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# A MICROECONOMIC MODEL OF DISCARDING BEHAVIOUR

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## ABSTRACT

This paper proposes a formal analysis of the discarding issue including the sorting labour costs. Empirical evidences from an application to the *Nephrops* fishery in the Bay of Biscay show that sorting is an important time consuming activity on board and a factor of discarding. However existing literature does not explicitly take into account the sorting activity and mainly focus on quota and catch constraints. The discarding model described in the paper includes sorting as a factor explaining discards. The costs of sorting landings and the time to sort them are included in the approach. The model is developed for one species studied at a tow scale with the assumption that catches are exogenous. It is shown that taking sorting costs into account, discarding of one species may occur and that time or effort constraints can induce an over incentive to discard.

**Keywords:** discarding behaviour, sorting, microeconomic model, *Nephrops* fishery, effort constraints

## 1/ INTRODUCTION

In the available literature describing microeconomic models of discarding behaviour, it is assumed that fishermen behaving rationally throw over board a proportion of the catches, the discards, to maximize their profit subject to the exploitation constraints ([1], [2], [3], [4], [5], [6]). Existing papers study discarding behaviour at different scales -year, season or trip- according to the structure of the profit function and constraints on the level of quotas or catch constraints

Arnason [1] focuses on effort and discarding levels that maximise profit per fishing operation according to a constraint of sustainability of the stock. The incentives to land or discard each grade depend on the price received per grade, the cost of effort, the costs of landings including preliminary fish processing, storing and handling and the costs of discarding fish. A discarding function defines the condition under which discarding occurs according to the value of the difference between the landing costs and the price and discarding costs. If the value is positive for a grade, the catch of that grade is discarded. If the value is negative the grade is retained. Arnason [1] finds that discarding may be socially optimal in a fishery that catches several grades and that in open access the incentives to discard lead to optimal behaviour. IQs on the other hand tend to increase the incentives to discard.

Anderson [2] presents a discarding model with an hold capacity constraint. He considered two grades in the catches one of high price the other of low price. The objective function to maximise is the profit per trip subject to the hold capacity constraint and the constraint that the amount of discards must be less than the total quantity caught. Landing costs are not taken into account in the profit function. Only the cost of effort and costs of discarding proportional to the quantity of discards are considered. He reaches the same conclusion as Arnason except that incentive to discard in open access is found to be lower than in an optimal fishery. Vestergaard [3] uses data from the shrimp fishery in Greenland in a discarding model similar to Anderson's. He considers several grades and the scale studied is the fishing season. He assumes that fishermen maximise their profit according to the discarding rate, the trip length and the number of trips per season. Landing costs are also neglected in the profit function. He finds that discarding may exist without any management of the fishery and that individual non-transferable quotas increase the incentive to discard. However the incentives depend on the quota price in the case of transferable quotas. In the paper of Arnason [4], the harvesting technology is endogenous and the fishermen decide to discard or to adopt a more selective technology according to the relative costs of selectivity and discarding. Impacts of the selectivity on the catch composition and therefore the sorting time is however not included in the analysis and the landing costs are therefore under estimated. Wiium ([6], [7]) extents previous work by including long term effects on fish stocks, costs of effort, landings and discards. This is a two grades model of the same species that enables to find the social optimum by considering a constraint of sustainability of the stock. The social optimum is compared to the individual optimum that only takes into account the catch constraint. The impacts of several management policies on economic incentives to discard and as a consequence on the stock depletion are assessed. He finds that if management policies may induce excessive discarding they are not responsible for a stock depletion as they limit the effort and the fishing mortality. These papers focus mostly on the major problem of high grading in fisheries submitted to quota constraints or hold capacity constraints.

Most of the discarding models don't mention the sorting costs [2], [3] and the other papers neglect them in the analysis or integrate them not explicitly in the landing costs [1], [4]. Time spent to sort, and therefore sorting costs are not taken into account. However, sorting the landings from the catches may be an important labour task for crews. Sorting is a productive activity that consists in extracting from the catches, landings that can be sold on the fishing markets, discards being thrown over board. This activity is a costly task with usage costs and potentially opportunity costs. Even if the sorting activity is more or less labour intensive, these inputs cost for the fishing units. Moreover, crew labour time is a rare resource and sorting, as a time-consuming and difficult activity may be in competition with other productive (hauling nets, etc) or/and non productive activities providing less displeasure (rest) In this context, it could be rational for fishermen to discard or not, according to the nature and level of sorting costs and the potential constraints on sorting time.

