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# SPATIAL STOCK COMPOSITION OF SALMON ON THE BASIS OF TAG RETURNS IN THE NORTHERN BOTHNIAN BAY FISHERY

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## ABSTRACT

In the northern Botnian Bay, the mouths of the regulated rivers with extensive compensatory stocking programmes and the unregulated rivers supporting wild salmon stocks are situated next to each other. There has been a need to enhance the escapement of wild salmon and at the same time harvest reared salmon stocks within this relatively small sea area. Therefore, the sea fishery close to the rivers with wild salmon stock has had restrictive regulation while the fishery close to the regulated rivers has been kept out of heavy regulation. The system has been based on the assumption that river mouth fishery is more or less stock-specific and is therefore subject to stock-specific management.

A close spatial examination of Carlin-tag returns from two wild and two reared salmon stocks was carried out near their home rivers in the northern Bothnian Bay. The study aimed mainly at testing the hypothesis lying behind the above-mentioned spatial fishing regulation system. The results showed a partial differentiation of the salmon stocks in the study area resulting from a tendency to stock-specific migration routes when river mouths are approached. However, no pure stock-specific fishery could be identified in the sea because of large variation in the migration routes of salmon. The results stand up for hypothesis that there is hardly any possibility for pure stock-specific harvesting of salmon in the sea, but restricted areas close to the rivers allow harvesting of salmon predominantly native to that river. Consequently, regionally adjusted fishery management near the river mouths seems to be appropriate, if safeguarding of wild salmon stocks and utilization of reared stocks are both as management objectives in the Baltic sea fishery.

## 1. Introduction

In the northern Botnian Bay the mouths of the regulated rivers with extensive compensatory stocking programmes and the unregulated rivers supporting wild salmon stocks are situated next to each other. There has been a need to enhance the escapement of wild salmon and at the same time harvest reared salmon stocks within this relatively small sea area. The Bothnian Bay is covered with ice during the winter and salmon appears there only on spawning migration. The salmon fishing season starts yearly at the end of May, when first salmon migrate from the southern feeding areas towards their home rivers and it ends in August, when salmon have entered into rivers. Trapnet is practically the only gear used in the salmon fishery. The trapnet fishery has been regulated lately by establishing boundaries for spatial fishing regulation: the fishery close to the rivers supporting wild stocks have had restrictive regulations while the fishery close to the regulated rivers have been kept out of the strongiest regulation. This system has been based on the assumption that the salmon fishery in a river mouth is more or less stock-specific fishery and is therefore subject to stock-specific fishery management. Relatively little effort has been put to study, if this theory holds good.

This paper presents the results of a close spatial examination of Carlin-tag returns for two wild and two reared salmon stocks near their home rivers in the northern Bothnian Bay. Migration pattern of salmon and spatial distribution of fishery are illustrated and spatial differentiation of salmon of different stocks are examined and tested. The study aims mainly at testing the hypothesis lying behind the spatial fishing regulation system enforced in the Gulf of Bothnia.

## 2. Materials and methods

The examined salmon stocks were (from north to south)

- River Tornionjoki (wild stock)
- River Kemijoki (reared stock)
- River Simojoki (wild stock)
- River Iijoki (reared stock)

The rivers are situated in the north-east corner of the Bothnian Bay and the river mouths are within approximate 100 km of coast line (Fig. 1). The recent number of total yearly smolt output from the rivers is over 1 million smolt, most of which are of reared origin (Table 1)(Anon. 1994, Huttula & Hiltunen 1990 a & b and Tapio Lovikka, Voimalohi oy, pers. comm.). The smolt production of the wild salmon stocks is a combination of naturally produced smolt and reared smolt, which are released in the rivers for enhancement purposes.

Smolt from the studied stocks have been tagged yearly by Carlin-tag since mid-80's and the tag returns originating from the taggings of the years 1985-1991 were used in this study. During that period almost 170 000 smolt were tagged (Table 1). 5-20 % of the total tag returns of the taggings were reported from the FGFRI (Finnish Game & Fisheries Research Institute) statistical rectangles 1, 2, 3, 5, 6, and 7, which constituted the study area (Fig. 1).

