Model identification for flexible multifleet-multispecies fisheries: a simulation study

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Model identification for flexible multifleet-multispecies fisheries: a simulation study

F. Laloë, N. Pech, R. Sabatier, A. Samba

Abstract

In multifleet-multispecies fisheries exploitation, fishing units of some fleets may choose between different fishing tactics targeting different species combinations. Such fishing units may be very important for different reasons, and must be accounted for in global frameworks. Such a framework was built in order to qualitatively represent the main features of the Senegalese artisanal fishery. Simulations may be carried out with output comparable to available data, so that the parameters of the model may be estimated using a least squares criterion. One of the sources of uncertainty comes from a lack of knowledge of both the real dynamics of the fishing strategies and the dynamics of the harvested populations. We show, with a simple simulated fishery, that very different models may fit classical catch effort data, and that the assumptions made on the 'biological' and on the 'socio-economical' aspects of the fishery are very closely linked. We also show some of the consequences of the choice of a model in terms of prediction of results for economical and biological aspects.

Keywords: Multifleet-multispecies fisheries; Population dynamics; Fleet dynamics; Adjustment; Model identification

1. Introduction

The main objectives of fisheries management – or the evaluation of the results of management – are usually based on the abundance of harvested stocks. ‘Optimal’ fishing effort and/or mortality, total available catches (TACs) or individual transferable quotas (ITQs) are mainly determined in this way (Stephenson and Lane, 1995). These management objectives and tools may be more or less efficient, depending on the strategies of fishing units and the socio-economic context of the fisheries exploitation. When each fishing unit is specialized in harvesting a given component (or a given set of components) of the resource, it is quite ‘easy’ to express its nominal effort in terms of fishing mortality. It is also the case when an ITQ or a TAC is given for each fishing unit, or set of fishing units. The problem is more difficult when fishing units change their target, due to the bio-socio-economical context. Such fishing units, as parts of integrated fisheries (Garrod, 1973), may appear efficient, they may also be very important for economical and social reasons. Moreover, in some significant cases, their flexibility may be a condition for their viability. Hence, they must be taken into account in the global frameworks of fisheries exploitation.
Such frameworks were built in many cases (Hilborn and Ledbetter, 1979; Silvert and Dickie, 1982; Allen and MacGlade, 1986; Laurec et al., 1991; Laloë and Samba, 1991; Hilborn and Walters, 1992). A common approach is to consider that a fishing unit has a strategy, defined by a set of tactics (or 'métiers') and a decision rule for adopting one of the available tactics with a certain probability at a given step of time. A set of fishing units having the same strategy constitutes a fleet. Tactics are defined by their impact on the various components of the resource (e.g. by catchability vectors if we represent the abundance of the various components of the resource with surplus production models). With such definitions, strategies refer to fishing units, and tactics refer to fishing actions or fishing trips.

2. A model

The framework we shall use here includes \( K \) strategies, \( J \) tactics and \( I \) resource components. Each resource component \( i \) is modelled by a surplus production model

\[
\frac{dB_{it}}{dt} = r_i \times B_{it} \times \left( 1 - \frac{B_{it}}{K_i} \right) - \sum_{j=1}^{J} q_{ij} \times f_{jm} \\
\times (B_{it} - \alpha_{ij,m} \times K_i)
\]

where \( B_{it} \) is the biomass at time \( t \) of the \( i \)th component of the resource, \( r_i \) and \( K_i \) the growth rates and carrying capacities and \( f_{jm} \) the number of fishing trips with tactic \( j \) during the step of time \( m \). Catchabilities \( q_{ij} \) depend on the resource component and the tactic. It is assumed that a proportion \( \alpha_{ij,m} \) of the carrying capacity relative to the \( i \)th species remains inaccessible to the tactic \( j \); this proportion may be seasonal, in which case \( \alpha_{ij,m} = \alpha_{ij,m+12l} \forall l \) (for a monthly step of time).

