Towards a sustainable pulse trawler fleet: insights from a spatial fishing effort allocation model of the Belgian fleet

1. Introduction

The Belgian fishery is specialized in targeting fish species living near the seafloor or in the top layer of the sediment. To catch these demersal species, Belgian fishing vessels typically tow beam trawl fishing gear over the seafloor with heavy tickler chains rigged in the net-opening [1]. Despite its efficiency to capture high quantities of fish, conventional beam trawling with tickler chains is under pressure. First, it has a strong impact on the benthic ecosystem [2], while ecological concerns are rising. Second, fuel usage is high, while fuel prices are increasing. Third, beam trawl fisheries are highly affected by the implementation of the discard ban of the Common Fisheries Policy [3], because discard ratios of non-commercial and undersized species are high due to a poor selectivity for target species [4].

As an alternative, the EU allowed the use of the electrotrawling (pulse trawling) for a part of the beam trawler fleet active in the North Sea [5]. However, pulse trawling is successfully implemented in the Dutch fleet [6], uncertainty about the socio-economic and ecological impact obstructs the transition to pulse trawling in the Belgian fishery and obstructs the development of a pulse trawler fleet in the Belgian fishery. Hidden disincentives such as extra costs, changed catch composition, spatial interactions and quota restrictions may lead to unexpected behavior of fishermen and result in the in the so called implementation error and unintended outcomes of fisheries management [7, 8].

Within the Benthis project, the objective of this study is to find alternative management scenarios to reduce the impact of the beam trawler fishery on the benthic ecosystem. In this study, we assess the socio-economic impact of alternative pulse trawl scenarios in the Belgian fleet. Therefore, a spatially explicit fleet dynamic model is developed to study the changes in fishing effort allocation patterns of the Belgian beam trawler fleet. With this model, two possible scenarios of the current debate concerning pulse trawling in the Belgian fishery are analyzed. A scenario, whereby pulse trawlers are only allowed to fish in the North Sea, is compared with an alternative scenario whereby pulse trawlers are allowed to fish in all areas where Belgian beam trawlers have fishing rights.

2. Methodology

2.1. Agent-based modelling

Tactical decisions of fishermen about when and where to fish are the outcome of their individual preferences, their interactions with the marine ecosystem and their mutual social-interactions [9, 10]. To address the complexity of coupled socio-ecological systems, agent-based modelling has emerged as an appropriate technique [11]. Moreover, agent-based models (ABMs) make it possible to avoid the *ecological fallacy* problem which may arise through aggregation of heterogeneous characteristics of individuals [12]. In fisheries, this internal variability may be caused through individual characteristics of fishermen (skipper effect) or vessel-specific characteristics. Another property of ABMs is the possibility to include qualitative factors, which is difficult in analytical approaches. By taking into account qualitative characteristics like experience, learning ability and bounded rationality, fishermen behavior may be represented in a more realistic way [11]. Other motives for the agent-based approach are the suitability to represent dynamics (e.g. migrations of fish species) and interactions (e.g. interference competition among fishing vessels) occurring at a spatial scale, and the possibility to create heterogeneous landscapes.

2.2. Model description

An agent-based model is developed to simulate the spatial dynamics of commercial Belgian beam trawlers (engine power > 662 kilowatt) during one year. The model simulates the daily behavior of individual fishermen about when and where to fish. We assume that individual fishermen are profit maximizers, which is valid to predict the short-term effort allocation patterns of commercial fishing vessels [13]. Nevertheless, fishermen are characterized by bounded rationality as they are not able to make optimal decisions since fishing is a stochastic process. Additionally, interactions among fishermen may affect their decision making process. This may be indirectly through sharing a common quota or directly through competitive interactions with other vessels on a fishing ground (interference competition) or information transfers whereby fishing tactics of other fishermen are observed through the Automatic Identification System (AIS).

Belgian fishermen are price takers and do not interact via the market. Interactions through depletion of fish stocks are absent as well because fish mortality through fishing activity of Belgian vessels is not significant compared to the total biomass due to the limited capacity of the Belgian fleet. Moreover, the simulation considers a period of one year during which the fluctuations of fish biomass is mainly determined by the seasonal effect as consequence of the migration of fish species.

During the simulation, fishing vessels are at each time step in the *harbor*, *steaming* or *fishing* state (Figure 1). The current state determines which simulation loop a vessel follows and which state a vessel will achieve the next day.

