WORKING PAPER 201Ɨ:ƕ

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AgriFood economics centre

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Abstract

Management decisions aiming at developing fish stocks will not only affect the ecological sustainability of the fishery, but the economic and social dimensions as well. The Swedish Resource Rent Model for Commercial Fisheries (SRRMCF) is developed for analysing effects on the size and structure of the Swedish fishing fleet when introducing new management measures. It is an optimization model solved with linear programming. The baseline version contains 10 vessel segments, 180 métiers, 40 species of fish and crustaceans, and 6 different fishing areas.

Contents

1 Introduction

EU fisheries are characterized by excess fleet capacity and over fished stocks. Thus, there has been an increased interest in new management tools for fisheries from both the EU and the Swedish government. Management decisions aiming at developing the fish stocks will not only affect the ecological sustainability of the fishery, but the economic and social situation as well. The economic and social consequences are often less analysed than the biological, despite being important considerations when fisheries policies are designed.

The fishing sector is a complex industry characterized by vessels participating in multiple fisheries. Each vessel will exploit several fish stocks enabling the fisherman to choose among them. If the fishing possibilities change, the fisherman will look for alternative fishing activities for using the company's labor and capital assets. Thus - as a result of rational economic decisions made by the actors within the fishing industry - a management action within one fishery may lead to effects in other fisheries that might be difficult for decision makers to predict. Designing an appropriate policy in such a situation requires understanding of the nature of the interactions between different fisheries.

The Swedish Resource Rent Model for Commercial Fisheries (SRRMCF), which is presented in this paper, aims at providing such a tool. [1] The model is developed for analysing effects on the size and structure of the Swedish fishing fleet when introducing new management measures. The SRRMCF model is highly flexible and can be adjusted to fit the characteristics facing the fisheries and situations that are to be analysed. In this sense the model can be viewed as a framework for modelling Swedish fisheries.

2 Existing fishery models

Bio-economic modelling is a growing discipline and several models covering fisheries around the world have been developed. The Swedish Resource Rent Model for the Commercial Fishery (SRRMCF) is an optimization model designed for the Swedish fishery. Similar models have been developed e.g.

[1] See Waldo and Paulrud (2012) for an application of the model concerning the introduction of an ITQ system for Swedish demersal fisheries.

for Denmark (Frost and Kjaersgaard, 2003; Andersen et. al. 2010) and Norway (Steinshamn, 2005). An optimization model identifies what the best solution is given a stated objective, e.g. profit maximization. The models mentioned above focus on national fisheries, but a similar approach can be applied on sea areas as well where multiple fleets utilize a shared single stock. The FcubEcon model (Hoff et al 2010) is an example of such a model that has been applied to the North Sea.

Alternative model approaches are *simulation models* where the model is iterated forward over time to show the development of a fishery, and *account models* calculating economic indicators to predict economic development in the short run. An example of the latter is the baseline version of the EIAA model used in the EU for short term predictions of economic impacts of the biological advice used in the setting of TACs. The number of existing fisheries models is extensive and will, due to the lack of space, not be further presented here. The interested reader is referred to Frost and Kjaersgaard (2003), ICES (2011), and Prellezo et al. (2009).

3 The Swedish Resource Rent Model for Commercial Fisheries (SRRMCF)

The Swedish Resource Rent Model for Commercial Fisheries (SRRMCF) is an economic tool designed for conducting policy analyses in a setting where fishermen are flexible to change fishing patterns within the limits of gear- and management restrictions. The scope of the model is the Swedish commercial fishery. The model comprises the entire Swedish commercial saltwater fishery (non-commercial activity and fresh water fisheries are excluded).

The SRRMCF is set up as a constrained optimization programme including

1. An objective function
2. Constraints

The objective function defines society's goal with the fishery and the model solution will show the fishery that maximizes the objective given the constraints. The optimization is performed using linear programming. The decision variable is days-at-sea, and the model thus determines both the number of days-at-sea and the allocation among fisheries (métiers) that optimizes the objective function. The modeling approach represents a social planner allocating fishing effort in order to maximize the stated objective. The model is static, and thus no stock- or fleet- dynamics are included.

In sections 3.1 and 3.2 the mathematical equations are presented and discussed. The model is flexible regarding both the objective function and the constraints, and the presentation below is a baseline version of the model.

