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GIS and Atlas of Salmons spatial-temporal distribution in the northwestern part of Japan (East) Sea

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Abstract

GIS, which contains the data of 34 scientific-research and fishery-research cruises in the northwestern part of Japan (East) Sea within the period from February 10, 1981 to November 26, 2003 (2483 trawl stations), used for preparation "Atlas of nekton species quantitative distribution in the northwestern part of the Japan Sea". The atlas in almost 950 maps summarizes catch data for fishes, cephalopods and crustaceans by 70 1x1-degree quadrangles. Based on the catch per area method the abundance and biomass (ind./km^2 and kg/km^2) of nekton groups and species per area were calculated in relation to seasonal and interannual dynamics. The atlas will be published in the next year in the Russian language in color in A4-format.

In this document the methods of statistical and cartographical data processing used for preparation of the atlas is briefly described. Further maps, made on the basis of same GIS with accordance to the described technology, are published. It is 28 simplified and diminished maps in gray scale, which show spatial-temporal density distribution of most abundant salmon species: Pink salmon, Chum salmon, Cherry salmon, and all Pacific salmon species totally, including rare Coho salmon catches (to make separate maps for it is not meaningful) in upper epipelagic water layer. Their whole can be considered as a small Atlas of Salmons spatial-temporal distribution in the northwestern part of the Japan (East) Sea.

This year in the Laboratory of Applied Biocenology, TINRO-Center, has been completed the works on creation of GIS, which contains more than 4300 electronic maps of nekton distribution in the northwestern part of the Japan (East) Sea. The data of 34 scientific-research and fishery-research cruises in this sea within the period from February 10, 1981 to November 26, 2003, during which at least one valuable pelagic trawling was made, were used when creating these maps. The following trawling were not considered as valuable: 1) emergency, 2) technical or adjustment, 3) purely fishery, 4) lasting for more than 3.5 hours or not more than 10 minutes (if in the latter case the trawl was taken out without a catch), and 5) conducted in epipelagic water layers (the depth of trawling is down to 200 m) with a speed not less than 3 knots. After quality control the number of sampling was equal to 2483 trawl stations (Table 1). The method of data processing is same, which was applied to preparation of "Atlas of quantitative distribution of nekton species in the Okhotsk Sea" (2003). It is in detail described in the several previous publications (see, for example, Volvenko, 2003a, b).

For all trawl stations the number and weight of every species or group of animals per trawled unit area – square kilometer (in ind./km^2 and kg/km^2) – were calculated by the following formulas:

$$\frac{N}{A}\cdot\frac{p}{k}=\frac{N\cdot p}{1.852\cdot v\cdot t\cdot 0.001\cdot a\cdot k} \quad \text{and} \quad \frac{M}{A}\cdot\frac{p}{k}=\frac{M\cdot p}{1.852\cdot v\cdot t\cdot 0.001\cdot a\cdot k}.$$

Where: N - number and M - weight of fishes in a catch (ind., kg);

A - an area trawled during towing (km^2);

v - towing speed (knots);

t - towing duration (hr);

a - horizontal trawl mouth opening (m);

p and k - correction factors;

1.852 - the number of km in a nautical mile, 0.001 - the number of km in m.

This procedure of calculation differs from the classical "area" method (see, for example, Volvenko, 2000) only by introduction of two corrections p and k, compensating under-calculation of animals, caused by imperfection of trawl and methods of its application.

The first correction ($p \geq 1$) is introduced in numerator as coefficient of extensionality and/or as ladder-shaped trawling compensation.

Introduction of p as extensionality coefficient is an attempt to combine advantages of "area" and "volume" approaches[1] to estimation of animal abundance. For this purpose readings of an echo-sounding device and a device, registering vertical opening of trawl mouth, were compared during trawling. On the basis of such observations a correction coefficient, equal to the ratio of height of trawled fishes swarm to the vertical trawl mouth opening, was introduced. For example, if in the process of trawling a 120 m thick fish school was caught at vertical trawl mouth opening of 40 m, the catch was multiplied by 3. All similar adjustments are reflected in the trawl cards. Such approach allows us to estimate animal abundance per area unit of the surveyed region more correctly, than the standard "area" method.

The other necessity of this correction application is connected with the use of a ladder-shaped method of trawling, when for some time trawl is towed on one depth level and after that they continue towing on the other depth level[2]. For example, within an hour trawling 200 m depth level was caught during the first 30 min, and the rest of the time – the surface water layer. In such a case a catch of salmons, inhabiting the upper epipelagic water layers was multiplied by 2. The same

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[1] Advantages of the second one are indisputable (Volvenko, 2000). However, for its correct application it is necessary to obtain detailed information on the limits of vertical distribution of each animal species and on features of their density distribution in different depths. It is known that for many species these parameters considerably depend on a place and time (season and time of the day) of sampling, and also on physiological condition of individuals. Up to now poor investigation of the most species chorology (including some mass commercial ones) leads to the fact that application of the "area" method just as it is results in the increase of not information but entropy.

[2] Naturally it reduces scientific significance of the collected data, but it is made very often, exclusively with the time, efforts and costs saving purposes during trawl survey.

thing was made to the catch of big walleye pollock, which tends towards near-bottom mode of life. Thus, the fact that habitats of each of these two species were trawled within only a half of the registered time was compensated.

In the other cases *p*-correction was automatically taken as equal to 1, and it did not affect calculation results.

The second correction ($0 < k < 1$) was introduced as a co-factor in denominator. It is a catchability coefficient, which means, by the original definition, "the ratio of the number of fishes caught to the total number of fishes on the trawled area" (Baranov, 1933).

A catchability coefficient is determined by a size and form of a body and also by the swimming velocity and peculiarities of animals' behavior. Besides, it depends upon the fisheries gear and conditions of its application, density of fishing objects concentration, their size and age structure and physiological state. But modern investigation methods do not permit to take into account all mentioned factors. That is why in our work these coefficients, differentiated by three different size-age groups of individuals (for salmons they are shown in Table 2), are applied only with reference to a small number of the most abundant and relatively well-studied fish species and squids. A catch of each size group of these species was recorded in a trawl card as a separate line. Catchability coefficients, independent of individual sizes, were applied for the other animal species. At the same time, the lowest limit was introduced for them as well: the minimal adopted in this work value of the catch ability coefficient equal to 0.01 was applied for the smallest individuals with a body length up to 5 cm and weight less than 1 g (generally these are fish larva), regardless of their affiliation with a certain species.