For a close spatial examination, FGFRI statistical rectangles were divided into 64 sub-rectangles (8*8) resulting in a grid of sub-rectangles each of which were about 40 km² (5.8*6.9 km) large (Fig. 1). A place of recapture for each tag return was identified and they were placed on the grid. The river sections under the lowest dams were also included into the data set as two extra "sub-rectangles". A few tag returns were discarded because exact places of the recaptures could not be identified.

The data set constituted of counts of tag returns in each sub-rectangle divided by salmon stock and year of return. Descriptive and explorative statistical analysis were carried out in order to illustrate common characteristics of the data and to examine suitable methods for statistical analysis (tests of independence). Sub-rectangles with no returns at all were always excluded in statistical analysis. The basic data set was often modified, as can be seen in the next sections.

## 3. Description of the data

The taggings contributed to a total of 1 329 tag returns reported in the study area during the years 1986-1994 (Table 2). The fewest tag returns were reported from the wild stocks because of the smallest numbers of tagged smolt. Bulk of the tags were returned in the middle of the time series and this distribution was naturally linked to the yearly variation in the amount of tagged smolt.

Figure 2 illustrates the spatial distribution of the tag returns for each stock. Tags were returned from 67 sub-rectangles close to the coast line and in the archipelagos, which constitute about 28 % of the whole study area (240 subrectangles). The number of tag returned varied between 0 and 102/sub-rectangle. Most of the returns were concentrated near the river mouths of the regulated rivers (Iijoki and Kemijoki). 30 tags were returned from the river sections below the lowest dams in the Rivers Kemijoki and Iijoki. Very few tag returns were placed in the open sea area, because there is actually no salmon fishery there: only one tag return was placed on the FGFRI statistical rectangle 5, which is located in the middle of the northern Bothnian Bay. Also very few returns were found west from the mouth of the River Tornionjoki despite the existence of Swedish salmon fishery there. That indicates that the studied stocks migrate mainly along the Finnish coast in the Bothnian Bay area, which has been observed also in earlier studies (eg. Anon. 1994).

Individuals from each stock were caught all around the coast of the study area, which indicates that migration routes are not distinct (Fig. 2). Especially the areas of outer archipelago consisted of a mixture of the stocks. On the other hand, the proportion of salmon originating from a certain river increased when that river was approached and sub-rectangles around each river mouth were usually dominated by the salmon stock originating from that particular river (Table 3). In the few tag returns from the Rivers Kemijoki and Iijoki, no non-native salmon were observed.

The data set consisted of frequencies of the tag returns in three dimension with the variables "Stock", "Sub-rectangle" and "Year of return". In spite of excluding the sub-rectangles with no tag returns at all, sampling zeroes still accounted for 82 % of the cells. This was due to uneven distribution of tag returns between the studied stocks and years and also due to remarkable differences in the spatial distributions of tag returns between the stocks.

# 4. Explorative statistical analysis

## 4.1 Drawbacks in the data and analysis

In theory, log-linear modelling seems to be the most appropriate method to analyze the effects and interactions of the variables in the data set. However, this method was ruled out because of the predominance of sampling zeroes in the data set. Combining sub-rectangles and selecting observations with highest frequencies did not result in sufficient improvement of the data.

When the effect of year and the effect of stock in the spatial distribution of the tag returns were examined separately, the resulting two-dimensional contingency tables contained still high numbers of sampling zeroes. Forming larger units of area by combining adjacent sub-rectangles did not improve the data set when the whole study area was concerned. However, selecting the sea areas and combining sub-rectangles with highest frequencies often resulted in contingency tables with adequate cell counts. This procedure obviously required more or less subjective selection and classification of the data, which is a drawback in the analysis.