3.1 Objective function

The *objective function* in the baseline version of the model is to maximize the profit in the sector. Alternatives such as maximizing the fleet size or employment are possible, but this is not further discussed here.

In the baseline version both variable and fixed costs are included in the profit maximization problem, i.e. the fishery is modelled in a long run perspective. The objective function including fixed costs is defined as:

$$\max \sum_{f=1}^{F} \sum_{s=1}^{S} \sum_{p=1}^{P} (P_{f,s} * Catch_{f,s,p}) - \sum_{f=1}^{F} \sum_{p=1}^{P} VC_f * Eff_{f,p} - \sum_{v=1}^{V} FC_v * Vessels_v$$

Where

$$Catch_{f,s,p} = CPUE_{f,s} * Eff_{f,p}$$

A segment is represented by *v*, a métier by *f*, a species by *s*, and a period by *p*.

Revenues are prices times catches summed over fisheries, species, and periods. Prices are constant over time in the baseline version of the model, but differ among areas and segments. This is further discussed in section 5.

$Catch_{f,s,p}$ is a function of effort performed in each métier in a period ($Eff_{f,p}$) and the catch per unit of effort in that métier for a period ($CPUE_{f,s}$). The *CPUE* is assumed to be constant over periods in the baseline version of the model. Thus, allocating effort to a métier will for each period generate an identical catch composition. $Catch_{f,s,p}$ shows the catch of each species for métier *f* in period *p*.

Costs are divided into variable costs (VC_f) and fixed costs (FC_v). The fixed costs are assumed to be the same for all vessels within a segment. Thus, the total fixed cost in the fishery is the cost per vessel times the number of vessels in each segment summed over the total number of segments. The variable costs vary with effort and are assumed to be equal among periods. The costs are discussed in section 5.

3.2 Constraints

Fishing companies face a number of constraints on their fishing activities that are due both to management restrictions and natural conditions such as fishing seasons etc. The regulatory framework for the fishery is extensive and the restrictions presented should be considered as examples of the constraints facing the industry. The level of detail in the model will have to be determined by the topic of analysis. A too restrictive model will decrease the usefulness of the results since the restrictions will give no room for changes in the structure of the fishery. On the other hand, not taking important restriction into account will give results that are not practically obtainable. The presentation of the constraints below contains both catch constraints (3.2.1) and effort constraints (3.2.2).

3.2.1 Catch constraints

The model works with three different limitations on landing possibilities: The *quota*, *biological constraints*, and *fishing seasons*.

Swedish fisheries are by large managed by using *quotas*. Each species under a quota has a restriction on the maximum possible landing for the Swedish fishing fleet. For many species, quotas are set separately for each fishing area. An example is the important Baltic cod fishery where the stock is divided into the eastern and western stock each having a separate quota. Since the fisheries are separated for each fishing area, catches will be restricted by the quota relevant for the fishery. Thus, in the Baltic, the cod fisheries are divided into fishing operations targeting the eastern and western stock respectively. The restriction is defined as

$$\sum_{f=1}^{F}\sum_{p=1}^{P}(Catch_{f,s,p}) \leq quota_{s,a} \qquad for\ all\ a$$

The sum of catches over all periods and all fisheries cannot exceed the total catch allowed for a species in an area. For species having quotas that overlap areas, special restrictions are imposed as to prevent the sum of catches in these areas to exceed the quota.

Some species are not regulated with quotas, and for these the quota is simply set to a very high number. These fisheries are instead restricted by *biological* *constraints* based on catch history for the species. An example of this is the eel fishery that is not managed by quotas.

In the baseline version of the model it is assumed that a métier generates the same catch composition in all periods. This is a simplification, not least since some métiers are not possible in all periods due to biological constraints. To take this into account, the model is prevented to allocate effort to métiers for periods when there is no *fishing season*. This is done by setting the possible effort to zero for relevant métiers and periods.

3.2.2 Effort constraints

Effort is modeled as being subject of two separate restrictions. The first one is based on the *physical number fishing days* possible to provide by the vessels per period, and the second one is based on *management effort restrictions*. The use of two effort restrictions allows the model to relax a management restriction on effort and still restrict the vessels from being out fishing 365 days a year since this is not a realistic option.

