catch, and thus variability in profit, is high [73, 76]. Risk aversion may lead to visiting the same fishing locations if they have been successfully fished in the past [99-100].^{iv}

Previous visitation will lead to familiarisation with a particular fishing site. This in itself does not cause future behaviour but forms a behavioural pattern, or habit, which influences behaviour [34, 102]. The effect of expectations based on previous experience from visiting a site may be termed “knowledge”, “experience”, or “tradition” [73, 76-78, 80]. The review of the literature suggests this variable has strong explanatory power in relation to location decisions. The variable is also sometimes referred to as inertia, meaning it creates a disposition to repeat previous actions. If for instance, the fishing has been good in certain location for several years this is likely to affect the fisher’s current decision to visit that same site. Repeating previous actions is distinct from the compliance related term ‘habituation’ used to indicate repeatedly breaking the regulations, or persistent offenders [36].

Compliance

Standard approaches to compliance are based on a deterrence model which assumes that fishers base their decisions to comply on the expected costs and benefits of infringing a given regulation [36, 103]. While expected benefits are influenced by the marginal value of illegal products, the expected costs will be influenced by the perceived risks of being detected and sanctioned, as well as the anticipated penalty if sanctioned. A greater perceived risk of detection, which will be affected by enforcement levels and the personal experience of fishers, will generally mean a lower incidence of non-compliance [36, 104-105]. More severe sanctions [38], which may be achieved through increasing fine levels, are also expected to lead to lower incidence of non-compliance. The response of individual fishers may however be strongly affected by their risk profiles [e.g. 106]. While the standard deterrence model has been shown to provide good predictions of compliance behaviour with fisheries regulations, a number of studies have also insisted on the importance of normative and social factors in this domain [36, 103]. These may relate to the perceived legitimacy of regulations [107], the norms to which fishers respond with respect to illegal action, or the perceived behaviour and response of peers with respect to compliance behaviour.

Discarding

Much of the initial work on discarding has been theoretical in nature and has largely focused on the incentives to discard [108-110]. The key drivers are the price difference between grades (in the case of highgrading), cost of fishing (to replace the discarded fish), the opportunity cost of quota (related also to quota availability) and the costs of landing and discarding fish. Many of these variables are difficult to measure, and are not constant precluding detailed application. However, many publications that focus on discarding behaviour are simulations of different management approaches aimed at addressing the discarding problem and include elements of the theoretical models described above see eg. [108, 111].

Entry and Exit

The decision to enter or exit a fishery is perceived as a long term decision, as distinct from the short term decisions of effort allocation or locations choice. Models of entry and exit behaviour have been relatively limited in fisheries (Table 1), possibly as most fisheries are subject to some form of limited entry. Where entry and exit are generally unconstrained (i.e. open access fisheries), entry, stay, and exit decisions are significantly associated with the profitability of the vessels [112-113], with fleet size (representing crowding pressure) and stock conditions of major targeted species also being influential in some fisheries [112]. For artisanal fisheries, the availability of alternative uses of labour is also an important determinant of exit behaviour [114]. In limited entry fisheries, revenue, stock status and alternative employment opportunities have been found to affect the rate of exit, with increasing management controls exacerbating this rate [65]. In general, the existence of a buyback scheme to remove excess capacity or some form of transferable quota is usually a necessary pre-condition for exiting behaviour, and most studies have examined exiting in this context.

DISCUSSION AND CONCLUSIONS

From the papers examined, a number of generic conclusions can be drawn. Most of the empirical analyses around fleet dynamics are relatively short term in nature and consider mostly economic factors. Profitability of alternative actions, or proxies such as maximising value per unit of effort, are the main explanatory variables in these fleet dynamics models. Whether this is an artefact of data availability and/or ease of obtaining such variables relative to others is not explicitly considered, but is likely to influence the set of explanatory variables used. Most fleet dynamics models applying statistical methods have focused particularly on location choice. Modelling of other behaviours, particular discarding, are also largely based on economic factors. Social factors are also found to

influence behaviour, particularly those that affect degrees of compliance in the short term (e.g. perceived legitimacy), and those that affect entry/exit behaviour to some extent in the longer term (e.g. job attachment). Individual socio-economic characteristics (e.g. family history, personality) of the fishers, regional economic conditions (e.g. unemployment rates) and social norms and values are also highly influential.

Previous reviews of fisher behaviour (e.g. [115]) have tended to question the validity of the profit maximisation assumption that underlies most of the models of fisher behaviour identified above. While we have also found that social factors are highly influential in some components of behaviour, profit, or more generally utility maximisation, remains the key driver. While we can be cognisant of the impacts of social factors, developing more integrated bioeconomic models that can account for these factors in fleet dynamics is a prerequisite.

At present, management change directly affects the profitability of vessels either positively or negatively through changes in catch rates or costs. These fishing business variables are key driver of change in fisheries. The current approach inherently assumes that social factors remain largely unchanged as a result of management. In the short term, this may be the case, and much of the behavioural models have had a short term focus. However, to assess the longer term effect of management changes the status quo of social factors is likely to be affected. From a pragmatic perspective, it is notoriously difficult to obtaining reliable estimates of the status quo of some of the social variables (e.g. perceived legitimacy), let alone measure and predict change. Quantitative models that include these difficult to measure variables, and that predict micro level social variables, may be limited in their capacity to predict macro level social phenomena.

Reliance on economic drivers alone, however, may result in the reduced reliability of estimates of longer term consequences. Social factors also influence the rate of change in the fishery (e.g. entry and exit), and, in the case of compliance, the success of the management strategy in achieving its objective. Ideally, a link between the management option and social outcomes is required in order to endogenise these variables, but this is an area that has received little attention in the literature other than through examination of co-management structures and their impacts on fisher buy-in. These sociological factors do provide a wealth of understanding in terms of contextualising each case study as many are specific in nature.

The study of fisher behaviour is an area that is still underdeveloped, despite its importance in determining fisheries management outcomes. Further, the translation of these behaviours into quantitative models that can be used to evaluate different management strategies is also relatively underdeveloped. It is likely that economic drivers will remain the key component of fleet dynamics models as the relationship between management changes and economic impacts is relatively well understood and readily quantifiable. Nevertheless, considerably more research is needed into such models. Similarly, developing reliable models of social impacts of management – particularly those that feed back to affect management outcomes – is an area that requires greater attention in the future.

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ENDNOTES

ⁱ The reference list includes only papers referred in text.

ⁱⁱ The term 'expected 'future wealth' was also used in the reviewed literature and was included in this category [81].

ⁱⁱⁱ There are many other aspects to risk that explain fisher decision making. For instance, fishers have risk profiles in terms of business risk (e.g. [94]) and risk associated with policy and management change (e.g. [95]).

^{iv} In the context of health and safety, risk averse fishers reduce fishing in remote grounds in spite of potentially higher yields and revenues [86, 89]. Risk aversion in terms of health and safety is not universal however, with some studies finding that fishers behave in a risk loving manner [72], whereas others found no risk effect at all [90, 101].