## 4.2 Analysis from a selected subset of the data

Selection of a subset of data and enlargening of sub-rectangles was carried out by the following procedure: sub-rectangles were combined in four different clusters representing the sea close to each river mouth (Fig. 3). A Sub-rectangle belonged to the area of a river mouth with the shortest distance. Study area far to the south from the River Iijoki and far to the west from the River Tornionjoki were excluded in order to form similar kind of spatial units for analysis. The rearrangement produced a data set shown in the Table 4. The data set had still too many sampling zeroes for three-dimensional log-linear modelling, but tests of independence using two-dimensional tables were enabled.

Separate contingency tables for each salmon stock resulted in three cases with high enough frequencies for testing the independence of the year to the spatial distribution of the tag returns (Table 5). This data represented only a portion of the whole time series and the results were partly contradictory. A dependence of year to the spatial distribution the River Iijoki salmon was quite obvious during the examined years. However, the results of other two analysis with the Rivers Kemijoki and Tornionjoki salmon indicated no yearly differencies in the tag distribution. The data from the River Simojoki salmon did not quite fulfill the requirements of the analysis, however, the results were in coherence with the results from the Rivers Kemijoki and Tornionjoki salmon. Consequently, year might be one factor affecting the spatial distribution of the tag returns in the study area, but probably it does not usually explain any substantial part of the variation in the observed frequencies.

Because of some suspicion that time is one factor affecting the spatial composition of tag returns, the test of independece of salmon stock to the spatial distribution of tag returns was carried out yearly. Again, only part of the data set could be used because of small frequencies in certain combination of year, area and stock. The requirements of the analysis were fulfilled in four years, of which only the year 1990 data contained enough observations for full-size (4 stocks*4 areas) contingency table (Table 6). The results of all the four analysis by year indicated a very strong (prob<0.1%) relation between the stock and the area of tag return. Of several other analysis, which did not quite fulfill the requirements of the analysis, only one analysis suggested a risk level higher than 0.1 % for rejecting the null hypothesis, that the analysed variables are independent.

Table 7 shows the result of analysis, where data from all the studied years was combined. A possible effect of year to the frequency distributions must be taken into account in this analysis. Also this test of independence supports very strongly the theory that the studied stocks have partially differentiated from each other in the sea around the river mouths resulting in fishery, which is not pure stock-specific, but which can not be considered as a usual mixed-stock fishery, either.

## 4. Conclusions

A partial spatial differentiation of the studied salmon stocks is obvious in the study area. No clear answer was found to the question, whether the spatial distribution of the stocks varies yearly. However, the analysis indicate that the effect of a stock is much stronger than the effect of time in the spatial distribution. More profound analysis could be carried out, if larger data sets were found somewhere in the Baltic coast for this purposes. The tag returns were artificially categorized into smaller or larger units of area, which is not fully satisfactory and other ways could be examined to find a sounder data treatment in terms of spatial identification of the observations.

Partial differentiation of the stocks close to their home rivers is in coherence with logical expectations and a question arises, to which degree stocks are actually differentiated. Description of the data using small units of area illustrated that, as a rule of thumb, the degree of differentiation rises towards the river mouths. Still, individuals from each stock were found virtually in every corner of the study area (where salmon fishing existed) - even in the sub-rectangles situated right in the river mouths.

The results do not quantify the actual stock composition or the degree of differentiation of salmon stocks in the study area. Quantification is very difficult using this kind of data, because the variation in the amount and quality of tagged fish between the stocks ought to be somehow standardized and scaled to the salmon production in each stock. Besides, natural salmon production is the most interesting part in the stocks, if safeguarding of wild stocks is concerned. The behaviour, mortality and catchability of wild smolt might differ from those of reared smolt, but only a very limited data from wild tagged smolts exists in the Baltic region. There are also other salmon stocks than the studied ones migrating in the study area and they should be taken into account in any quantification of the stock composition. Finally, data collected by Carlin-taggings is dependent on the existence and distribution of fishery, which causes serious limitations to the data and its usability.