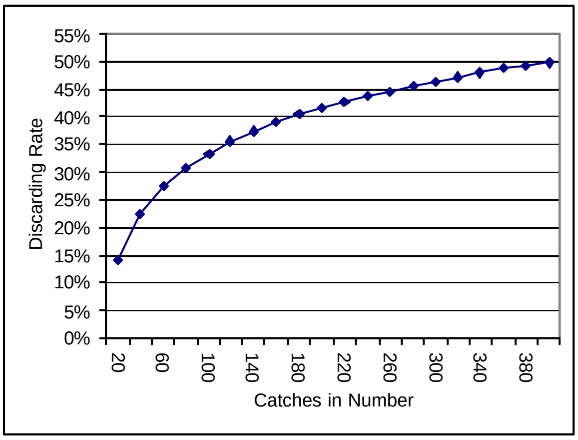
The objective of the paper is to present a formal microeconomic model of discarding including sorting. The case study of the *Nephrops* fishery in the Bay of Biscay provides empirical evidences of the importance of the sorting activity and sorting costs as a factor of discarding. Based on these results, a discarding microeconomic model is described that assumes fisherman profit maximisation at a tow scale. The model is one grade model with exogenous catches. The sorting function of the landings is expressed as a concave function of the sorting time and the volume of catches. Discarding behaviours are presented without any time constraints then with a constraint on trip or tow duration. Changes on the optimal levels of discards are discussed in the context of an increasing number of regulations on the level of effort and time at sea.

## 2/ EMPIRICAL EVIDENCES FROM THE NEPHROPS FISHERY IN THE BAY OF BISCAY (ICES SUB-AREA VIIIa,b)

The trawler fleet operating in the Nephrops fishery is one of the most important in the Bay of Biscay. In 2003, 234 bottom trawlers were indeed involved in the fishery representing around one quarter of the trawlers operating from the Bay of Biscay districts [8]. This fishery encounters a major problem of discarding in a context of the low selectivity of the trawling gear. In 2003, 60% of the Nephrops caught in number was indeed estimated to be discarded [9]. High levels of by-catches and large quantities of discards are also yielded for hake, anglerfish and megrim.

Surveys carried out in the Nephrops trawl fleet in the Bay of Biscay [10] provide two important preliminary qualitative results. Sorting appears to be the main task aboard as about one third of the labour time on board is spent to sort the fishes and it is moreover the more difficult activity compared to all the others. Another qualitative result was that the sorting time increases with the volume of the catches and that it becomes more and more difficult therefore longer and longer to sort.

Since 2002, landings and discards data by tow have been collected on board (Obsmer, IFREMER). About 130 trips and 300 tows were sampled. Based on this data set, a statistical analysis of the factors explaining the catches and discards expressed in number per tow was carried out. The preliminary results of a General Linear Model are provided in the appendices. The results validate and complete the qualitative approach. Figure 1 and 2 present the results of the statistical GLM analysis, giving a representation of the relationship between the discarding rate in number of individuals, the catches in number and the crew size, respectively (see appendices for detailed results). Figure 1 shows that the higher the level of the catches is, the higher the discarding rate is and that discarding rate increases at a decreasing rate. This means that given a level of sorting effort (crew size, time available to sort), a high catch level will yield higher discards. A part of this result can also be explained by a change in the catch composition made of a higher proportion of small individuals to be discarded because of a minimum landing size for example. Figure 2 shows increasing the size of the crew from 1 to two members contributes to a reduction of the discarding rate of less than a proportional reduction in the discarding rate, *ceteris paribus*. The decrease in the discarding rate, when the crew size increases may validate a non linear sorting function.