Coefficient values for all species and inter specific taxa of nekton in the Japan (East) Sea vary from 0.01 to 0.5. Some of them, judging by published data, obtained by the methods of underwater observation (for example, for shrimps), others – by comparison of trawl survey data with catch data (for example, for salmons), the third ones – with the help of extrapolation and analogy on the basis of data on animal's size and behavior. Unfortunately up till now the latter approach in estimation of the catchability coefficients prevails over the others. Strictly speaking, the modern level of knowledge permits to affirm with 100% certainty only that a catchability coefficient value is always more than 0 and less than 1. The first limit is conditioned by the fact that an animal with 0 catchability coefficient can never be caught. The second one results from the fact that catchability equal to 1 can be attributed only to an ideal fisheries gear, which service area tends to infinity, and coefficient of catch variation per effort unit tends to 0 (Kadilnikov, 1987).

The way of calculation of horizontal trawl mouth opening (*a*), which is a part of denominator of density calculation formula, deserves a separate description. The matter is that 13 different trawl systems were used for work in pelagic water layers during the mentioned cruises. At that none of the ships was equipped with devices for measuring horizontal trawl mouth opening. Till recently it substantially aggravated quantitative estimations of nekton abundance because of vagueness of estimations of areas and volumes trawled within one towing. Original and for the present the only possible solution of the problem was suggested by investigation of mathematic model of trawl systems behavior, developed on the Faculty of Fishery of the Far-Eastern State Technical Fishery University (Gabruk, 1988, 1995).

Using the Program of Trawl Systems Adjustment (NTS, the authors are Gabruk V.I. and Osipov E.V.), functioning of different trawl types under different conditions and towing regimes was simulated. Statistical treatment of the obtained data using the method of stepwise multiple regression analysis (Draper, Smith, 1986-1987) allowed deriving empirical equations describing statistical dependence of horizontal trawl mouth opening upon trawl system specification and trawling parameters: vertical trawl opening, towing speed, towing depth and warp length. The method of derivation and investigation of such equations on the example of one of trawl systems was publishes previously (Volvenko, 2000).

A digital map created by the Pacific Institute of Geography, Far-Eastern Division of the Russian Academy of Sciences, on the basis of a national map No 60091 with a scale 1:5000000 served as a cartographic basis for GIS. Coastline and 100, 200, 500 and 1000 m isobaths were taken from that map. All cartographic material and quantitative information on nekton are united in Arc-

View 3.2. Using this program a part of the Japan (East) Sea area, where trawl station were located, was divided into 70 1x1-degree trapezoids with centers in points of crossing meridians and parallels (fig. 1). Trapeziums, adjoining land or sea borders, and also including islands, were transformed into polygons with more complicated forms. The other one-degree trapezoids in Mercator projection (see, for example, Map projections…, 1994), which is used for standard navigating charts manufacture, look as rectangles.

Digits, indicating average long-term values of density (in unites of number, ind./km^2, or biomass, kg/km^2), calculated by data of all trawl stations, located in this polygon, and usually rounded up to integers, were placed in the center of polygons. Sometimes, for species with low density, approximation was made up to one digit after decimal point[1]. The trapezoids are colored in accordance with these numbers in such a way that color intensity is proportional to animal density. Color gradations were chosen in accordance with the following three principles:

1) The number of classes in any map legend does not exceed 7 for easy perception. The value 7±2, known as Muller's number in psychophysiology, determines mean volume of human operative memory, and thereby the limit quantity of precisely identified alternatives (Tatarinov, 1977).

2) Class intervals for every chart were calculated using equal area method. This method classifies polygon features by finding breakpoints in the attribute values so that the total area of the polygons in each class is approximately the same. Classes formed with the equal area method are typically similar to quantile (for details see: Using ArcView GIS, 1996).

3) Trapezoids, for which data are not available, are not colored. On the maps they look blank or transparent: a grid can be seen through them.

Distribution of total sample size between one-degree trapezoids is shown on Fig. 1. The maps, based on the data of all 2483 trawl stations, show average long-term situation with nekton distribution in the northwestern part of the sea in total water layer during 1981-2003 regardless of a season. Besides, in order to reveal peculiarities of spatial-temporal distribution of animals, three principles of grouping and selection of basic data were employed:

A) According to the trawled water layers they are subdivided into:
  1) epipelagic - the depth of headrope towing down to 200 m,
  2) upper epipelagic - the depth of headrope towing down to 25 m,
  3) mesopelagic - the depth of headrope towing down not less than 200 m.

B) According to seasons[2] they are subdivided into:
  1) summer - sampled from June 1 to September 15,
  2) autumn - sampled from September 16 to November 31,
  3) winter - sampled from December 1 to March 31,
  4) spring - sampled from April 1 to May 31.

C) According to years they are subdivided into three long-term periods:
  1) the eighties - 1981-1990,
  2) the first half of the nineties - 1991-1995,
  3) from the second half of the nineties to the present - 1996-2003.

According to this classification the spatial-temporal density distribution of any species, interspecific, or intraspecific size-age group of animals can be fully described using the series of 64 maps. Almost 950 of the most indicative and interesting of them are in press in a form of color atlas of quantitative distribution of nekton in the northwestern part of the Japan (East) Sea (Atlas …, 2004). It will be published in the current or next year in the Russian language in A4-format.

Using GIS in accordance with the described above technology, I prepared 28 simplified and diminished maps in gray scale, which show spatial-temporal density distribution of most abundant salmon species: Pink salmon (Figs. 2-8), Chum salmon (Figs. 9-15), Cherry salmon (Figs. 16-22), and all Pacific salmons totally (Figs. 23-29), including rare Coho catches (to make separate maps for it is not meaningful) in upper epipelagic water layer. Their whole can be considered as a small Atlas of Salmons spatial-temporal distribution in the northwestern part of the Japan (East) Sea.

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[1] It is not possible to supply the sketchy maps of this publication (Figs. 2-29) with figures because of the scale of the charts and the lack of color printing facility.

[2] In this case not calendar but biological seasons of the sea are meant (see Shuntov, 2001).