(1) When vessels are in *harbor*, fishing opportunities are evaluated. Firstly, fishermen evaluate both their fishing opportunities by looking to their available quota and the success of the last fishing trip. If the revenue of the last trip was above the expected revenue, fishermen will return to the same fishing ground. If not, the profit from each potential fishing ground is estimated by predicting the revenue and associated variable costs of steaming, fishing and wages for the crew from fishing on a certain patch. Hereafter, the fishing ground with the highest expected profit is set as target ground and the vessel changes its state to *steaming*.

(2) During the steaming phase, all vessels steam at the same speed towards the target patch following the shortest path calculated through the A* path algorithm [14]. If the target ground is reached, a vessel changes its state to *fishing*, otherwise, vessels stay in the steaming loop. The fuel used during steaming is a linear relationship with the engine power of the vessel.

(3) In the fishing loop, a vessel catches an amount of fish related to the patch-specific catch per unit effort (CPUE) which is derived from the electronic logbook data. This stochastic process has a log-linear relationship with the engine power of the vessel and is negatively correlated with the presence of other vessels fishing on the fishing ground through the mechanism of interference competition. At the end of each fishing day, landing quota are updated and fishermen decide whether they will return to harbor or continue the fishing trip. Therefore, the current trip length is evaluated against the average trip-length derived from the logbook data. When the current trip is shorter than the average trip length, a fishermen has the option to continue the fishing trip on the same patch or to switch to an adjacent patch.

    The decision to change from patch is based on the success of fishing on a fishing ground. Therefore, after each fishing day, fishermen compare the catch with the expected catch and decide whether to leave or stay on the current fishing ground.

    When vessels decide to move to another fishing ground, the neighboring fishing ground with the highest number of other vessels is selected since this might indicate a good spot to fish. If there are more than one fishing grounds with the same number of fishing vessels, the fishing ground with the highest expected revenue is selected.

    When the average trip length is exceeded, fishermen decide to return to the harbor and the vessel changes its state to *steaming* until the harbor is reached. In *harbor*, the catch of the trip is sold at the current fish price, the wages for the crew are calculated and the trip-costs, trip-catch and trip-length are reset to zero.

At the beginning of each simulation run, a map is created representing the different fishing grounds of the Belgian fishery on the scale of ICES statistical rectangles (1 degree longitude x 0.5 degree latitude). Each rectangle has a CPUE which fluctuates per month and each rectangle belongs to an ICES area (IVb,c, VIIa, d, e, f, g, h and VIII). CPUE for each species (i: sole, plaice, cod and anglerfish) were derived from the electronic logbook data from the period 2011 – 2013 using a generalized additive regression model (GAM) (eq. 1) with negative binomial error term (ε). In this model, the coefficient β_1 represents the annual effect, the coefficient β_2 is the log linear relationship with a vessels engine power, and the monthly variation in each ICES rectangle is captured by a non-parametric smoother term.

$$CPUE_{sp_i} = \beta_0 + \beta_1 year + \beta_2 + f(month)_{rectangle} + \epsilon \qquad \text{(eq. 1)}$$

Steaming and fishing costs were estimated from econometers which register the daily fuel usage of fishing vessels. Average monthly fish prices were calculated from sales data. Catch efficiency and fuel usage of pulse trawlers were obtained from a study in which Dutch pulse and beam trawlers were compared [15] (table 1), however in this model, a higher catch efficiency of pulse trawlers for sole is used since Belgian beam trawlers fish at lower speeds compared to Dutch beam trawlers using tickler chains.

Table 1: Catch and fuel efficiency of pulse trawlers compared to beam trawlers

	pulse/ beam
Fuel usage (fishing)	42%
Fuel usage (steaming)	100%
CPUE (kg h^{-1})	
Plaice	72%
Sole	110%
Cod	31%

All fishing vessels have an individual quota which is related to their engine power. During each simulation run, the environmental conditions are equal. In the preliminary model, a virtual fleet is setup. Vessels' engine power is a randomly selected integer between 662 to 1200 kilowatt and differs among each simulation run.