The \( f_{jm} \) values are computed from the proportion of fishing units of the various strategies having chosen tactic \( j \) during the step \( m \). Those proportions are functions of the previous choice and of revenues \( R_{f(k),m} \) expected from previous results in terms of revenues obtained with the available tactics during the previous month and the same month of the previous year

\[
p_{kj,m+1} = f(p_{kj(k),m}, R_{f(k),m}, R_{f(k),m-1})
\]

\( p_{kj,m+1} \) is the proportion of fishing units of the \( k \)th strategy which adopt the \( j \)th tactic during step of time \( m+1 \). \( J(k) \) the set of tactics available to units of strategy \( k \). \( f \) a function, which leads to an increase or decrease in \( p_{kj} \) if expected revenues with \( j \) are globally higher or lower than the revenues obtained with the other tactics in \( J(k) \). Revenues are obtained by

\[
R_{j,m} = \sum_{i=1}^{I} P_{i} \times q_{ij} \times (B_{i,m} - \alpha_{ij,m} \times K_i) - C_j
\]

where \( P_{i} \) is the price of the component \( i \) (per kg), \( B_{i,m} \) the mean biomass of component \( i \) during the step \( m \) and \( C_j \) the cost of a fishing trip with tactic \( j \). \( C_j \) may also represent the opposite of opportunity cost for tactics that consist of a non-fishing activity.

Such a model includes a great number of parameters. If there are \( K \) strategies, \( J \) tactics and \( I \) resource components, there are at least \( I \) growth rates, carrying capacities and, prices; there are \( J \) costs, \( JI \) catchabilities and \( JID \) inaccessibilities (\( D \) being the number of time steps in a year). There are also \( K \) number of fishing units. Eventually, there are the parameters of the function \( f \) (Eq. (2) which could be different among the \( K \) strategies)... These parameters may not be constant over time, and changes may be introduced in order to reflect changes in the environment of the fishermen and the fish. These changes may be very straightforward (a change in the prices of a resource component) or introduced to reflect a change in something not explicitly stated in the model (e.g. an arbitrarily high cost of fishing with a tactic that is undesirable for some reason, may be reduced to a 'normal' value if this tactic becomes accepted). Using such a model, with initial values of the variates describing the system (initial biomass \( B_{i,0} \) and initial proportions \( p_{kj,0} \), we may simulate a fishery, and obtain times series values of many variates (biomass, efforts, catches, revenues etc.).

This model has been used in order to represent the main features of the Senegalese artisanal fishery (Laloë and Samba, 1991). In that case, the framework included \( K=9 \) strategies, \( J=11 \) resource components and \( J=18 \) tactics. Results were acceptable, with some plausible explanation of main changes observed in the fishery, which were difficult to reflect with models assuming that units of a fishing fleet always use the...
same tactic. But those results were obtained by tuning parameters, without using any quantitative fitting method.

However, it is important to use such quantitative methods in order to estimate the values of the parameters that lead to the minimization of some criterion reflecting the resemblance between observed (available) and fitted data. Those data are relative to both the fishing activity and the fishing results.

3. Parameter ‘estimation’

Parameter estimation is done for subset $\theta_1$ of the whole set of parameters $\Theta$, by searching for the values $\hat{\theta}_1$ that minimize a mean squared criterion, as given for example in the Eq. (4), for a given values of the other parameters ($\Theta = \{\theta_1, \theta_2\}$). This operation is carried out done with a computer program written with the S-PLUS© statistical package.

$$
\hat{\theta}_1 = \arg \min_{\theta_1} \left[ \sum_{h,m=1}^{H,M} W_h \left( \frac{f_{hm} - \hat{f}_{hm}}{\sigma_{fh}} \right)^2 
+ \sum_{h,l,m=1}^{H,J,M} W_{hl} \left( \frac{c_{hlm} - \hat{c}_{hlm}}{\sigma_{chl}} \right)^2 \right]
$$

(4)

where $f_{hm}$ and $\hat{f}_{hm}$ are observed and fitted number of trips during the step of time $m$ with a given set $h$ of one or several tactics, $c_{hlm}$ and $\hat{c}_{hlm}$ are the observed and fitted catch or logarithms of catch per trip obtained with the set of tactics $h$ on component $l$ of the resource, $\sigma_{fh}^2$ and $\sigma_{chl}^2$ are the estimated variances of the $f_h$ and $c_{hl}$ series, $w_h$ and $w_{hl}$ are weights.