The analysis did not include any examination of timing of the migration and its possible implications to the stock distributions and fishery regulations. Wild, old and female salmon has been noted to migrate earlier in the season along the Finnish coast than reared, young and male salmon (Ikonen & Kallio-Nyberg 1993). The reproductive value of old female spawners has been found to be much higher than that of young spawners (Romakkaniemi et al. 1995). These observations emphasize the importance of timing to be taken into account in this kind of studies. Timing as one new variable would probably intensify the observed partial differentiation of the salmon stocks during their spawning migration, especially from the management point of view. In fact, the time aspect has already included in regulations of the coastal fishery of Gulf of Bothnia by opening dates, which try to increase the escapement of early migrating salmon.

In spite of the drawbacks of this study, the results stand up for hypothesis that there is hardly any possibility for pure stock-specific harvesting of salmon in the sea, but restricted areas close to the rivers allow harvesting of salmon predominantly native to that river. Consequently, regionally adjusted fishery management near the river mouths seems to be appropriate, if safeguarding of wild salmon stocks and utilization of reared stocks are both as management objectives in the Baltic sea fishery.

## References


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Table 1. The estimated mean smolt output and number of tagged smolt during the years 1985-1991 in the studied salmon stocks (Anon. 1994, Huttula & Hiltunen 1990 a & b and Tapio Lovikka, Voimalohi oy, pers. comm.).

| Salmon stock | Smolt output, mean / year | No of tagged smolt in 1985-1991 |
|---|---|---|
| Tornionjoki | 130 000 | 19 352 |
| Kemijoki | 654 000 | 60 300 |
| Simojoki | 33 000 | 16 563 |
| Iijoki | 335 000 | 69 609 |
| Total | 1 152 000 | 165 824 |

Table 2. The data base for the spatial examination: the yearly number of tag returns in the study area.

| | Year of tag return | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Salmon stock | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | Total |
| Tornionjoki | 1 | 6 | 6 | 20 | 39 | 30 | 48 | 8 | 2 | 160 |
| Kemijoki | 21 | 32 | 42 | 131 | 103 | 33 | 28 | 8 | 0 | 398 |
| Simojoki | 0 | 4 | 6 | 25 | 39 | 8 | 55 | 16 | 0 | 153 |
| Iijoki | 54 | 43 | 116 | 182 | 141 | 46 | 33 | 2 | 1 | 618 |
| Total | 76 | 85 | 170 | 358 | 322 | 117 | 164 | 34 | 3 | 1329 |

Table 3. The proportion of Simojoki salmon in the tags returned from certain distances from Simojoki river mouth: an example of the changes in the stock compositions in the study area.

| Area within radius from Simojoki river mouth | Total no of tag returns | Number of Simojoki tag returns | Proportion of Simojoki salmon in tag retuns, % |
|---|---|---|---|
| 0-5 km | 19 | 15 | 79 |
| 5-15 km | 96 | 41 | 43 |
| 15-25 km | 253 | 44 | 17 |
| 25-35 km | 434 | 17 | 4 |
| 35-50 km | 328 | 22 | 7 |
| > 50 km | 166 | 14 | 8 |

Table 4. The data divided into four selected areas (see Fig. 3) representing the mouths of the studied rivers.

