



Modelling the strategy of mid-water trawlers targeting small pelagic fish in the Adriatic Sea and its drivers



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ABSTRACT

Mid-water pair trawling (PTM) targeting small pelagic resources represents a key fishing activity in the Adriatic Sea. This fishery is experiencing a long period of crisis due to resource depletion and the lack of appropriate market strategies, and vessels spend most of the time searching for fishing schools. The searching strategy largely depends on the interaction between vessels: the captains of the PTM units take their decision also checking the position and the fishing status of other vessels. Understanding this strategy represents a key step towards a more effective resource management, since strategies directly determine the pattern of fishing effort. A Conditional Logit model has been devised to analyze fishermen's strategy as a non-cooperative game. This category of games is characterized by the existence of (at least) one equilibrium point – a Nash Equilibrium – in which each player plays his strategy, that is a *Best Response* to the strategies of the other players. This equilibrium point was estimated for the different scenarios defined by environmental (sea surface temperature and atmospheric pressure) and economic (fuel and fish prices at market) variables. Vessel Monitoring System data were used to capture fleet activity, while different datasets were collected to reconstruct environmental and economic drivers. Results indicate a good predictive power of the model, and suggest that the equilibrium strategy that guides units' behaviour is invariant with respect to environmental conditions, whereas it is largely influenced by economic factors. These latter, via strategies, may determine important consequences on the resources in terms of exploited areas and the impact of fishing activity. In particular, a low fuel price when fish price is high leads to higher values of CPUE, and then to a more efficient but also impacting fishing activity.

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1. Introduction

Attempting to face the general crisis of fisheries observed worldwide, fishermen's behaviour and fleet dynamics have been indicated as fundamental factors to be considered in fisheries management, together with resource dynamics and environmental changes (Hilborn, 1985a). Indeed most fisheries management failures actually may derive more from misinterpretations or erroneous predictions about fishermen's behaviour than from limited knowledge about resource status. In addition, socio-economic issues must be explicitly taken into consideration in the modern

ecosystem approach to fisheries underlying the new Common Fisheries Policy (CFP – EU, 2013). Fishermen's behaviour can be observed at different spatial and temporal scales, among which the movement in space (i.e. the decision making about what, where and how to fish) is of great interest because it has direct effect on the relationships between catches and abundances of living resources (Russo et al., 2009, 2014b), definitively providing new insights into fishery management (Booth, 2000; Pelletier et al., 2009). Accordingly, exploitation dynamics models have been proposed as a tool to evaluate *ex-ante* the effects of new management measures regulating fishing effort in space (Russo et al., 2014b; Vermard et al., 2010). It is also important to consider that fishermen are able to partially but systematically compensate for the depletion of stocks (Walters, 2003), for instance by concentrating the fishing effort to accommodate the progressive contraction of stocks distributions.

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Then the understanding of the main factors regulating fishing activity and the identification of strategies adopted to maximize catches can provide a basis for efficient management actions. The case study examined in this paper clearly belongs to the family of stock exploitation in relatively shallow (<200 m) continental shelves of the temperate areas, in which the huge fishing effort has caused widespread depletion (Strong and Frank, 2010).

The Adriatic Sea is a semi-enclosed basin (Geographic Sub Areas 17 and 18 of the FAO partitioning) representing one of the most extensively fished and productive areas of the whole Mediterranean. The main fishing activities practiced in this area comprise the exploitation of two small pelagic species: the anchovy (*Engraulis encrasicolus*, Bleeker 1852) and the sardine (*Sardina pilchardus*, Walbaum 1792). Small pelagics are mainly planktivorous fishes sharing the surface layers of the water column above the continental shelf and in waters not exceeding 200 m in depth.

Both species stocks are harvested mainly by means of mid-water pair trawl fishing system (PTM in the métier list of European Data Collection Framework), commonly denoted as “*Volante*”. The PTM fishing system was introduced in the nineteen-fifties (Ferretti, 1981). This fishery is now in crisis, since the stock biomass of both anchovies and sardines appears to be reduced. In the period 1976–2002 the biomasses of both species gradually decreased: anchovy passed from 3×10^5 to 1.5×10^5 tons, while sardine dropped from 8×10^5 to 2×10^5 tons (Cingolani et al., 2003, 1996; Santojanni et al., 2005, 2003). Nowadays, although the stock biomasses appear to have increased with respect to the first years after the 2000, intense fishing activity prevents a complete recovery (Morello and Arneri, 2009), while younger ages and small-size individuals prevail in catches (data from DCF GSA17 PTM – GFCM-SAC, 2012)], thus leading to a severe reduction of fishing yields/incomes and endangering the conservation of both resources in this area (GFCM-SAC, 2014, 2012). Since the 1990s CNR-ISMAR of Ancona has been carrying out an observers programme aimed to improve the knowledge of the behaviour and the operations of the most important fishing fleets targeting small pelagic species in the Adriatic Sea (Cingolani et al., 1998; Santojanni et al., 2005). Furthermore, in 2003 CNR-ISMAR of Ancona started the Fishery Observing System (FOS), in which a sample of commercial vessels fishing for small pelagic species in the north and central Adriatic Sea was equipped with an integrated system for the collection of data regarding catches, position of the fishing operation, depth and water temperature during the haul (Falco et al., 2011, 2007; Martinelli et al., 2012). This background provides knowledge of many features of PTM fisheries. The peculiarity of PTM fisheries is that net towing is carried out by two vessels which operate in pairs for the entire duration of the fishing operation. The vessel pairs are formed at the beginning of each day and share the catches and the related returns at the end of sales. We will refer to a generic pair of vessels as a unit and to the captain of the unit as the fisherman that makes all the strategic choices for both vessels. The fishing trips start and finish within the same day. The market takes place within 17.00 PM and 21.00 PM. Vessels operate only in daytime, from dawn to the late afternoon/sunset and so catches are landed every evening.