With some hypotheses, such as nil covariances between the $f_{hm}$ and the logarithms of $c_{hlm}$, and normality of those variances, this fitting procedure leads to estimated values of the parameters that have good asymptotical statistical properties. As for most of the data set used in fisheries analysis, those hypotheses are probably not met and we shall not make any statistical test whose quality would be difficult to assess.

In Eq. (4), we consider sets of tactics (with subscript $h$) because available data do not generally correspond to individual tactics. For example we may, through a stratified sampling design, have data on the number of trips involving the use of handlines made from a port, but we may know that at least two different tactics satisfy this criterium, because fishermen do not operate in the same manner if they target demersal or pelagic fish.

The number of tactics is not always known. This lack of knowledge is a source of uncertainty, the consequence of which may be important for a lot of reasons.

The first consequence is that the mean catch per trip, for a given component of the resource, is not necessarily a function of one catchability and one abundance, but may be a weighted mean of such functions, the weights depending on the decisions made by the fishermen. Thus, a variation in catch per trip may be the result of a variation in abundance or of changes in target species, or of both. The various catchability vectors and their potential combinations define a set of potential mortality vectors, whose dimension and form depend on the existing and available catchability vectors.

The knowledge of this set may be important in terms of viability of the exploitation and in terms of predictability of the impact of changes in the environment for the fish and the fishermen, and which may or may not result from management decisions. Hence, analysis of data, such as nominal effort and catch per trip time series, may be done according to questions on the existing strategies, on the sets of available tactics, the catchabilities of those tactics, etc. Thus, these questions also deal with model identification (how many tactics are needed in the model in order to reflect the data in a convenient way). This question is similar to the question of model identification in ARMA modelling (Box and Jenkins, 1970) when assessing the degrees of autoregressive (AR) and moving average (MA) components of the model. Schnute (1985) also addressed this question using a general class of surplus production model including the most usual ones, as particular cases defined by constraints on the parameters.

However, with a given data set, at least two different models that give equivalent results can be obtained, thus the identification must be done with the help of experts.

We shall try to illustrate these two aspects (identification and estimation) and the related question on uncertainty, with the help of a simple simulated fishery.
4. The simulation and the ‘available data’

We consider a fishery, with fishing units having one strategy ($K = 1$) with two possible fishing tactics and a ‘no fishing’ tactic ($J = 3$). Two ‘species’ are catchable ($I = 2$). We give (Table 1) the values of the parameters of the two surplus production models, the price of species, the quantities of inaccessible biomass, the values of catchabilities. In this simulation, we consider only two inaccessibility parameters $\alpha_1$ and $\alpha_2$ only depending only on the species $i$ (i.e. inaccessibilities do not depend on the season nor on the tactic).

The cost per trip is equal to 50 for the two fishing tactics and the revenue of the non-fishing tactic (opportunity cost) is equal to 10.

The function $f$ is defined by the following equations:

$$p_{kj,m+1} = p_{kj,m} + \lambda(\overline{Re}_{j,m+1} - \overline{Re}_{j(k),m+1})/\overline{Re}_{j(k),m+1}$$

(5)

where $\overline{Re}_{j(k),m+1}$ is the mean of the expected revenues $Re_{j,m+1}$ with available tactics in $J(k)$, $\overline{Re}_{j,m+1} = (R_{j,m} + R_{j,m-1})/2$ (see Eqs. (2) and (3)). $\lambda = 30$, which corresponds to a very flexible fishing fleet. If needed, corrections can be made to ensure that the sum of $p_{kj,m}$ over $j$ is equal to 1 and that each $p_{kj,m}$ belongs to the $[0,1]$ interval.