Table 1

A list of selected cruises, with indication of a sampling size, conducted in the northwestern part of the Japan (East) Sea from 1981 till 2003

Date		Trawler	Number of stations
starting	ending		
10-Feb-81	15-Feb-81	BATM "Babaevsk"	6
26-Aug-81	19-Sep-81	BATM "Pulkovsky Meredian"	23
19-Mar-82	20-Mar-82	BMRT "Mys Teahiy"	2
23-Jul-82	12-Sep-82	BATM "Pioner Nikolaeva"	55
24-Jan-84	28-Jan-84	RTM "Shantar"	2
12-Jul-84	10-Aug-84	STM "Ochakov"	26
25-Nov-84	08-Dec-84	RTMS "Gissar"	26
06-Jun-85	01-Oct-85	RTMS "Novodrutsk"	341
12-Oct-85	17-Nov-85	BMRT "Mys Babushkina"	4
20-Dec-85	20-Feb-86	BATM "Pioner Nikolaeva"	68
30-Apr-86	02-May-86	SRTM "Lesozavodsk"	5
02-Jun-86	06-Jun-86	SRTM "Shursha"	21
28-Jun-86	22-Jul-86	BATM "Babaevsk"	77
04-Oct-86	08-Oct-86	BMRT "Prof. Deryugin"	8
30-Jul-87	09-Sep-87	RTMS "Gissar"	49
15-Oct-87	15-Oct-87	SRTM "Antiya"	2
16-Mar-88	18-Mar-88	STM "Prof. Levanidov"	4
11-Apr-88	28-Aug-88	RTMS "Novoulyanovsk"	11
10-May-88	28-Aug-88	STM "Prof. Soldatov"	304
02-Jul-88	02-Jul-88	RTMS "Novokotovsk"	1
16-Mar-89	10-May-89	SRTM "Lesozavodsk"	21
29-Apr-89	16-May-89	SRTM "Gorniy"	46
26-Jun-89	28-Oct-89	STM "Prof. Kizevetter"	295
10-Apr-90	10-May-90	SRTM "Tamga"	29
17-Apr-90	16-May-90	SRTM "Antiya"	18
23-Jul-90	28-Aug-90	STM "Prof. Kizevetter"	149
07-Sep-90	07-Sep-90	RTMS "Gissar"	2
25-Oct-90	28-Nov-90	STM "Prof. Kaganovsky"	30
29-Jan-91	15-May-91	STM "Prof. Levanidov"	350
06-May-91	27-May-91	SRTM "Gorniy"	50
06-Oct-93	25-Oct-93	STM "Prof. Levanidov"	47
27-Sep-95	21-Nov-95	STM "TINRO"	202
31-Aug-97	15-Sep-97	STM "Prof. Levanidov"	60
03-Nov-03	26-Nov-03	STM "Prof. Kaganovsky"	104

Table 2

A fragment of the table of catchability coefficients (*k*) for nekton species, for which they were differentiated by size-age groups, defined by body length (*L*) and body weight (*W*) of individuals. The entire Table contains more than 50 lines, whereas here only data for common to the area salmons are shown

Species	Small			Medium			Big		
	L, cm	*W*, g	*k*	*L*, cm	*W*, g	*k*	*L*, cm	*W*, g	*k*
Oncorhynchus gorbuscha	-	-	-	$L \leq 30$	$W \leq 316$	0,40	$L > 30$	$W > 316$	0,30
Oncorhynchus keta	-	-	-	$L \leq 30$	$W \leq 297$	0,40	$L > 30$	$W > 297$	0,30
Oncorhynchus kisutch	-	-	-	$L \leq 30$	$W \leq 352$	0,40	$L > 30$	$W > 352$	0,30
Oncorhynchus masou	-	-	-	$L \leq 30$	$W \leq 332$	0,40	$L > 30$	$W > 332$	0,30

Note: 1) *k* coefficients are applied in accordance with individuals size *L*, registered in trawl cards. Only in cases, when such record is not available, or size ranges overlap class limits, the mean weight of an individual in a catch *W* is calculated for selection of the most appropriate *k*. 2) All *W* values of this Table were found using regression equations $W=a \cdot L^b$. 3) Dashes (-) in columns 2-4 indicate that the youngest size-age group is not met in the Sea water area (salmons spawn in fresh waters).