For each month it is possible for a vessel to spend a *physical number of fishing days* which is set based on the what is appropriate for the specific question that is to be analyzed. E.g. 20 days per month will allocate a maximum of 240 days a year per vessel. It is assumed to be necessary for vessels to stay at port a part of the fishing periods due to reparations, bad weather, etc. The constraint is imposed as follows:

$$f \in SEG_i \qquad \sum_{f=1}^{F} (Eff_{f,p}) \leq \ Vessels_v * Max\_eff\_V_{v,p}$$

Where SEG_i = 1,...,N are subsets of métiers such that the métiers are those performed by the vessels in segment i. Observe the notation where $Max\_eff\_V_{v,p}$ is defined over segments such that it is the maximum number of fishing day per period *p* that is possible to conduct with a typical vessel in segment *v*.

Both the EU and Swedish managers are working with *management effort restrictions* as a means of reducing fishing effort. This is modeled as a number of allowed fishing days per period. E.g. a cod fishing stop in the Baltic implies that maximum effort is set to zero for relevant periods and métiers. Maximum effort allocated to a métier in a period is the number of vessels in the segment times the allowed number of fishing days per vessel in the period.

$$f \in SEG_i \qquad Eff_{f,p} \leq Vessels_v * Max\_eff\_M_{f,p}$$

Where SEG_i = 1,...,N are subsets of métiers such that the fisheries are those performed by the vessels in a specific segment. The restriction implies that for all métiers in segment *v*, the total effort per fishery cannot exceed the number of vessels (in the optimal solution) in the segment times the maximum effort per vessel allowed in that period, $Max\_eff\_M_{f,p}$.

The total effort of vessels fishing in the Skagerrak, Kattegat and North Sea are restricted by EU regulations on maximum effort. In the regulation, Sweden is allocated kilowatt days[2] divided into effort performed in specific areas with different types of gear. This restriction is modeled by restricting the total Swedish effort in each effort-group (EG_i) from exceeding the maximum kwh-days.

$$f \in EG_i \qquad \sum_{f=1}^{F}\sum_{p=1}^{P}(kwhD_{f,p}) \leq \; Max\_kwhD_{EGi}$$

Where EG_i i=1,..., I, are subsets of métiers (*f*) in which the fishing gear and area is defined from the EU regulation. $kwhD_{f,p}$ is the kilowatt days allocated to metier *f* in period *p*, and Max_kwh_{DEGi} is the maximum kilowatt days.

[2] The kilowatt days are the vessels' engine power in kilowatt multiplied with days at sea.

4 The structure of SRRMCF

The level of detail in the baseline version of the model is:

1. Fleet segments	(10 alternatives)
2. Métier	(180 alternatives)
3. Area	(6 alternatives)
4. Species	(40 alternatives)
5. Fishing periods	(12 alternatives, month)

The fleet segmentation is described in section 4.1, the métiers in section 4.2, the areas in section 4.3, the species in section 4.4, and the periods in section 4.5. In 4.6 the model is presented graphically based on segments and métiers.

4.1 Segments

The model is based on average vessel characteristics for vessels within a segment, where a segment is a set of relatively homogeneous vessels. Of course not all vessels in a segment are identical, and the model uses the segmentation strategy defined by EU's Data Regulation Framework (DCF).[3] According to the DCF a dominance criteria shall be used to allocate each vessel to a segment based on the number of fishing days used with each gear. If a fishing gear is used by more than the sum of all the others (i.e. a vessel spends more than 50 % of its fishing time using that gear), the vessel shall be allocated to that segment. If not, the vessel shall be allocated to the following fleet segment:

(a) 'Vessels using Polyvalent active gears' if it only uses active gears;
(b) 'Vessels using Polyvalent passive gears' if it only uses passive gears;
(c) 'Vessels using active and passive gears'.

In cases where a fleet segment has less than 10 vessels clustering may be necessary in order to design the sampling plan and to report economic variables according to secrecy regulations. Since the number of vessels in the Swedish fleet is low most of the segments need to be clustered.

Based on EU's segmentation, the baseline version of the model uses a comprised segmentation with only 10 segments. The reason for this is that vessels will otherwise change segments if their fishing patterns change. As an

[3] Commission Regulation (EC) No. 665/2008 of the 14 July 2008.

example, the segmentation does not differ between vessels using net or hook since many vessels alter between these two fishing activities and it might be arbitrary whether net or hook is used for more than 50 % of the fishing days. The segments used in the model are presented in Table 1.