Catchabilities of the two fishing tactics for the two species are positive, the first tactic mainly targeting the first species, and the second tactic mainly targeting the second species. The inaccessible quantity of biomass of species 1 is 1/5 of the virgin biomass which leads to an equilibrium relation similar to the relation of a Pella and Tomlinson (1969) model with the exponent parameter $m$ lower than 1 (Laloë, 1988). The inaccessible quantity of biomass for species 2 is quite negligible, which leads to an equilibrium relation similar to the relation of a Schaefer (1957) model ($m = 2$). Species 1 is ‘under-exploited’ and species 2 is ‘over-exploited’.

The simulation was carried out for a period of 20 years study with a monthly step of time and with an increasing number vector of units from year 1 (500 units) to year 13 (900 units) followed by a decreasing phase (600 units for the last year). We assume that the available data (Table 2, first three columns) consist of the total number of daily trips and the total catches for each species per year, which is a quite common situation. In Table 2, we also give (last two columns) the number of trips made with each of the two fishing tactics (with the values of the parameters and the number of units used for the simulation; the non-fishing tactic was never used).

5. Adjustment with one tactic

With such a data set, we may try to consider a model with one fishing tactic and a non-fishing tactic giving results similar to the ‘available data’. This may be done by estimating some of the surplus production models parameters. These parameters are the two catchabilities, the two inaccessibilities $\alpha_i$, the two growth rates $r_i$ and the two initial biomasses. The cost per trip remains equal to 50 for the two fishing tactic and the revenue of the non-fishing tactic (opportunity cost) remains equal to 10. The estimated values are obtained by minimizing the standardized squared difference in observed and fitted yearly logarithms of catches per trip (as only one fishing tactic is used, there is no difference between observed and fitted numbers of trips):

$$\hat{\beta}_1 = \arg\min_{\beta_1} \sum_{i,a=1}^{2,20} \left(\frac{c_{ia} - \hat{c}_{ia}}{\sigma_{cl}}\right)^2$$

The results (estimated values of the parameters) are given in Table 3

The ‘observed’ (from the simulation) and fitted yearly catch per trip given by the two models are presented in Fig. 1, which shows that these two models are equivalent in terms of ‘explanation’ of the available catch data.
### Table 2
Available data on the simulated fishery (columns 2-4) and number of trips with the two fishing tactics (columns 5,6)