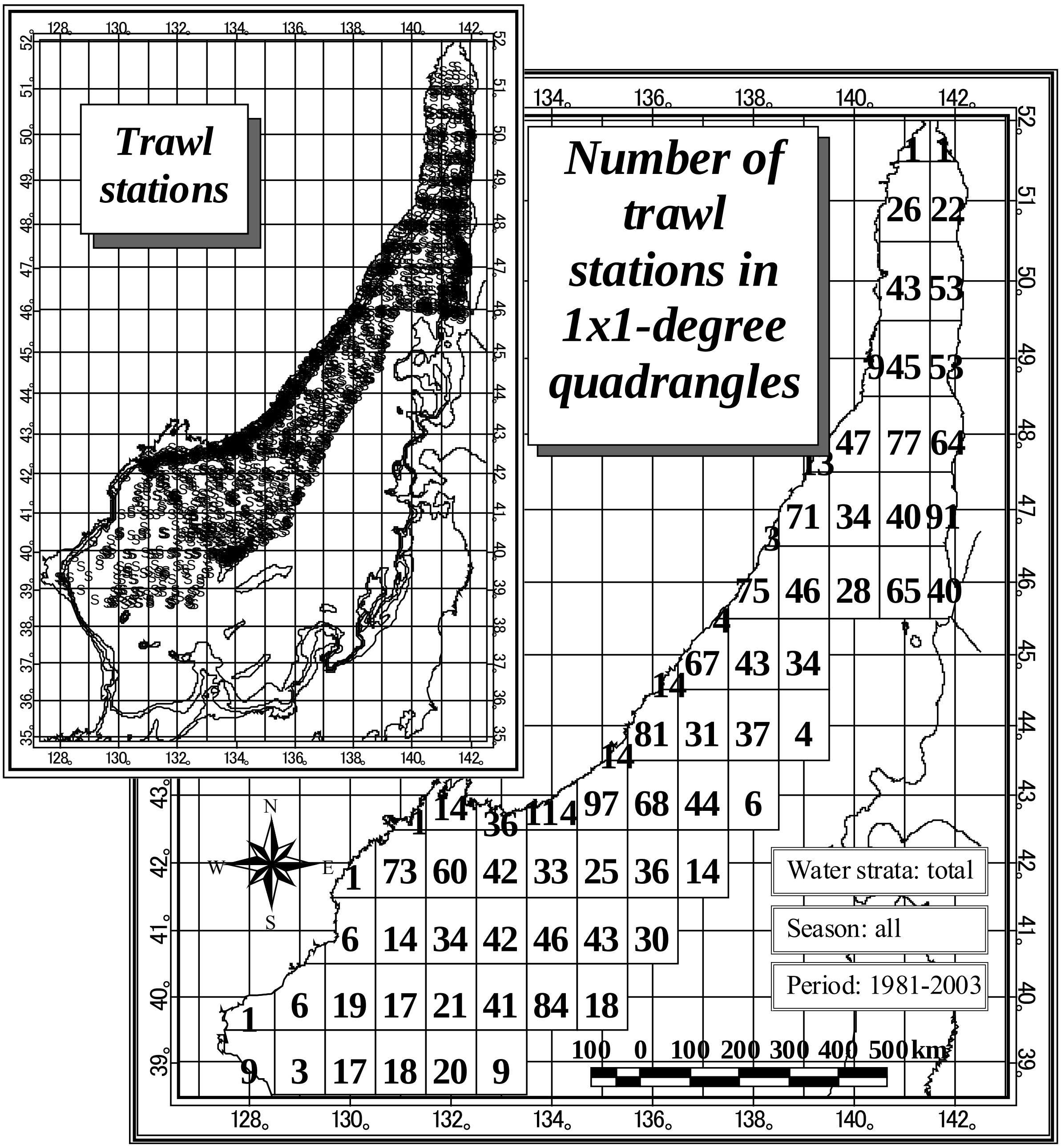

Fig. 1. A scheme of location of 2483 trawl stations and distribution of the number of stations between 70 of 1x1 degree quadrangles with centers in points of meridians and parallels intersection

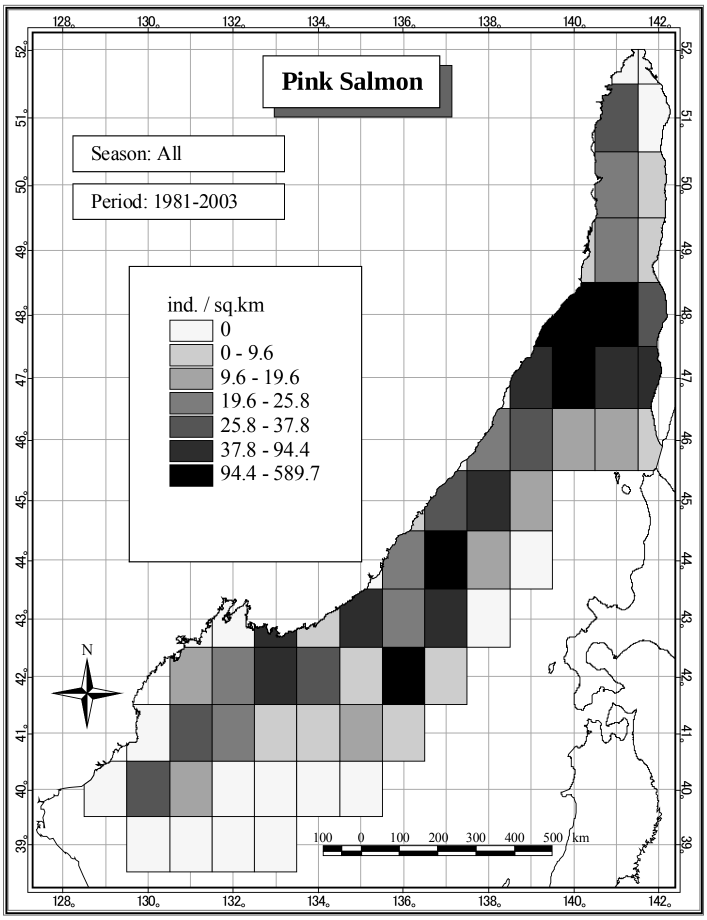

Fig. 2. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer irrespective of season. The data for the years 1981-2003

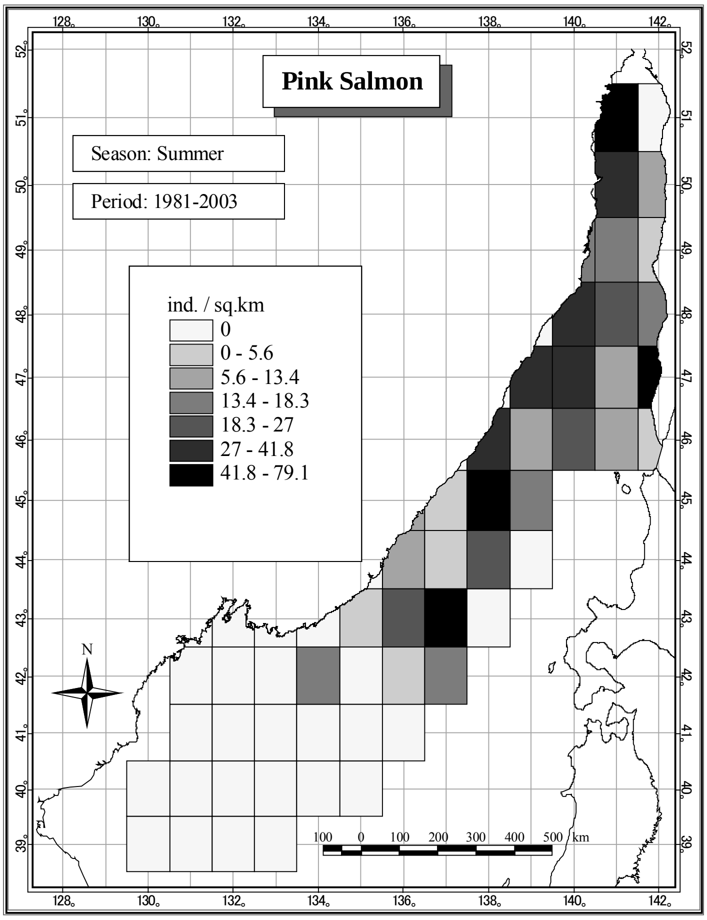

Fig. 3. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer in summer. The data for the years 1981-2003