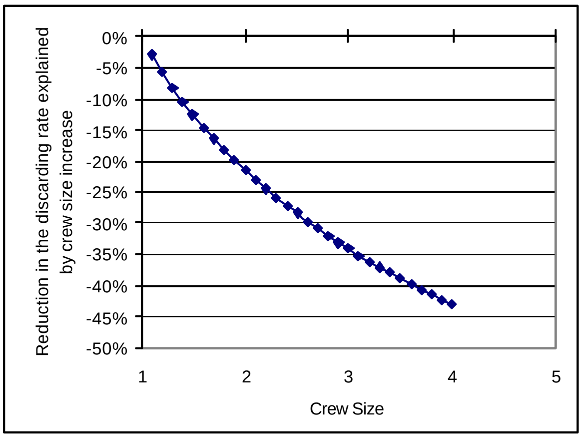


**Figure 1.** Discarding rate as a function of the catches in number

**Figure 2.** Reduction of the Discarding Rate explained by crew size increase

The results (fig.3) also show that fishing effort measured as the duration of the tow by the horse power of the vessel, has a significant influence on the level of the catch, but the variability of the catches per haul is mainly explained by other external factors (90%). A similar indication of the high variability of the standardized catch per unit of effort at the tow scale is provided by the following figure. This means that the catches are beyond the control of fishermen and can be assumed as exogenous in the model

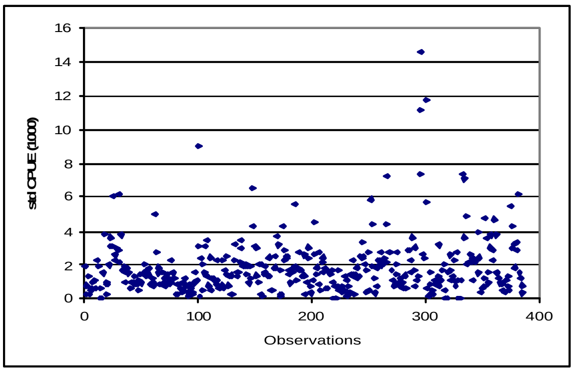


**Figure 3.** Standardized catches per unit of effort Source: Ifremer Obsmer
Note: catches in number, fishing effort measured as tow duration by the horse power

Empirical aspects therefore prove the importance of the sorting task and enable to justify a part of the assumptions of the model presented in the next section.

## 3/ THE DISCARDING MODEL AND THE SORTING FUNCTION

### Assumptions and notations

In this section, the structure of the discarding model including sorting costs is presented. We assume that the fisherman behaves rationally and tries to maximize his profit per tow. The optimization model enables to determine the level of landings to sort (therefore the optimum level of discards) that maximizes the profit of one boat by tow. We assume that only one species of positive market value is to sort among a total volume of catch constituted of the species studied, other species that do not have any market value or substratum.

Let $Y$ be the catch of the species to sort, $L$ the landings and $Y - L$ the discards of this species. $bY, b \geq 1$ represents the total volume caught in the trawl. These variables can be defined by tow or trip. The volume of the species studied caught $Y$ per tow or trip is assumed to be exogenous. We assume here that the total volume caught is a function of the volume of the species of interest caught $Y$. Another assumption would be to suppose that the volume of substratum or other catches $Y_o$ is independent of the volume of the species caught and to assume a total volume caught $Y + Y_o$.

### The sorting function

Sorting is a productive activity that results in landings as output and requires catches and sorting labour as inputs. A comparison to the productive activity of fishing can be made. Catches would be the equivalent of the biomass and the sorting labour, the equivalent of the fishing effort. As catches results in the fishing effort on the biomass, landings results in the sorting labour on the catches.
According to the empirical results obtained and the previous considerations, we assume that the production function of landings or sorting function is a function of the time to sort T and the catches Y. L=f(Y, T). We assume that it is longer and longer to sort, to extract the landings from the catches as sorting efficiency is decreasing. We thus suppose that the sorting time is as long as the volume of landings of the species to sort is important with regard to the tiredness and the difficulty of this task. The sorting function is therefore a concave function (fig.4). The sorting function also depends on the total volume of catches[1].

The sorting function is also assumed to tend asymptotically to Y the total catch.
L=f(Y, T) has the following properties:

- if Y=0 or T=0 then L=0
- $\frac{\partial f}{\partial Y} > 0$
- $\frac{\partial f}{\partial T} > 0, \frac{\partial^2 f}{\partial^2 T} < 0$
- $\lim\limits_{T(L)\to\infty} f_Y(T) = Y$

We assume in this work that the catches are exogenous, the landings function becomes: L=$f_Y$(T).