<table>
<thead>
<tr>
<th>Year</th>
<th>Catches on species 1 (tons)</th>
<th>Catches on species 2 (tons)</th>
<th>Number of fishing trips (total, 10^3)</th>
<th>Number of fishing trips (tactic 1, 10^3)</th>
<th>Number of fishing trips (tactic 2, 10^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2715.2</td>
<td>6558.6</td>
<td>182.5</td>
<td>81.23</td>
<td>101.27</td>
</tr>
<tr>
<td>2</td>
<td>2731.7</td>
<td>5955.6</td>
<td>182.5</td>
<td>85.643</td>
<td>96.857</td>
</tr>
<tr>
<td>3</td>
<td>2799.6</td>
<td>5510.7</td>
<td>182.5</td>
<td>91.328</td>
<td>91.172</td>
</tr>
<tr>
<td>4</td>
<td>2834.5</td>
<td>5277.0</td>
<td>219.0</td>
<td>94.628</td>
<td>87.872</td>
</tr>
<tr>
<td>5</td>
<td>3327.7</td>
<td>5896.1</td>
<td>219.0</td>
<td>116.48</td>
<td>102.52</td>
</tr>
<tr>
<td>6</td>
<td>3330.4</td>
<td>5305.8</td>
<td>219.0</td>
<td>122.72</td>
<td>96.283</td>
</tr>
<tr>
<td>7</td>
<td>3391.2</td>
<td>4890.5</td>
<td>219.0</td>
<td>129.95</td>
<td>89.048</td>
</tr>
<tr>
<td>8</td>
<td>3855.1</td>
<td>5246.6</td>
<td>255.5</td>
<td>156.7</td>
<td>98.8</td>
</tr>
<tr>
<td>9</td>
<td>3825.2</td>
<td>4717.0</td>
<td>255.5</td>
<td>164.22</td>
<td>91.276</td>
</tr>
<tr>
<td>10</td>
<td>3864.9</td>
<td>4358.4</td>
<td>255.5</td>
<td>172.46</td>
<td>83.036</td>
</tr>
<tr>
<td>11</td>
<td>4257.4</td>
<td>4643.7</td>
<td>292.0</td>
<td>201.47</td>
<td>90.532</td>
</tr>
<tr>
<td>12</td>
<td>4190.3</td>
<td>4213.9</td>
<td>292.0</td>
<td>209.27</td>
<td>82.728</td>
</tr>
<tr>
<td>13</td>
<td>4551.5</td>
<td>4254.2</td>
<td>328.5</td>
<td>246.19</td>
<td>82.31</td>
</tr>
<tr>
<td>14</td>
<td>4436.3</td>
<td>3855.8</td>
<td>328.5</td>
<td>255.7</td>
<td>72.801</td>
</tr>
<tr>
<td>15</td>
<td>4079.7</td>
<td>3360.2</td>
<td>292.0</td>
<td>232.66</td>
<td>59.344</td>
</tr>
<tr>
<td>16</td>
<td>4126.4</td>
<td>3612.5</td>
<td>292.0</td>
<td>226.24</td>
<td>65.756</td>
</tr>
<tr>
<td>17</td>
<td>3766.4</td>
<td>3407.1</td>
<td>255.5</td>
<td>193.22</td>
<td>62.277</td>
</tr>
<tr>
<td>18</td>
<td>3855.1</td>
<td>3710.0</td>
<td>255.5</td>
<td>187.78</td>
<td>67.72</td>
</tr>
<tr>
<td>19</td>
<td>3417.7</td>
<td>3531.3</td>
<td>219.0</td>
<td>154.81</td>
<td>64.186</td>
</tr>
<tr>
<td>20</td>
<td>3473.2</td>
<td>3921.5</td>
<td>219.0</td>
<td>148.53</td>
<td>70.472</td>
</tr>
</tbody>
</table>

### Table 3
Parameters of the model obtained from the fit of the general model assuming the existence of only one fishing tactic (estimated values in bold, the other parameters remaining unchanged from the simulation)

<table>
<thead>
<tr>
<th>Species (i)</th>
<th>Carrying capacity ($k_i$, tons)</th>
<th>Growth rate ($r_i$)</th>
<th>Price ($P_i$)</th>
<th>Inaccessibility ($a_i K_i$, tons)</th>
<th>$q(10^{-6})$ fishing tactic</th>
<th>$q(10^{-6})$ non-fishing tactic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10000</td>
<td>2.524</td>
<td>4</td>
<td>5, ($\alpha_1=0.0005$)</td>
<td>1.81</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>40000</td>
<td>0.650</td>
<td>2</td>
<td>3860, ($\alpha_2=0.0965$)</td>
<td>4.08</td>
<td>0</td>
</tr>
</tbody>
</table>

Thus, we have two likely, but very different results. The population dynamics models obtained from the two models are given in Fig. 2(a and b).