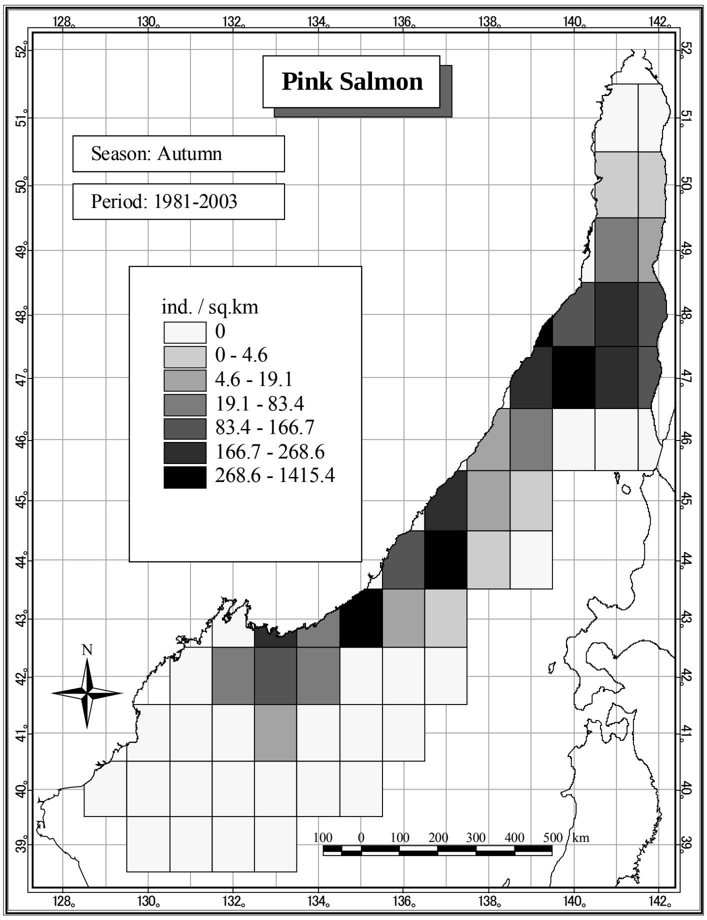

Fig. 4. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer in autumn. The data for the years 1981-2003

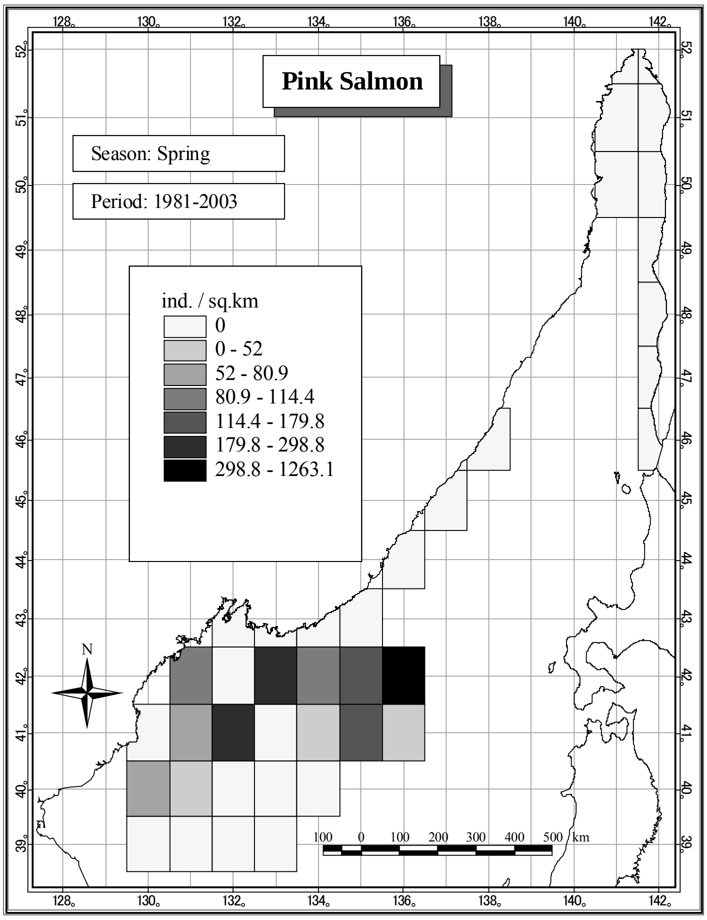

Fig. 5. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer in spring. The data for the years 1981-2003

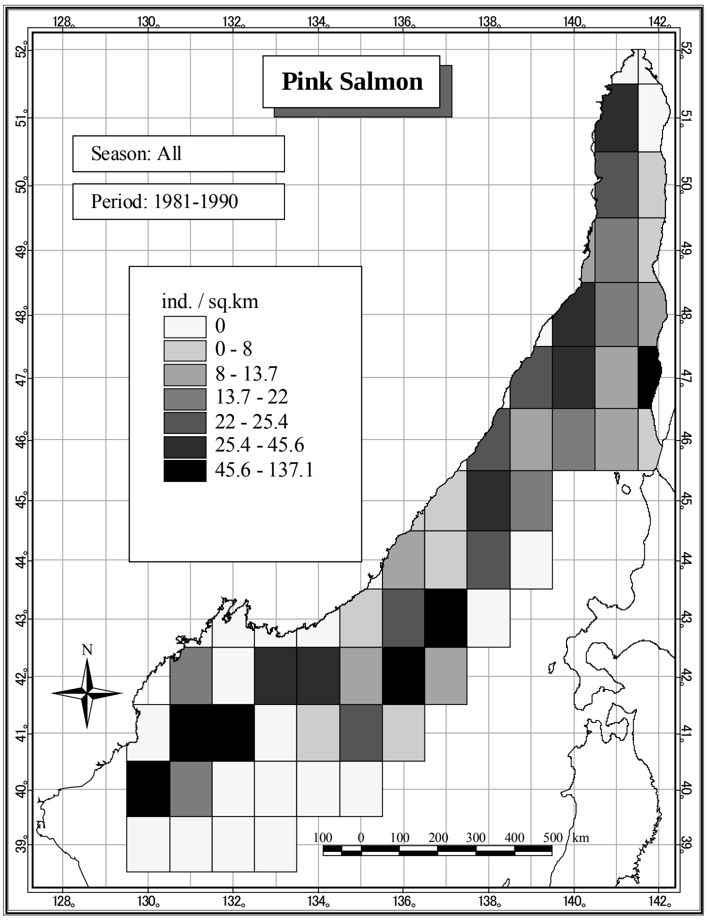

Fig. 6. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer irrespective of season. The data for the years 1981-1990