| Sea area | Salmon stock | Year of tag return 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tornio area | Tornionjoki | 0 | 2 | 2 | 4 | 4 | 8 | 2 | 2 | 0 | 24 |
| | Kemijoki | 7 | 5 | 6 | 19 | 12 | 4 | 4 | 2 | 0 | 59 |
| | Simojoki | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Iijoki | 6 | 1 | 4 | 1 | 1 | 0 | 0 | 0 | 1 | 14 |
| | Total | 13 | 8 | 12 | 25 | 17 | 12 | 6 | 4 | 1 | 98 |
| Kemi area | Tornionjoki | 1 | 2 | 3 | 12 | 22 | 14 | 32 | 1 | 2 | 89 |
| | Kemijoki | 8 | 15 | 19 | 75 | 65 | 25 | 23 | 3 | 0 | 233 |
| | Simojoki | 0 | 1 | 4 | 4 | 2 | 1 | 15 | 0 | 0 | 27 |
| | Iijoki | 4 | 5 | 9 | 13 | 9 | 4 | 1 | 0 | 0 | 45 |
| | Total | 13 | 23 | 35 | 104 | 98 | 44 | 71 | 4 | 2 | 394 |
| Simo area | Tornionjoki | 0 | 0 | 0 | 4 | 8 | 5 | 7 | 5 | 0 | 29 |
| | Kemijoki | 1 | 5 | 7 | 21 | 13 | 2 | 1 | 3 | 0 | 53 |
| | Simojoki | 0 | 2 | 2 | 11 | 26 | 6 | 23 | 5 | 0 | 75 |
| | Iijoki | 4 | 7 | 9 | 23 | 18 | 14 | 6 | 0 | 0 | 81 |
| | Total | 5 | 14 | 18 | 59 | 65 | 27 | 37 | 13 | 0 | 238 |
| Ii area | Tornionjoki | 0 | 0 | 1 | 0 | 4 | 0 | 5 | 0 | 0 | 10 |
| | Kemijoki | 2 | 2 | 2 | 5 | 2 | 1 | 0 | 0 | 0 | 14 |
| | Simojoki | 0 | 0 | 0 | 6 | 11 | 1 | 12 | 7 | 0 | 37 |
| | Iijoki | 31 | 25 | 84 | 128 | 96 | 19 | 21 | 0 | 0 | 404 |
| | Total | 33 | 27 | 87 | 139 | 113 | 21 | 38 | 7 | 0 | 465 |
| Grand Total | | 64 | 72 | 152 | 327 | 293 | 104 | 152 | 28 | 3 | 1195 |

Table 5. The results of testing the independence of year to the spatial distribution of tag returns.The testing had to be carried out separately for each salmon stock in order to rule out the possible effect of stock in the tag returns.

| Salmon stock | Tested years | Tested sea areas | Total no of cell counts | Pearson chi-square | | Likelihood ratio chi-square | |
|---|---|---|---|---|---|---|---|
| | | | | Value | Prob | Value | Prob |
| Tornionjoki | 1990-92 | Kemi & Simo | 88 | 0.912 | 0.634 | 0.925 | 0.630 |
| Kemijoki | 1987- 90 | Tornio, Kemi & Simo | 262 | 2.649 | 0.851 | 2.652 | 0.851 |
| Iijoki | 1987-91 | Kemi, Simo & Ii | 463 | 21.14 | 0.007 | 18.29 | 0.019 |

Table 6. The results of testing the independence of salmon stock to the spatial distribution of tag returns.The testing had to be carried out separately for each year in order to rule out the possible effect of year in the tag returns.

| Year | Tested stocks | Tested sea areas | Total no of cell counts | Pearson chi-square | | Likelihood ratio chi-square | |
|---|---|---|---|---|---|---|---|
| | | | | Value | Prob | Value | Prob |
| 1988 | Kemijoki & Iijoki | Kemi, Simo & Ii | 130 | 59.00 | 0.000 | 59.37 | 0.000 |
| 1989 | All four stocks | Kemi, Simo & Ii | 302 | 185.9 | 0.000 | 209.2 | 0.000 |
| 1990 | All four stocks | All four areas | 293 | 226.8 | 0.000 | 241.0 | 0.000 |
| 1992 | All four stocks | Kemi, Simo & Ii | 146 | 81.65 | 0.000 | 86.75 | 0.000 |

Table 7. A contingency table and a test of indepencence between the salmon stock and the sea area using tag returns from all the examined years (1986-1994). A possible effect of year to the spatial distribution of tag returns must be taken into account in the interpretation of the results. The table is a printed output from SYSTAT statistical computer programme.