With the model for one fishing tactic, effective effort is given in number of trips. With the model for two fishing tactics, effective effort is a weighted mean of the number of trips with each tactic, the weight depending on the catchabilities. If we choose a trip with tactic 1 (respectively 2) as unit of effort on species 1 (respectively, species 2) the effective efforts are $f_1+f_2/4$ for species 1 and $f_1/4+f_2$ for species 2, where $f_1$ and $f_2$ are the numbers of trips with tactics 1 and 2 (Table 2). When assuming the existence of only one tactic, the model fitted for species 1 is equivalent.

Fig. 1. Catch per trip for the two species obtained with models assuming one (fitted values with symbols) or two (values from the simulation in continuous lines) fishing tactics.
Fig. 2. Catches and efforts values and equilibrium relationships assuming two (a) or one (b) fishing tactics.

to a Schaefer model ($\alpha_1$ is nil). We have a very different result with species 2, since $\alpha_2$ equals 0.1 (see Fig. 2(b)). There is thus an inversion in the form of the surplus production models, when considering general models with one or two tactics. This result may be at least partially explained. As a consequence of the decision rule of the fishermen Eq. (5), for a given number of fishing units, the proportions of choice of each of the tactics result in equivalent revenues from each tactic. A new fishing unit will choose each of the available tactics with a proportion that maintains this result, and this proportion will be higher for tactics that lead to a lower change in revenues. Here, the dynamics of species 2 satisfies a Shaefer-like model and is over-exploited, which means that an increasing effort on species 2 will rapidly lead to a collapse of that species in terms of biomass and catches. For the first species, the existence of an important quantity of inaccessible biomass and higher growth rate lead to lower decreases in CPUE when the fishing effort increases. Hence, the new fishing unit will have a higher probability to choose the tactic targeting species 1. This explains why the variation of effective effort is much lower for
species 2 than for species 1 with coefficients of variation equal to 0.095 and 0.28, respectively. (see Fig. 2(a and b)). But these variations are identical (coefficient of variation equal to 0.19) if we assume the existence of only one fishing tactic, leading to an increase of the α value for species 2, and a decrease of the α value for species 1.

Given the fit obtained here with the information on yearly catch effort data, we cannot clearly choose between these two models. We need some further knowledge on the way the fishermen work or on the 'true' population dynamics in order to be able to choose one model. In such a situation, if we consider, as is usually the case, a global framework where fishing units have only one available tactic, the first model will turn out to be the best. This decision may also be preferred since this model is more parsimonious. But the choice of one model may have consequences on the way we may consider management. This can be illustrated here in terms of prediction of the impact of changes in the environment on the fishermen or the fish.

6. Comparison of the models

The two models, with one or two tactics, are equivalent in terms of catch for the effort time series used in the simulation. But we saw that they can be different, for example, if we consider the equilibrium model.
relationships of the surplus production models. They may also produce different results if they are used in a new context. We may, for example, consider the consequences of changes in the species prices for various numbers of fishing units.

We used each of the two models to simulate the long-term results in terms of revenues of fisheries with 100, 300, 500 or 1000 fishing units with various prices of species 1 and 2. For this, we multiply the initial species prices (4 and 2) by $\lambda_1$ and $\lambda_2$, with $\lambda_1$ and $\lambda_2$ values varying from 0 to 2 in 0.1 steps. In Fig. 3 we give for each of the models, the results in terms of total revenues per year.

When $\lambda_1=\lambda_2=1$, the results from the two models are quite similar, which may be explained by the fact that the prices remain unchanged. There is no simple general description, with differences between the models that depend on the number of fishing units. If $\lambda_1>\lambda_2$, the model with two fishing tactics usually gives higher results than the model with one fishing tactic, but we may observe that, with 1000 units, if $\lambda_1=2$ and $\lambda_2=0$, this result is no more true, probably because of an excessive effort on species 1. If $\lambda_2=2$, the model with one tactic give higher results. This observation may be at least partially explained by considering the very different dynamics models obtained in each case. Firstly, the consequences of over-exploitation are much more important for species 2 than for species 1 if there are two fishing tactics. Secondly, the estimated catchability coefficient is greater for species 2 than for species 1 in the model with one fishing tactic.