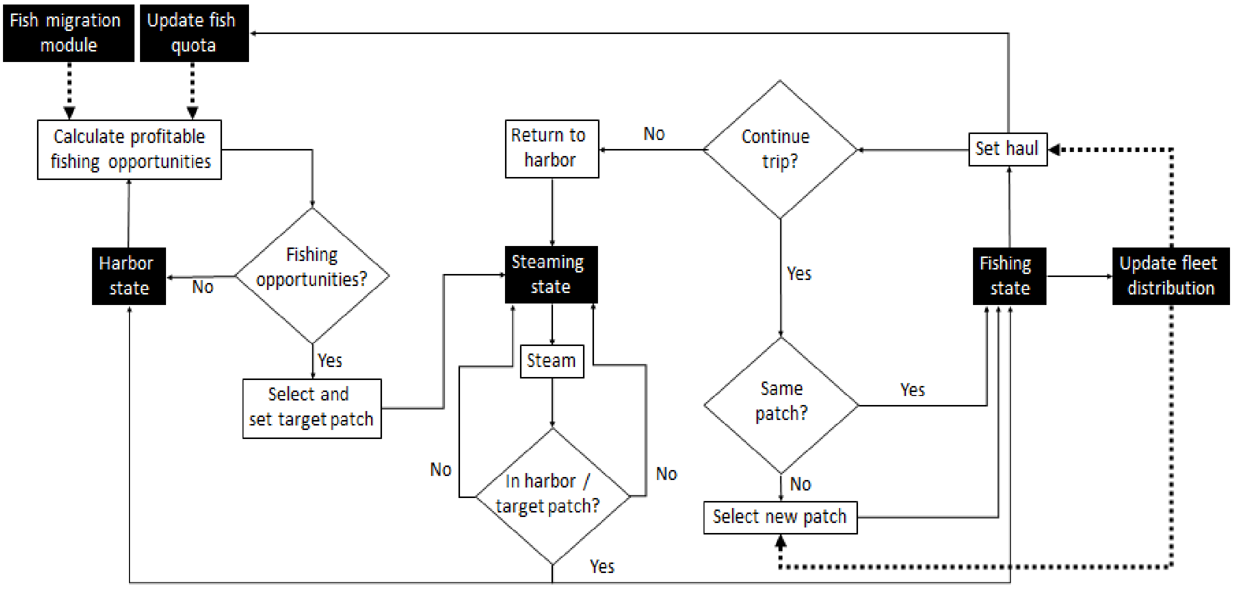

Figure 1: Model flow chart

3. Preliminary results and discussion

Two different scenarios - pulse trawling limited to the North Sea area (IVc) (sc_1) and pulse trawling allowed in all fishing areas (sc_2) - were compared in a simulation with 26 beam trawlers and 4 pulse trawlers with fuel prices ranging from 0.70 to 1.00 euro per liter. Due to time constraints, only one hundred iterations per parameter configuration were conducted.

When the beam and pulse trawler fleet have equal fishing opportunities, the average annual profit of beam trawlers is higher than average annual profit of pulse trawlers when fuel prices are low (<0.82 € l^{-1}) (Figure 2). This is a consequence of the lower catch efficiency for other species than sole which are important bycatches for Belgian fishermen. However, when fuel prices are high, pulse trawlers are more profitable when they are allowed to fish in all areas. This is a consequence of the lower fuel usage during fishing and obviously, this difference strengthens with rising fuel prices. Nevertheless, when the fishing activity of the pulse trawler fleet is limited to the North Sea area, they are less profitable. Firstly, pulse trawlers do not have access to the most profitable fishing grounds at each time step. Secondly, pulse trawlers are not able to fish during the whole year since the North Sea sole landing quota is sooner depleted when they are allowed to fish year-round in the North Sea area.