Table 1. Segments

Segment No.	Definition (gear, vessel length)	
1	Net and hook,	< 12m
2	Net and hook,	>12m
3	Pots and traps	< 12 m
4	Bottom trawling,	<12 m
5	Bottom trawling,	12 – 24 m
6	Bottom trawling,	24 – 40 m
7	Pelagic trawling,	<12 m
8	Pelagic trawling,	12 – 24 m
9	Pelagic trawling,	24 – 40 m
10	Pelagic trawling,	> 40 m

4.2 Métiers

The notion of a métier is used in order to categorize the activities of the fishing fleets (Council Regulation (EC) No 199/2008 of 25 February 2008). The categorization is based on what kind of gear is used, in what area the fishery takes place, mesh sizes, etc. In the baseline version of the model 180 métiers are defined for the Swedish fishery based on data from logbooks. A typical métier in Sweden would be trawling with a vessel that is between 12 and 24 meters in the eastern Baltic Sea. The definition of a métier also includes target species. For example, bottom trawling for pelagic species and bottom trawling for demersal species are two different métiers.

Not all métiers possible in Swedish fisheries are used in the baseline version; some have been merged to larger métiers, and métiers with less than 20 Days at Sea have been excluded.

4.3 Areas

The same fishing activity performed in different areas will generate different catch compositions and are therefore defined as different métiers. The métiers are defined over six areas as presented in table 2: The Baltic Sea (divided into 3 ICES-areas, see below), the Kattegat, the Skagerrak, and the North Sea.

Table 2. Model areas

Model area	Corresponding ICES area
Eastern Baltic sea	25-29 + 32
Western Baltic sea	22-24
Northern Baltic sea	30-31
Kattegat	IIIaS
Skagerrak	IIIaN
North Sea	IV

4.4 Species

In table 3 the 40 different species of fish and crustaceans used in the model are presented. Some of these species are caught from more than one separate stock. In this case the model treats each stock separately by defining a stock specific catch quota. This follows the ICES biological advice. Since the model is based on economic behavior, some species (e.g. herring) is, furthermore divided into landings used for consumptions and landings used for industrial purposes.

Table 3. Species used in the model.

Species	Species
Perch	**Turbot**
European eel	**Anglerfish**
Witch	**Plaice**
Blue Whiting	**Lemon sole**
Common bream	**Dogfish**
Pollack	**Dab**
Pike	**Whitefish**
Sting fish	**Northern pink schrimp**
Pike-perch	**Vendace**
Saithe	**Flapper skate**
Catfish	**Herring**
Haddok	**Lumpfish**
Edible crab	**Sprat**
Lobster	**Flounder**
Norwegian lobster	**Brill**
Hake	**Cod**
Ling	**Sole**
Salmon	**Whiting**
Mackerel	**Horse mackerel**
Sea trout	**Sand eel**

4.5 *Fishing periods*

The fishery is modeled in 12 periods each representing a month with a pre-specified number of possible fishing days. For some periods, fishing is not possible in order to restrict the fishery from taking place when biological constraints prevent fishing. An example is fishing for roe (e.g. vendace or lumpfish) which can only take place during spawning season.

4.6 *Graphical representation of the model*

All vessels within a segment have the same possible métiers to choose from. Fishing in a métier generates a certain catch volume and composition of species. Figure 1 shows the possible métiers of two hypothetical segments A and B and the catch composition associated with the specific métier.