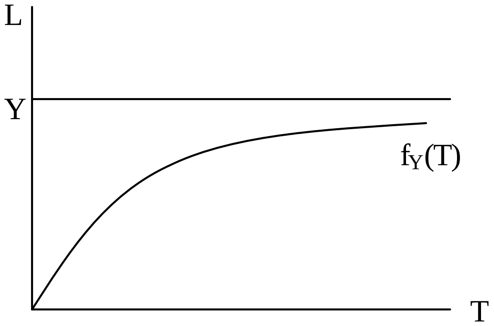


**Figure 4.** Shape of the sorting function

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[1] It is indeed easier to sort L=50kg of Nephrops in a global volume Y1 of 100kg of substratum, Nephrops or other by catches, with (if ) than the same amount in a volume Y2 of 500kg (fig 1), with (if ).

A possible specification for the sorting function is to use the Spillmann function:

$$L = Y(1 - e^{-bT)}), b > 0$$

### The profit function

The profit from the landings $L$ is defined as following:

$$\Pi_Y(L) = R(L) - Cs = pL - Cs = pL - c_s T \qquad \text{(Eq.1)}$$

Where R(L)= $pf_Y(T)$ is the revenue from the landings L and $Cs$, function of the time to sort the landings $T$ , represents the sorting costs of the landings. $c_s$ being the unit cost of sorting time, Cs=csT (fig.5). The price p is first supposed to be exogenous; fishermen are assumed to be price-takers. Discarding costs are assumed to be insignificant with regard to the sorting costs of landings.

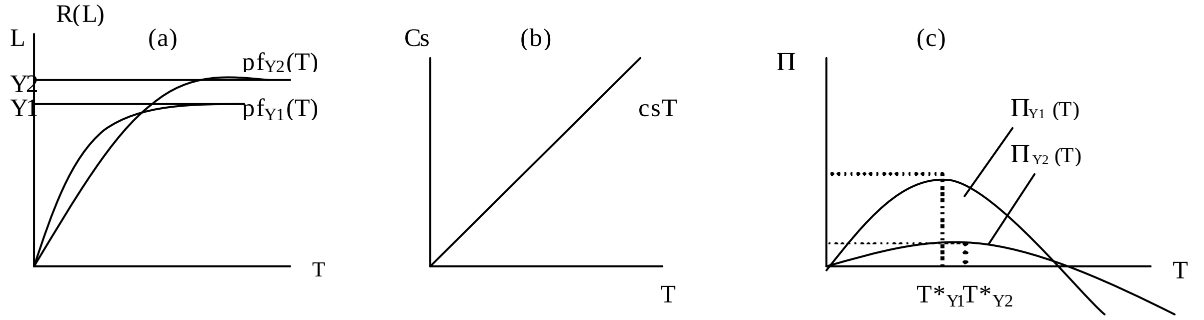

**Figure 5**. Shape of the functions of revenue (a), sorting costs (b), and profit (c)

Assuming $Y_1 < Y_2$, $f_{Y1}(T)$ and $f_{Y2}(T)$ are represented in figure 5(a). The corresponding profit functions $\Pi_{Y1}(T)$ and $\Pi_{Y2}$ (T) represented in figure.5 are so that $\Pi_{Y1}$ (L) > $\Pi_{Y2}$ (L) for each L and the optimum level of landings L* is smaller when the global catch is higher: $L^*_{Y2} < L^*_{Y1}$.

## 4/ OPTIMUM LEVEL OF DISCARD WITHOUT CONSTRAINT

In order to maximize the profit per tow, the fishermen choose the optimum sorting time $T \geq 0$ that gives the level $L$ of sorted landings.

The maximum profit is fund by maximizing the function:

$$\max_T \Pi_Y(L) = \max_T(R(L) - Cs = \max_T(pL - csT), T \geq 0 \qquad \text{(Eq. 2)}$$

With L=$f_Y$(T).

Which maximizes the difference between the revenue from landings and the cost of sorting them.