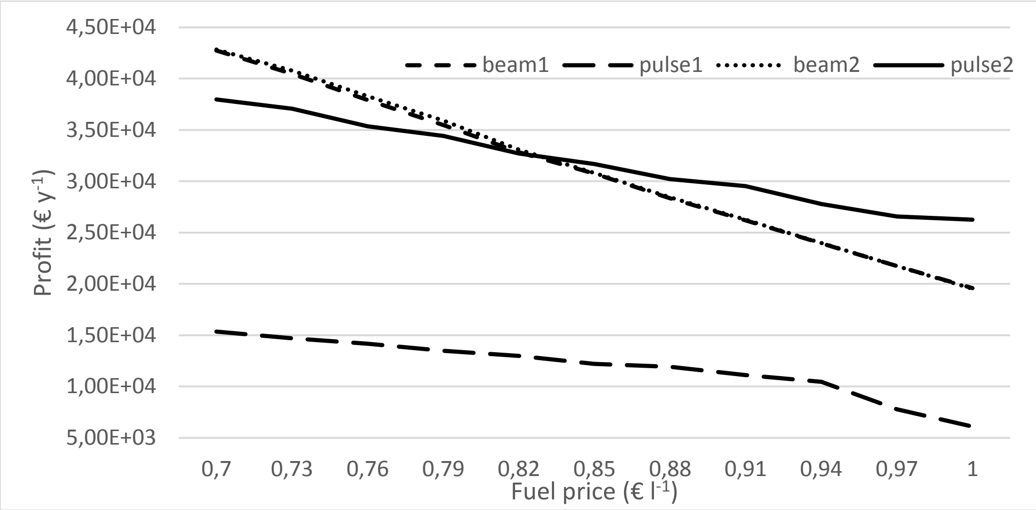

Figure 2: Average profit of beam and pulse trawlers (1: scenario 1; 2: scenario 2).

An important difference between pulse and beam trawlers is that pulse trawlers fish more in the Southern part of the North Sea and the Eastern English Channel and thus closer to Belgian harbors. Since pulse trawling is characterized by a lower catch efficiency for plaice, cod and anglerfish, pulse trawlers avoid fishing grounds with high abundance of these species and allocate more fishing activity on fishing grounds where the ratio of sole in the total catches is higher. Additionally, fishing costs per day are 50% lower of pulse trawlers while steaming costs per day are equal compared to beam trawlers. Hence, the ratio of the steaming costs is higher in the total fuel costs for pulse trawlers. As a result, pulse trawlers have a stronger incentive to reduce steaming costs and allocate more fishing effort on fishing grounds closer to harbors. This is the reason why steaming costs of pulse trawlers are lower compared to beam trawlers when they have similar fishing opportunities (Figure 3).

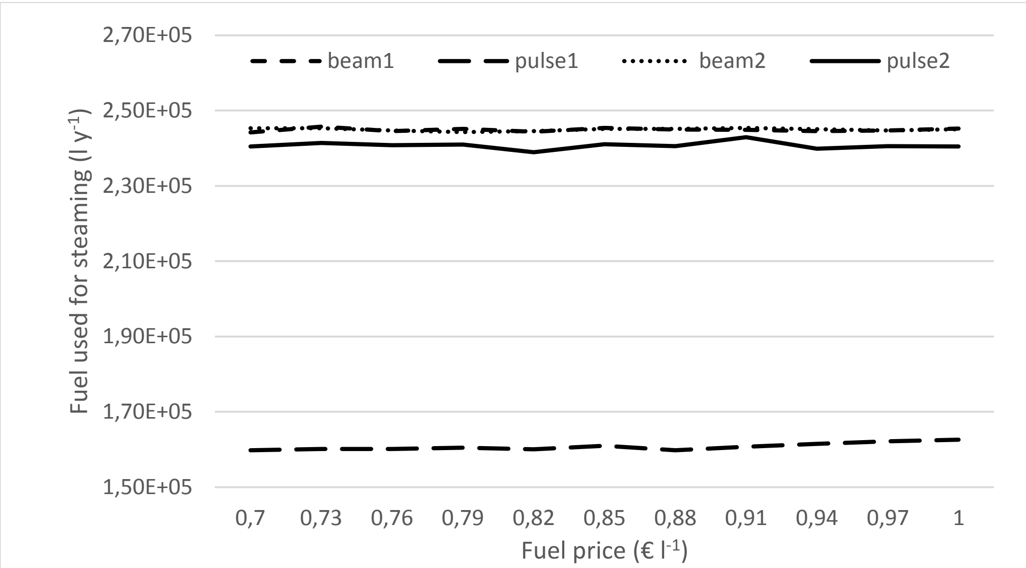

Figure 3: Average fuel usage of beam and pulse trawlers to steam to fishing grounds (1: scenario 1; 2: scenario 2).

The current model is under construction and further parametrization and validation needs to be done. Therefore, results should be interpreted carefully and no unequivocal conclusion can be drawn. Nevertheless, it is clear that such an approach, starting from the decision making process of individual fishermen, offers a robust framework to evaluate ecological and socio-economic outcomes of different management scenarios by providing insights in the underlying process mechanisms. Hence it may be used as a tool for the evaluation of policies with different stakeholders, or for individual vessel owners to evaluate investment strategies (e.g. new fishing gear) taking into account their personal characteristics and vessel characteristics.

The preliminary model used in this abstract is a simplification based on literature and expert knowledge. By means of interviews with fishermen and experts, the model will be validated in the next step. This will allow to gain more insights in qualitative factors affecting the operation of fishing vessels and improve the accuracy of the results.

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