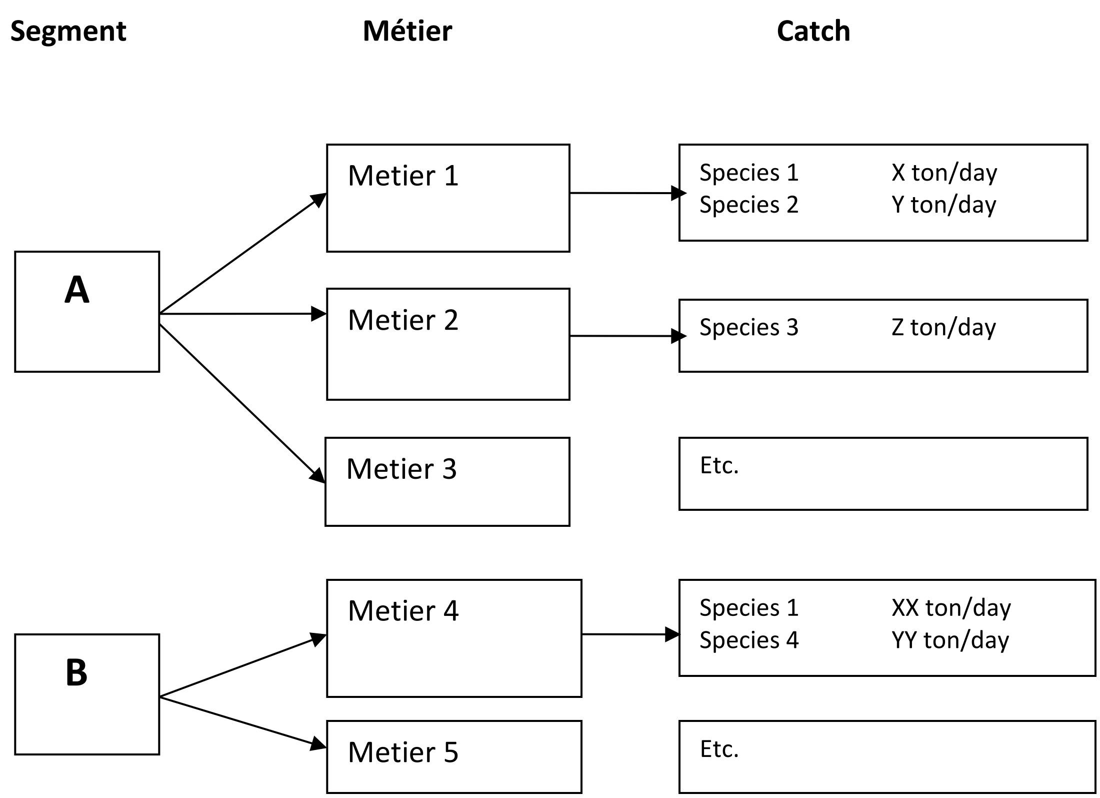

Figure 1. The model structure

Segment A in figure 1 has three possible métiers to choose from. The revenue from fishing in a métier is calculated as the landing times the price for the fish. The cost consists of both fixed costs for the vessel and variable costs associated with fishing in a métier. In the optimization, given that profit is maximized, the model will first allocate fishing effort to the most profitable métier until one of the constraints limits further fishing. The model will then search for the second most profitable métier, etc.

5 Cost and revenue data

In this section the input data is further discussed.

5.1 Costs

The primary data source is the yearly cost study performed within EU's Data Collection Framework (DCF) by the Swedish Agency for Marine and Water Management (former Swedish Board of Fisheries). Data follows the requirement of the DCF (Commission Regulation (EC) No. 665/2008 of the 14 July 2008). Thus, fleet segmentation, cost data and vessel characteristics, as well as the data on production, fit the EU data.

The cost data is organized as four variable cost items and two fixed as presented in table 4.

Table 4. Fixed and variable costs

Cost	**Definition**
Maintenance	Cost for repair and maintenance of the vessel
Fuel	Fuel costs
Labour costs	Labour costs at alternative employment
Other variable costs	Variable costs that are not maintenance, fuel or labour. See also "other fixed costs"
Capital cost	Capital costs are calculated by assuming remuneration to capital of 6 % of the vessels' insurance value, and a depreciation cost of 5 % per year.
Other fixed costs	E.g. harbour fees. Calculated by the Swedish Agency for Marine and Water Management as a fixed percentage of costs not related to maintenance, labour or fuel. The rest of this cost item is "other variable costs". The percentage differs between segments based on the observed cost structure in previous year's book keeping.

The labour costs in the tax statistics are biased since it is possible for a Swedish company owner to choose between defining his remuneration as profit or labour. Because of this bias, values of labour costs are calculated as the opportunity cost of labour, i.e. the wage that the fisherman could be expected to get in an alternative employment.

The fixed costs are calculated as averages based on the model (i.e. DCF) segmentation. Variable costs are calculated as averages using an alternative (national) segmentation based on economic landing data. This is based on species. E.g. vessel catching in value more than 50 % of either Norwegian lobster, shrimp, or vendace is grouped separately within each segment when calculating variable costs.