It is equivalent to determine:

$$\max_{T(L)}(pf_Y(T) - csT), T \geq 0 \qquad \text{(Eq.3)}$$

The first order condition is:

$$\frac{d\Pi_Y(L)}{dT} = 0 \Rightarrow p\frac{df_Y(T)}{dT} - cs = 0 \qquad \text{(Eq.4)}$$

$$\Rightarrow \frac{df_Y(T)}{dT} = \frac{cs}{p} \qquad \text{(Eq.5)}$$

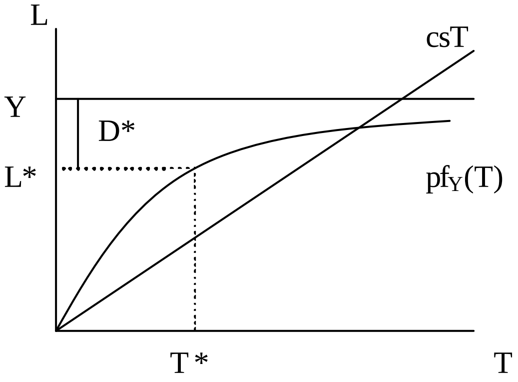

**Figure 6.** Shape of the cost and revenue functions and optimal level of sorting time, sorting and discarding

The second order condition is:

$$\frac{d^2\Pi_Y(L)}{d^2T} < 0 \Leftrightarrow p\frac{d^2 f_Y(T)}{d^2T} < 0 \Leftrightarrow \frac{d^2 f_Y(T)}{d^2T} < 0 \text{ that is true per assumption} \qquad \text{(Eq.6)}$$

The optimal sorting time is the one that verifies the first condition that means that the marginal production of the sorting equates its real costs, the optimal sorting time being positive or null.
An optimal volume of landings corresponds to the optimal sorting time. In this case, a part of the catches Y-L*=D* is to be discarded to reach the optimum of profit.

Application: assuming a Spillmann sorting function $L=Y(1-e^{-bT})$, the first condition gives:
$f'_Y(T) = bYe^{-bT}$

and T* the optimum sorting time is so that $e^{-bT^*} = \frac{Cs}{bpY} \Leftrightarrow T^* = \frac{1}{b}(\ln pY + \ln b - \ln Cs), bpY > Cs$

From T* , assuming p=1, we deduce L* and the level of discard.

This shows that discarding can occur even in the case of only one species or grade to sort among a volume of substratum or other catches. According to the sorting cost of landing and the benefits expected, the fisherman may be incited to discard.

When assuming that the volume of catch is endogenous, the fisherman can choose the effort E that enables him to catch the volume Y and he chooses as well the volume of landings L that he wants to land per tow and therefore per trip. In the case of one species or grade to sort the fisherman adjusts his effort to not discard. He chooses the effort corresponding to a volume of catches that if landed maximizes the profit.

## 5/ OPTIMUM LEVEL OF DISCARD WITH TIME CONSTRAINT

Fisheries are often submitted to time constraints that are not developed in the literature. These constraints can be vessel operation constraints; the trip may be limited by the auction time for example, by habits [11], the need to haul the next tow to preserve the quality of the catches may limit the sorting time per tow. Time constraints can also result in management measures as trip duration limit in fisheries regulated by effort.

In this section we express explicitly the sorting costs as a function of the sorting time and we assume that there is a time constraint, either a maximum tow duration (over which catches quality becomes bad for example) or a limitation on the trip duration (or hold capacity). We assume that the sorting work has to be achieved when the next tow is hauled. The time constraint is expressed as a sorting time constraint. If the analysis level is the trip, we consider that the sorting time can not exceed the maximum trip duration.
The sorting time constraint is expressed as following:

$$T \le T_{\max}$$

In this case the fishermen choose the volume of landings that maximises the profit subject to the constraint that landings have to be less than catches and sorting time can not exceed the trip length or tow length. The catches are assumed to be exogenous. The maximisation problem is:

$$\max_{T} \Pi_Y(L) = \max_{T(L)}(R(L) - Cs) = \max_{T(L)}(pL - csT), \mathrm{T} \ge 0$$

subject to (Eq. 7)

$$T \le T_{\max}$$

$c_s$ represents the unit sorting cost (per time unit)
The Lagrangian is expressed as:

$$\ell(L, l) = \Pi_Y(L) + l\,(T_{\max} - T) \qquad \text{(Eq. 8)}$$

where λ is the Lagrangian multiplier associated with the sorting time constraint.