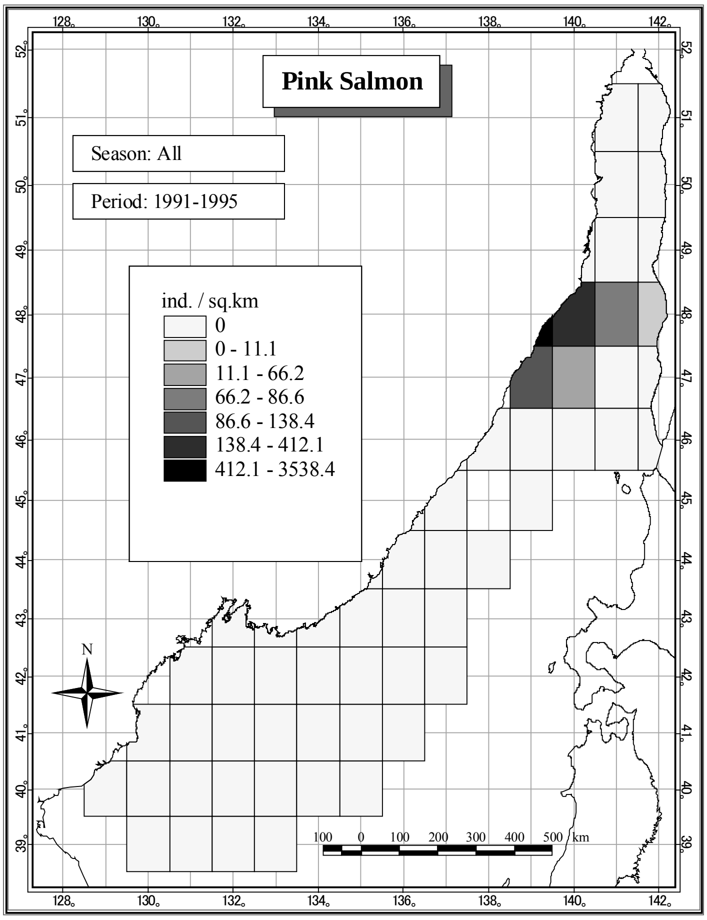

Fig. 7. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer irrespective of season. The data for the years 1991-1995

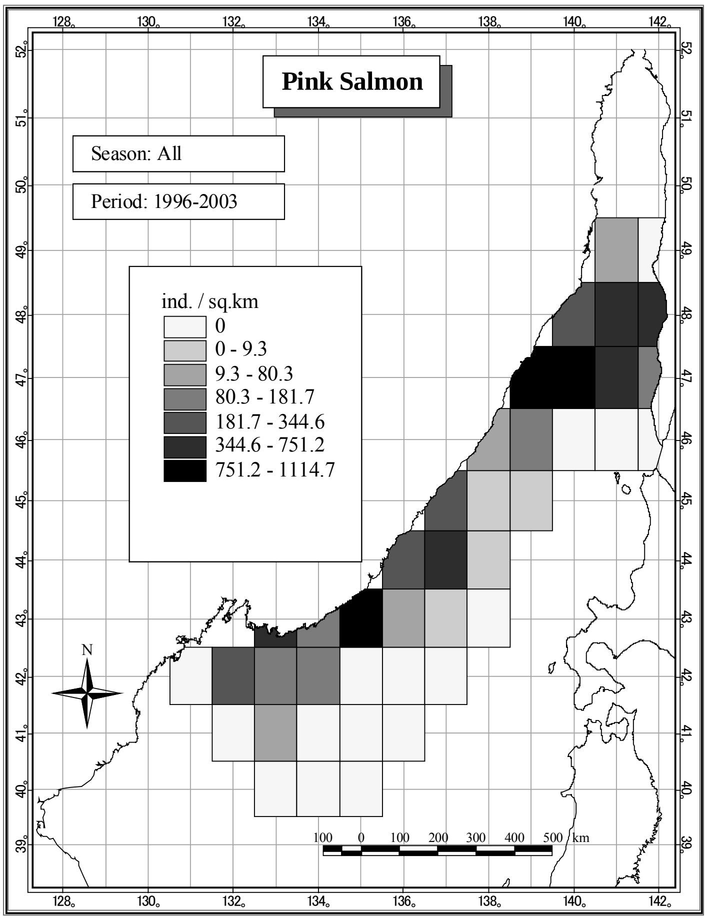

Fig. 8. Density of Pink Salmon *Oncorhynchus gorbuscha* in the upper epipelagic water layer irrespective of season. The data for the years 1996-2003

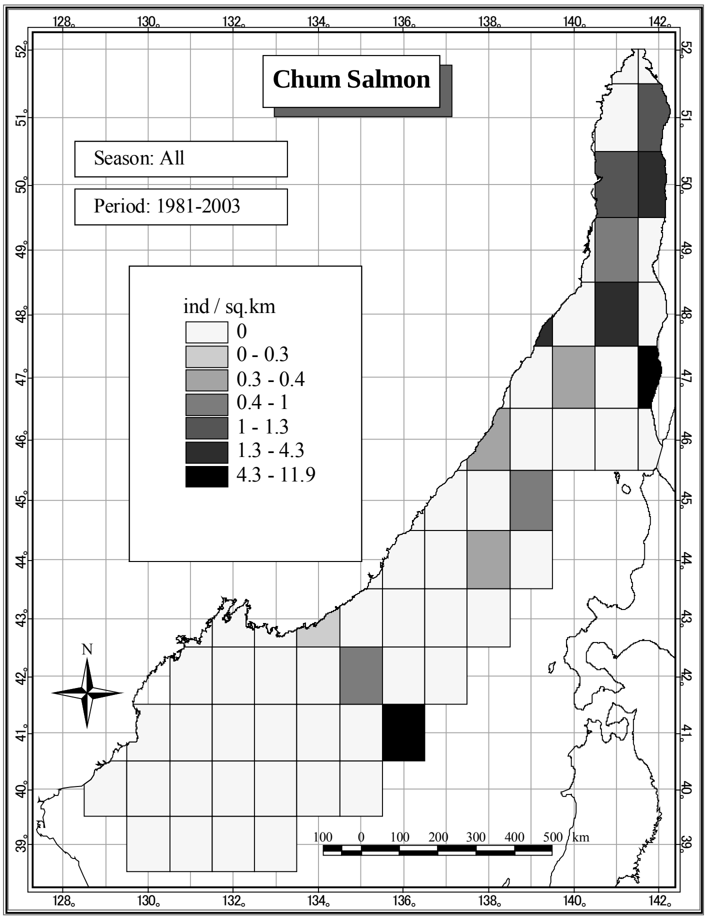

Fig. 9. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer irrespective of season. The data for the years 1981-2003