5.2 Landings and prices

Revenues from fishing depend on catch volumes and the landing price. Catch volumes are defined for each métier, but only species representing at least 5 % of total catch volume for the métier are included in the catch data. The reason for this is that all fisheries occasionally catch non-target species that are of less importance.

Data on landing prices are available from Swedish landings statistics. Since prices will vary among different kinds of fishing operations and different fishing areas we differentiate among prices depending on segment and area (statistics are available for each segment, but not separately for each métier). Thus, all vessels in a segment are assumed to get the same price for products that are caught in the same fishing area. Since the categorisation of the segments is primarily based on type of gear and size of the vessel, the assumption of equal prices seems reasonable. Fish caught with trawling and fish caught with passive gear will get different prices. A segment might have fisheries in some or all of the different sea areas. Price data is divided into two areas: The Baltic and a cluster of North Sea, Skagerrak, and Kattegat. Thus, the price for a cod caught by the same segment will differ if it is caught on the Swedish west coast or in the Baltic Sea. Both volumes and prices are assumed to be constant over the periods.

6 Institutional setup and readiness to use

The model is managed by the AgriFood Economics Centre, Department of Economics, SLU, and the Swedish Agency of Marine and Water Management, SwAM (former Swedish Board of Fisheries) in cooperation with the Department of Aquatic Resources at SLU. Presentations of earlier versions of the model can be found in SEC(2006), ICES(2011), Paulrud and Waldo (2011 and 2012) and Paulrud (2005). The model is programmed in GAMS (General Algebraic Modelling System) software with links to Excel for data input and output. Data is provided by the SwAM and Department of Aquatic Resources.

7 Strengths, weaknesses, opportunities and limits

An important feature of the baseline SRRMCF model is that it is static; a model-run will describe the optimal situation at a given point in time, and there are no 'built-in' stock dynamics. Changes in fishing effort and vessels are incorporated, but possible paths towards a new situation (solution) are not investigated within the model. It is possible to include dynamic analysis in the model in the future, but this requires a substantial model development. A dynamic analysis could include both economic dynamics and a biological module describing the stock development as a function of the optimal fishing behaviour found in the model.

Different states of the system (scenarios) can be used for comparative analyses, where scenarios might be formulated in terms of the objective function, the constraints, assumptions about exogenous variables and parameter values. Examples of scenarios are new regulations restricting specific metiers or affecting allowable catches.

One of the strength of the model is that it can estimate the effects of regulatory changes not only on the regulated fishery, but also on fisheries that are alternative activities for the affected vessels. The starting point for the modelling is the entire fishing fleet and the different fishing opportunities available for the vessels. This differs from modelling approaches starting from a stock perspective with (potentially) many fleets utilizing it. In the SRRMCF approach the fleet and possible reallocations of effort between e.g. large and small scale fisheries within the fleet are analysed.

The model has limited possibilities to perform regional analyses (as opposed to e.g. the Danish EMMFID model) since data on geographical level does not exist for Sweden. Although not possible to analyse regional development, it is possible to analyse in which area of the sea the fishery takes place.

The optimization is performed using linear programming. Using linear programming as opposed to non-linear models assures that the model will always find the optimal solution (if such a solution exists). However, linear models could be criticized because small changes in the parameters may sometimes result in substantial changes in the solution. The opposite may occur as well i.e. the optimal solution will be the same in spite of the changes in parameters. This is due to the fact that the optimal solution is selected from a limited number of available solutions. A possible development of the model would be to include non-linearity, e.g. by allowing catches to decrease per fishing day when effort is increased, to avoid this

Examples of other possible developments are to make prices and/or catches vary between fishing periods. In the baseline version these are the same for all periods. There may be good reason for using different catches and prices over the year. Catches could be expected to vary due to fishing opportunities being better in some periods. Also, prices might depend on e.g. the quality of the fish which might be better during some part of the year.

Acknowledgements

Our work has benefited by information and comments from Tore Gustavsson, Katja Ringdahl, Johan Lövgren, Joakim Hjelm, Anna Jonsson, Anna Larson, Marie Ingerup, Lars Hultkrantz, Magnus Allgulin, Mark Brady, and Ewa Rabinowicz.

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