TABLE OF FREQUENCIES AREA$ (ROWS) BY STOCK$ (COLUMNS)

| | Iijoki | Kemijoki | Simojoki | Tornionjoki | TOTAL |
|---|---|---|---|---|---|
| Ii | 404 | 14 | 37 | 10 | 465 |
| Kemi | 45 | 233 | 27 | 89 | 394 |
| Simo | 81 | 53 | 75 | 29 | 238 |
| Tornio | 14 | 59 | 1 | 24 | 98 |
| TOTAL | 544 | 359 | 140 | 152 | 1195 |

| TEST STATISTIC | VALUE | DF | PROB |
|---|---|---|---|
| PEARSON CHI-SQUARE | 746.350 | 9 | 0.000 |
| LIKELIHOOD RATIO CHI-SQUARE | 801.289 | 9 | 0.000 |

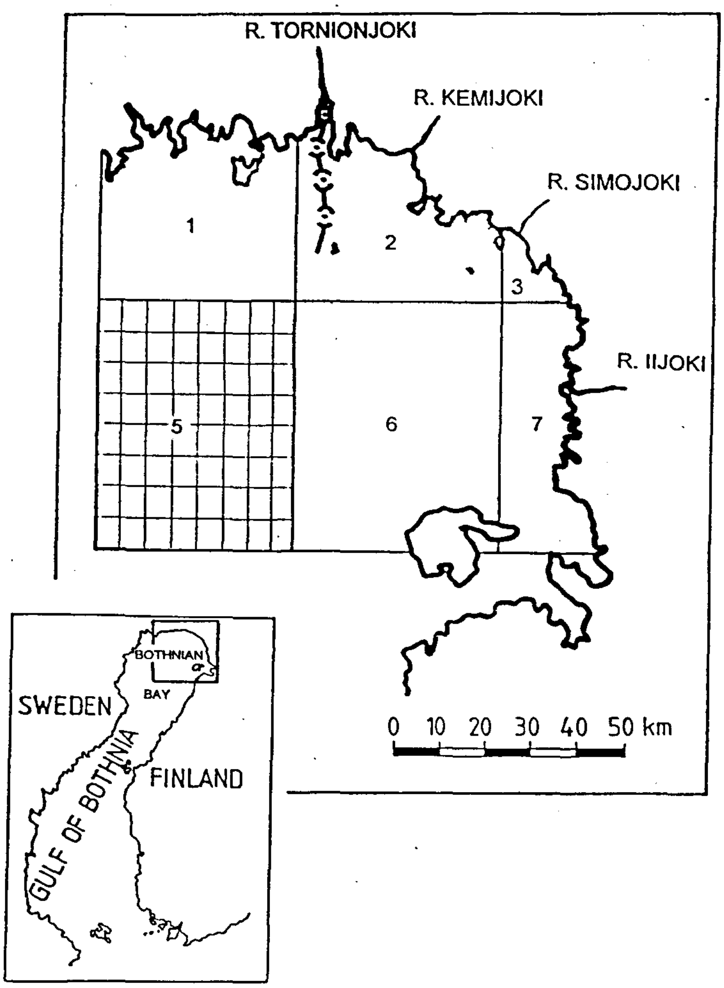


Figure 1. The study area and an example of the grid of sub-rectangles: each FGFRI (Finnish Game & Fisheries Research Institute) statistical rectangle was divided into 8*8=64 sub-rectangles for a close spatial examination of the tag returns. The River Tornionjoki is situated on the border between Finland and Sweden.