The first order conditions are:

$$\frac{\partial \ell}{\partial T} = 0 \Leftrightarrow \Pi'_Y(L) - l = 0 \Leftrightarrow \Pi'_Y(L) = l \qquad \text{(Eq. 9)}$$

$$\Rightarrow \frac{df_Y(T)}{dT} = \frac{cs + l}{p} \qquad \text{(Eq. 10)}$$

The exclusion conditions are:

$$l\,(T_{\max} - T(L)) = 0 \Rightarrow \begin{cases} T(L) < T_{\max} \Rightarrow l = 0 \\ l > 0 \Rightarrow T(L) = T_{\max} \end{cases} \qquad \text{(Eq. 11)}$$

According to the value of $T_{\max}$ and T(L*) several cases are possible:

Case 1:

$$T(L^*) < T_{\max}$$

In this case, the sorting time constraint is not binding and λ the Lagrangian multiplier is null, a part of the catches Y-L* is discarded to reach the optimum profit as in the case without time constraint

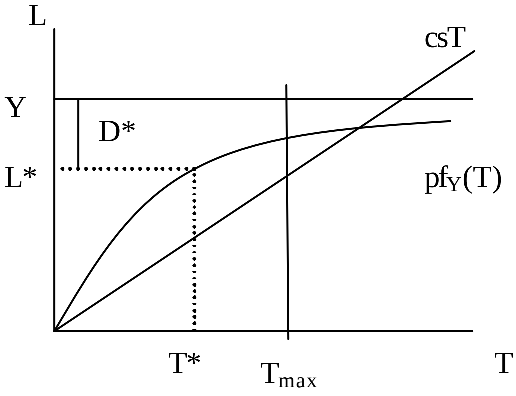

**Figure 7.** Shape of the cost and revenue functions and optimal level of sorting time, sorting and discarding in the case of a time constraint $T(L^*) < T_{\max}$

Case 2:
$T(L^*) > T_{\max}$
In this case, the sorting time constraint is binding ( $l > 0$ ) and a part of the catches Y-Lmax is discarded to reach the optimum profit

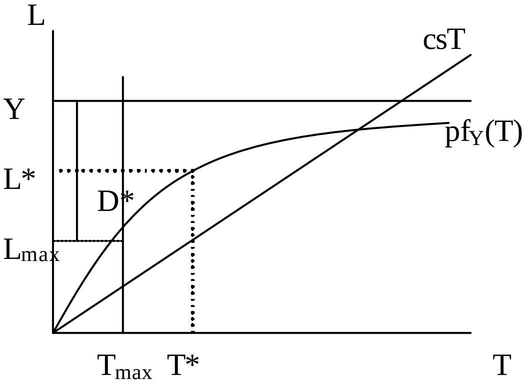

**Figure 8.** Shape of the cost and revenue functions and optimal level of sorting time, sorting and discarding in the case of a time constraint $T(L^*) > T_{\max}$

In comparison with a situation with no constraint of sorting time, there is additional discarding: $L_{\max} - L^*$
Time constraints can therefore induce over incentives to discard as well as constraints on the outputs mainly studied in the literature (quota constraints and hold capacity constraints)
In the case of decreasing sorting efficiency, the sorting time constraint can become binding during the tow or the trip. A part of the catches is discarded in this case.
This enables to understand heterogeneous discarding behaviours along the trip or tow. At the beginning of the sorting work fishermen would have the discarding behaviour of the first case then the sorting costs increasing they would discard as in the third case.
A sorting time constraint incites to discard more.