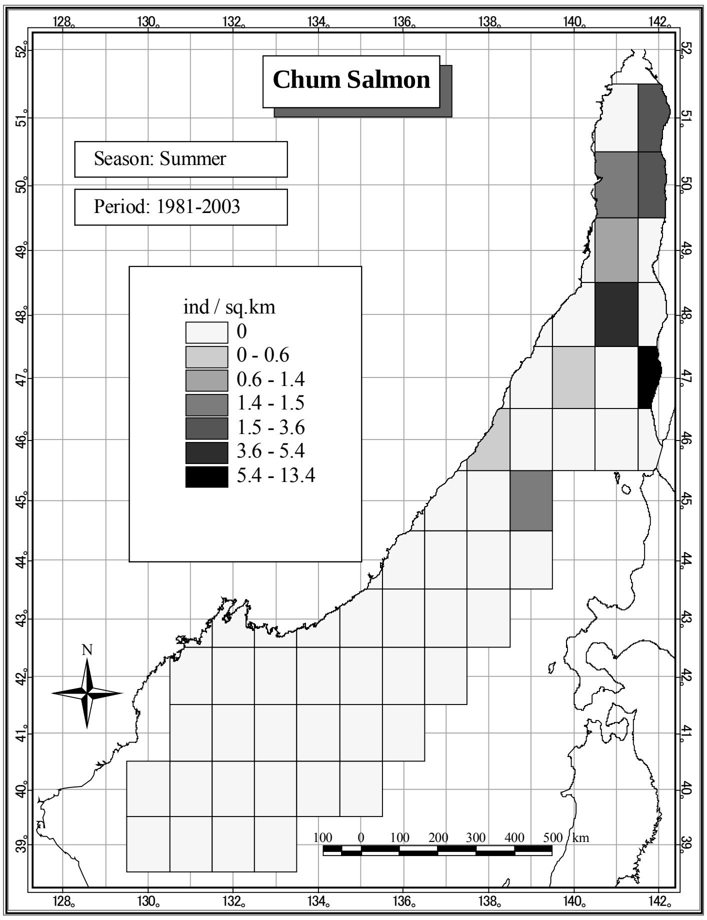

Fig. 10. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer in summer. The data for the years 1981-2003

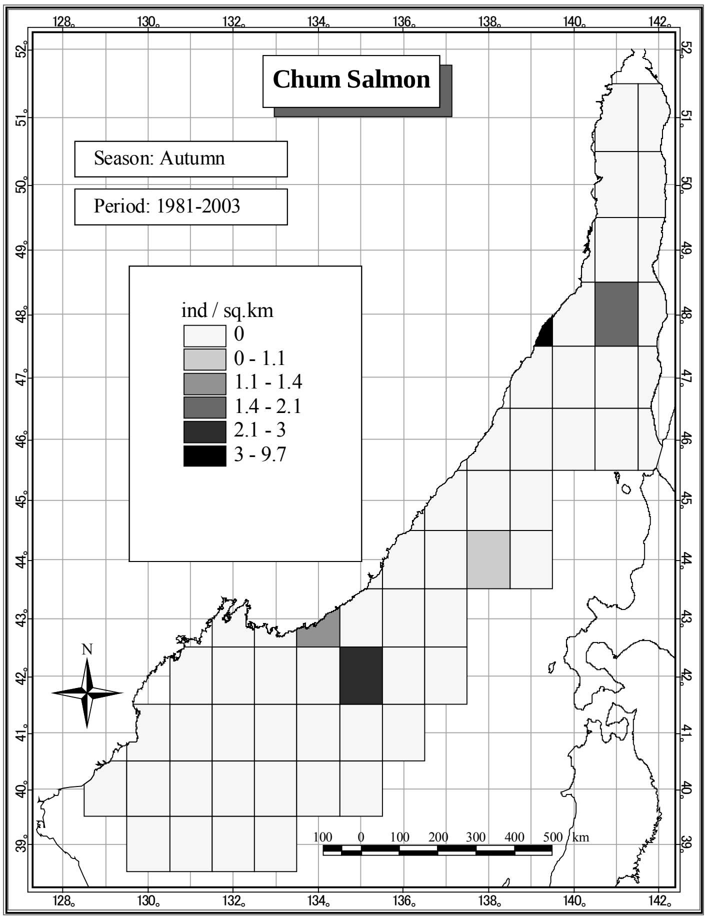

Fig. 11. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer in autumn. The data for the years 1981-2003

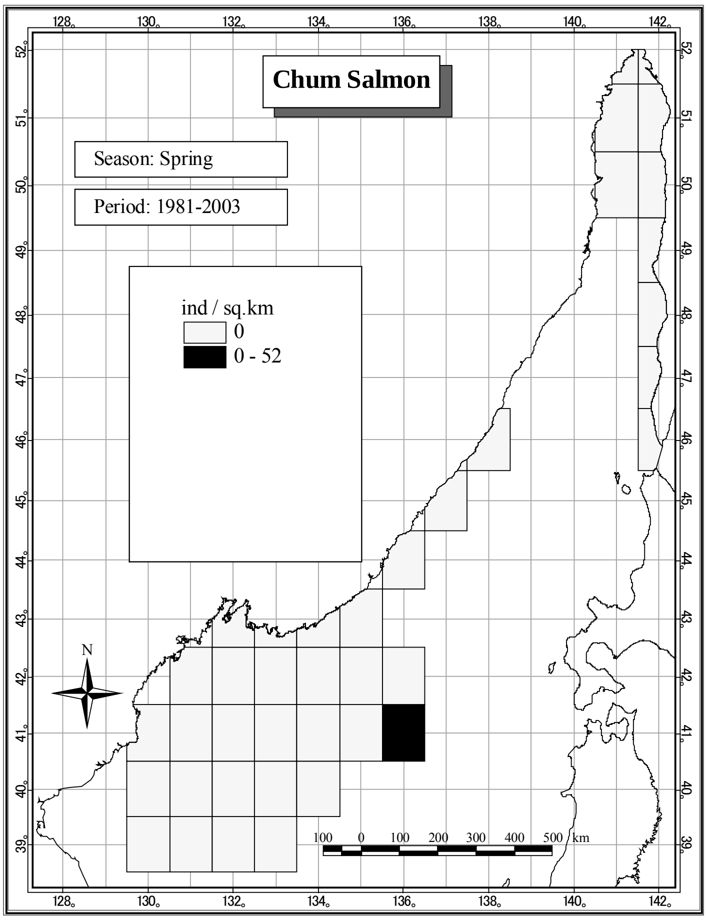

Fig. 12. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer in spring. The data for the years 1981-2003