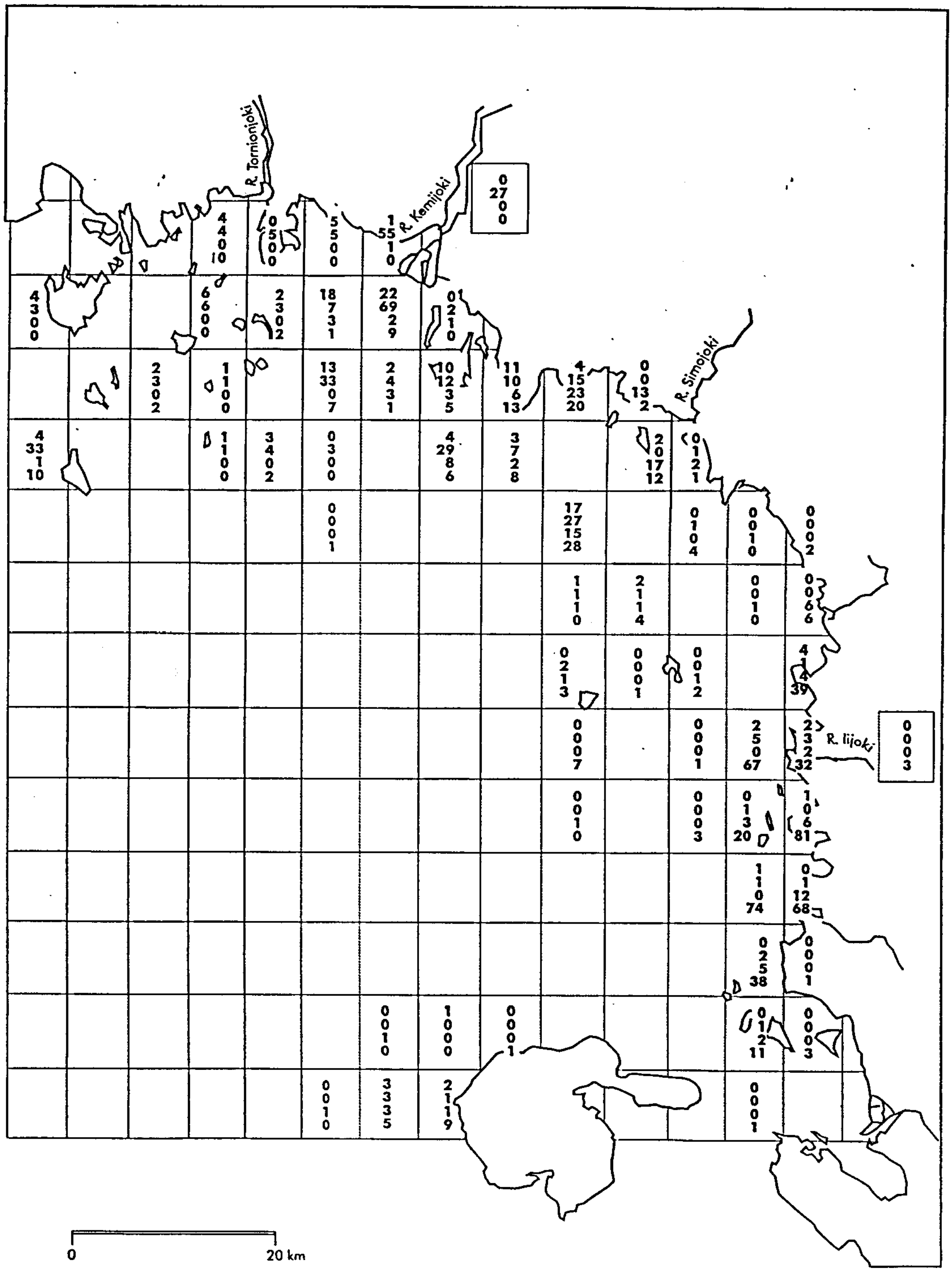


Figure 2. Number of tag returns from the studied salmon stocks in each sub-rectangle. The numbers are presented in a following order:

highest no = Tornionjoki salmon

2. highest no = Kemijoki salmon

3. highest no = Simojoki salmon

lowest no = Iijoki salmon

No tag returns were reported from the sub-rectangles with no numbers. The most western parts of the study area is not shown in the map because of only few tag returns: total of 2 Tornionjoki, 5 Kemijoki, 0 Simojoki and 2 Iijoki tag returns were reported there.