In Fig. 4, we give the total numbers of fishing trips per year when there are 1000 fishing units.

The number of trips is are nil when $\lambda_1=\lambda_2=0$. It increases with increasing values of $\lambda_1$ and $\lambda_2$. This is due to the presence of the non-fishing tactic that gives a positive revenue (opportunity cost). When $\lambda_1=\lambda_2=2$, the non-fishing tactic is never used. In intermediate situations, the nominal effort is not systematically higher for a given model. When $\lambda_1=0$ and $\lambda_2=2$, the yearly number of trips is higher with the model with one tactic, which also comes from the difference between the fitted production models. With the model with two fishing tactics, it is useful to consider the impact of the fishermen decision on the distribution of nominal effort among the two fishing tactics. For this, we show (Fig. 5) these proportions in equilibrium conditions when there are 100, 300, 500 or 1000 fishing units and, again, prices multiplied by $\lambda_1$ and $\lambda_2$ varying between 0 and 2.

With 100 fishing units, none of the two species can be over-exploited and all the fishermen generally adopt only one of the two fishing tactics. When the number of units increases, the area of $(\lambda_1, \lambda_2)$ values for which the two tactics are used also increases, because if all the fishermen were choosing one given tactic, the impact on the targeted species would be sufficient to make the other species more attractive.

7. Conclusion

Considering the model that provides higher predictions as the better one would be a mistake. What is important here is the knowledge of the true model or at least the most robust one according to the addressed questions.

The differences observed in the revenues, the nominal fishing efforts or in the over-exploitation risks, in the ‘predictions’ given by the two models are important from a management point of view. Hence, in the case presented here, usual catch–effort data are not sufficient in order to clearly identify the model. We need further information and knowledge on the biological component of the system, that cannot only be provided by fitting surplus production models. We also need further information and knowledge on the social
and economical components of the system. But we have shown with the simulated example, assumptions made on one part of the system can have a very important impact on the perception of the other part of the system. Hence, we need monodisciplinary and multidisciplinary researches in order to progress in building useful fisheries exploitation frameworks.

We must, however, acknowledge that we were surprised when comparing the two models. In our mind, the results given by the ‘true’ model with two tactics were to be ‘better’ than those of the model with only one tactic. This was not the case, and the two models give results that are not as different as we were expecting.

This ‘result’ comes from the fact that, each of the model is fitted with ‘real data’ and with an explicit framework including both, a model of fishing activity and another of the resource. And the two solutions are coherent with the data. What is essential is to consider a model as a whole; if we suppose that there is either one or two tactics, we must consider the surplus production models obtained with the corresponding assumption. In our simulation, we observe that the data set is coherent with the conclusion that the first species is under-exploited and that the second is over-exploited, but this over-exploitation appears to be quite viable because we do not observe a collapse in catches on that species. If we look at Fig. 2(a and b), we observe this ‘viable over-exploitation’ with the two models, but with very different explanations. The model with two tactics shows that an increase in fishing mortality would lead to a collapse, and that

Fig. 5. Proportion of choice of fishing tactic 1 (black grid) and fishing tactic 2 (grey grid) made by the fishermen, with 100, 300, 500 and 1000 fishing units and various species prices. Prices of species 1 and 2 are multiplied by $\lambda_1$ and $\lambda_2$. 


any increase should be prohibited. But we also observe that the flexibility of the exploitation system induces a self-regulation. If there is only one tactic, such a self-regulation no longer exists but the corresponding surplus model indicates that an increase in mortality on species 2 will have no dramatic consequences.

In conclusion, it would be a mistake to consider that the second species will collapse if the fishing mortality increases (which may be the truth) and, at the same time, to also consider that there is a single fishing tactic. In such a case, managers would be too cautious. A symmetric error, supported by too optimistic managers would be to consider that the second species is not endangered, together with the idea of a self-regulation ability of the fisheries.

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