## 6/ DISCUSSION AND CONCLUSION

Empirical evidences have shown the importance of the sorting task and therefore the need to take this productive activity into account when describing discarding behaviour. When sorting is neglected, the costs of landings are therefore underestimated as well as the optimal level of discards and the constraints on the sorting time are not included. By taking into account the sorting costs, we show in this paper that discarding behaviour might occur when only one commercially species is to be sorted among other species or non-commercially species. The existence of at least two grades of different price is not a necessary condition to observe discards. The analysis of discarding also show that time constraints (e.g. constraint on the input of the sorting function of the landings) can create conditions for over discarding in comparison with a situation with no limitation on the effort. As the constraints on the landing (quotas, IQ, hold constraints) described in the literature, limitation on the effort may induce over incentives to discard.

This work is to be developed to describe sorting behaviour when catches are assumed to be endogenous and in the case of several grades of positive market value to sort. This is the general case in mixed fisheries, in the *Nephrops* fishery of the Bay of Biscay for example at least two grades of *Nephrops* are sorted and a high number of other species. Sorting and discarding behaviour should also be analyzed at the trip scale. Additional data analyses are still in process to identify the factors of discard and validate the approach.

This analysis has vocation to be developed and adapted to be able to include a discarding behaviour component in bio economic models of simulation of management measures. This would enable to take into account the changement of discarding behaviour resulting from the modifications in costs and benefits induced by the adoption of a management measures as selectivity measures that would enable to "sort on the bottom instead of on board".

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## APPENDICES

**Table .** Results of the GLM models

| | R2 | F Value | Pr > F | | | R2 | F Value | Pr > F | |
|---|---|---|---|---|---|---|---|---|---|
| **% of discards in number** | 0.683 | 202.830 | <.0001 | | **Ln Catches in number** | 0.082 | 4360.590 | <.0001 | |
| Parameter | Estimate | S.E | t Value | Pr > \|t\| | Parameter | Estimate | S.E | t Value | Pr > \|t\| |
| Intercept | -0.142 | 0.136 | -1.040 | 0.3001 | Intercept | 4.466 | 1.309 | 3.410 | 0.001 |
| Ln Catches in Number | 0.119 | 0.011 | 11.010 | <.0001 | Ln TowDur.*HPower | 0.380 | 0.127 | 3.000 | 0.003 |
| Ln Crew Size | -0.310 | 0.067 | -4.650 | <.0001 | annee 2002 | -0.762 | 0.168 | -4.540 | <.0001 |
| Year 2003 | -0.284 | 0.053 | -5.390 | <.0001 | annee 2003 | -0.517 | 0.147 | -3.510 | 0.001 |
| Year 2004 | -0.044 | 0.021 | -2.090 | 0.0382 | annee 2004 | -0.321 | 0.156 | -2.060 | 0.040 |
| Year 2005 | 0.000 | . | . | . | annee 2005 | 0.000 | . | . | . |
| Quarter 1 | -0.026 | 0.034 | -0.780 | 0.437 | | | | | |
| Quarter 2 | -0.163 | 0.029 | -5.620 | <.0001 | | | | | |
| Quarter 3 | 0.022 | 0.028 | 0.760 | 0.4461 | | | | | |
| Quarter 4 | 0.000 | . | . | . | | | | | |
| Riggs 1 | -0.095 | 0.025 | -3.820 | 0.0002 | | | | | |
| Riggs 2 | 0.000 | . | . | . | | | | | |
| Harbour Belon | -0.189 | 0.097 | -1.940 | 0.0541 | | | | | |
| Harbour Concarneau | -0.202 | 0.050 | -4.030 | <.0001 | | | | | |
| Harbour La Cotiniere | -0.292 | 0.102 | -2.860 | 0.0048 | | | | | |
| Harbour Le Guilvinec | -0.007 | 0.028 | -0.250 | 0.8042 | | | | | |
| Harbour Les Sables | 0.021 | 0.083 | 0.250 | 0.8036 | | | | | |
| Harbour Lesconil | -0.066 | 0.043 | -1.540 | 0.1253 | | | | | |
| Harbour Loctudy | -0.029 | 0.050 | -0.570 | 0.5707 | | | | | |
| Harbour Lorient | 0.072 | 0.055 | 1.320 | 0.1893 | | | | | |
| Harbour Quiberon | 0.074 | 0.085 | 0.870 | 0.3856 | | | | | |
| Harbour Saint Guenole | 0.000 | . | . | . | | | | | |
| Depth in meters | 0.002 | 0.001 | 2.420 | 0.0164 | | | | | |