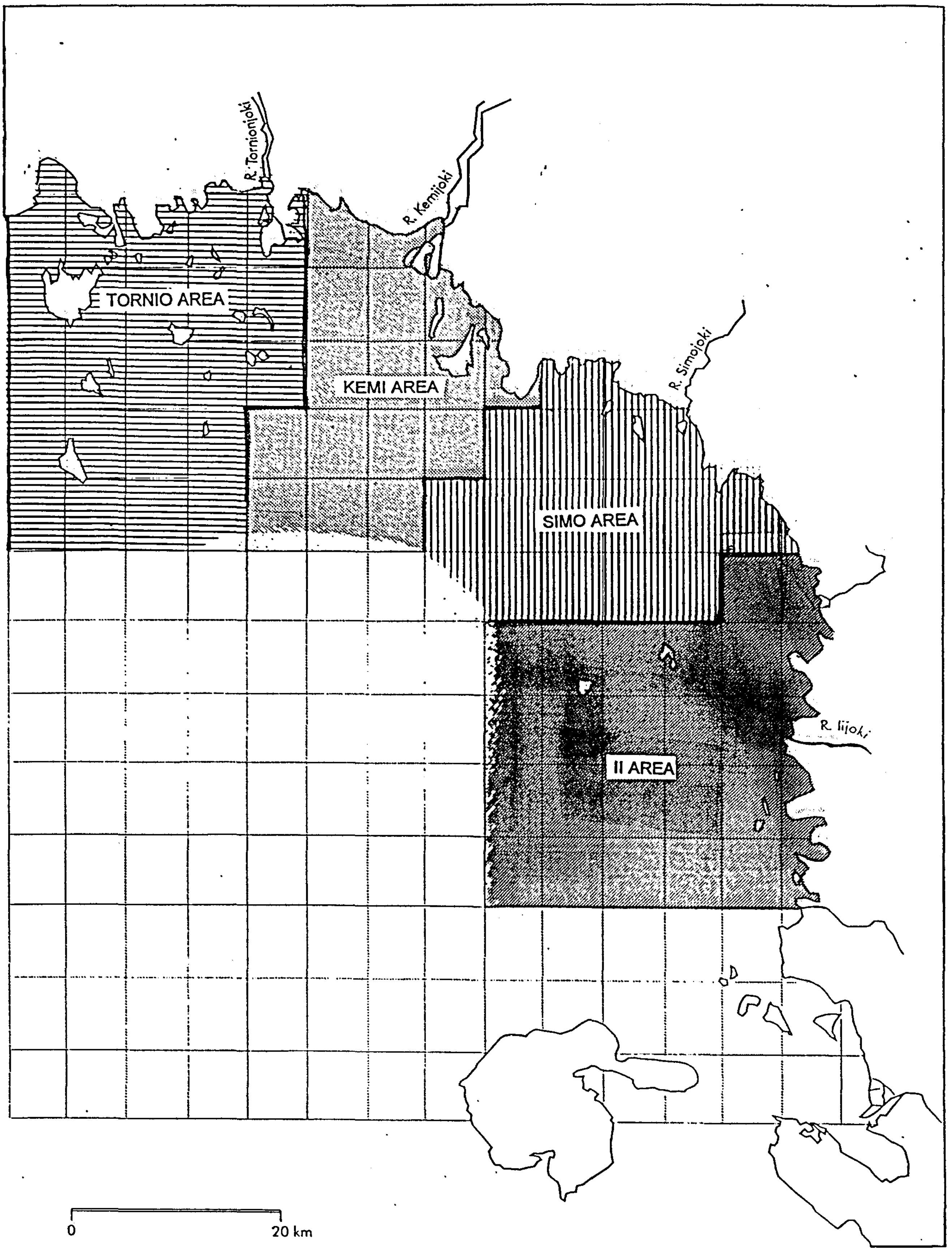


Figure 3. The four selected areas representing the mouths of the studied rivers. A sub-rectangle belonged to the area of a river mouth with the shortest distance. The data in the sub-rectangles shown in the Figure 2 were combined in these areas. The areas are named Tornio, Kemi, Simo, and Ii area.