In the PTM, the fishing activity is always preceded by the searching activity, which could be considered as the main driver of fishing effort pattern because it implies movement, which in turn implies temporal and financial costs (Mangel, 1982; Salas and Gaertner, 2004). Although in the last century technological advances in on-board equipment (e.g. acoustic fish-finders, electronic navigation tools) have modified vessels' efficiency in fish detection (Marchal et al., 2006), the searching stage remains largely affected by uncertainty and resource location strategies are the main determinant of fishing effort allocation (Dreyfus-Leon, 1999; Hilborn, 1985b). Several models have been proposed to analyze searching strategies in fisheries sciences (Dreyfus-Leon, 1999; Wise et al., 2012;

Bertrand et al., 2005; Gillis, 2003; Rijnsdorp et al., 2011; Holland and Sutinen, 1999; Wilen et al., 2002) but few studies addressed the case of small pelagic fisheries (Bertrand et al., 2005; Rijnsdorp et al., 2006; Vermard et al., 2010) and, to our knowledge, none of them specifically addressed the strategic aspects of interaction among PTM fishermen, at the scale of individual choices, and their consequences on the whole system at the scale of individual choices (Mulazzani and Malorgio, 2013).

In Europe, since 2005, the analysis of fishing activity on a fine space-time scale has become possible thanks to the enforcement of the Vessel Monitoring System (VMS), a satellite-based technology that allows tracking position of a fishing vessel with a Length Over All (LOA) larger than 15 m (EC, 2008). Therefore, VMS also allows the reconstruction of complex interactions among units in searching mobile (pelagic) resources at sea.

Given that the subject of this investigation is represented by the activity of fishing vessels driven by human decisions which reciprocally influence each other, it seemed reasonable to situate this study in the framework of Game Theory (Nash, 1950; Osborne, 2003). Although Game Theory has been widely applied in fishery science (Bailey et al., 2010), the use of this approach for the analysis of vessel movement as captured by VMS data represents a novelty.

The explicit aims of this study are: (1) to investigate the possibility of modelling the decision-making process (the strategy) applied by fishermen (the captains of PTM units), thus determining the pattern of fishing effort; (2) to assess the dependency of searching strategy from environmental conditions (i.e. using atmospheric pressure and sea surface temperature as proxies), and from two main external economic factors: fuel price and the fish price at market; (3) to clarify the differences in terms of impact on resources for the different scenarios defined by economic and environmental factors.

2. Materials and methods

2.1. Model rationale

The PTM fisheries can be represented as a daily game in which different players compete in order to find and catch the pelagic resources, which are scarce and patchily distributed in the marine space. Finding resources and coming back in time for the market signify success in the game. Basically, each player is able to detect resources in the water column below the unit by an echosounder (Simmonds and Mac Lennan, 2005). Hence, where to search for resources represents the challenge for each player. In this way, each player plays the game choosing the heading of his fishing unit and, in doing this, he observes the behaviour (position and state) of the other players. This because all the units are equipped with radar, which gives a real-time shot of all the other units both in terms of position and speed (inferred by the observation of temporally close signals). Thus, the strategy of each single player can be represented by the series of heading selections, at each 10 min time frame, made throughout the fishing trip. Each player uses different information to select the most appropriate heading. A tentative list of the main factors affecting this decision-making process comprises: (1) the positions of other units currently fishing (if any), since this gives information about areas in which the resources are present; (2) the positions of other non-fishing units, since this could influence the captain's behaviour by suggesting the probable absence of resources (Van Putten et al., 2012); (3) the positions of fishing grounds exploited by the unit itself in the last five days of fishing activity. If the movements of the resources are sufficiently slow, it is likely that resources in the near proximities of the areas already exploited will be found (Carpi et al., n.d.); (4) the position of the harbour and the time required to reach the target fishing

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