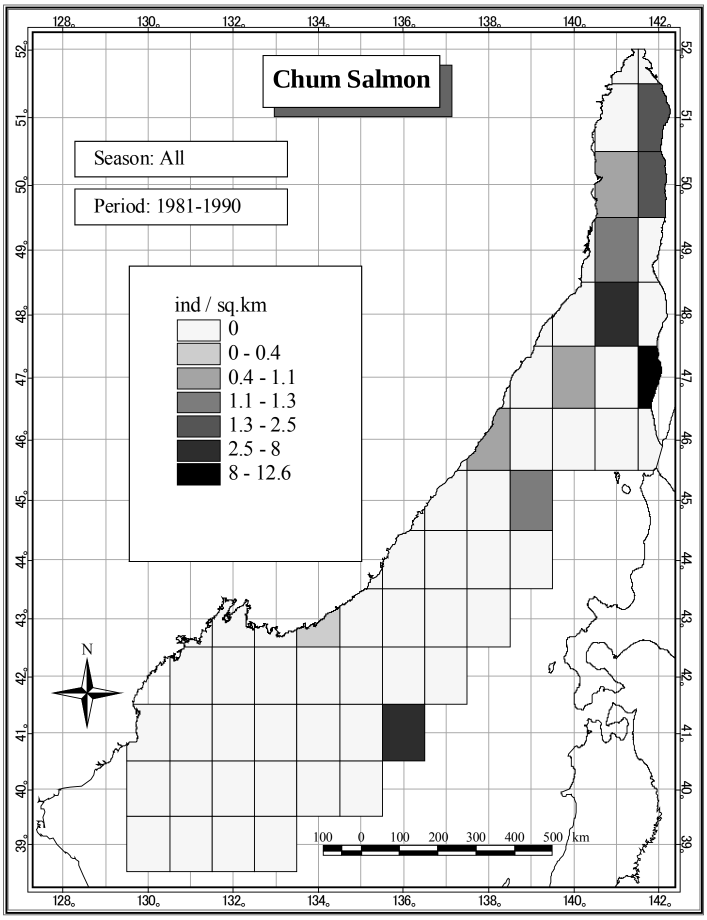

Fig. 13. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer irrespective of season. The data for the years 1981-1990

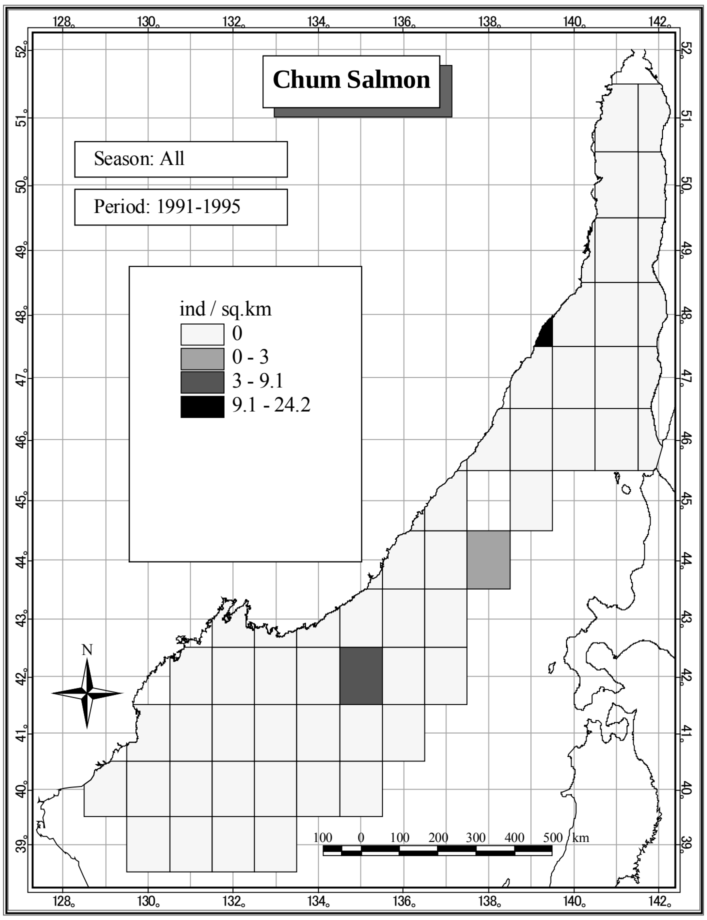

Fig. 14. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer irrespective of season. The data for the years 1991-1995

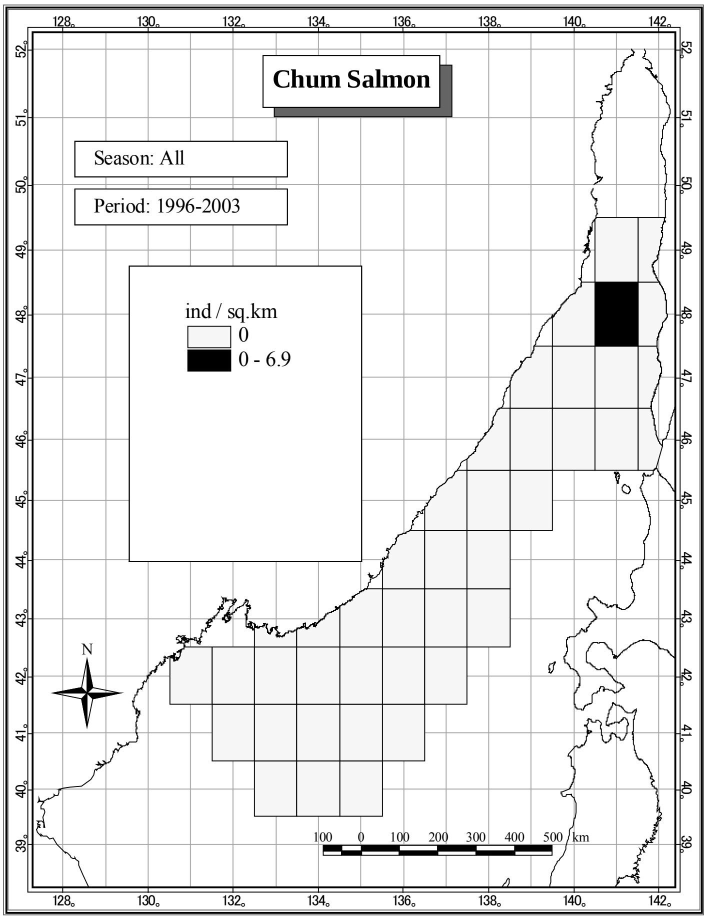

Fig. 15. Density of Chum Salmon *Oncorhynchus keta* in the upper epipelagic water layer irrespective of season. The data for the years 1996-2003

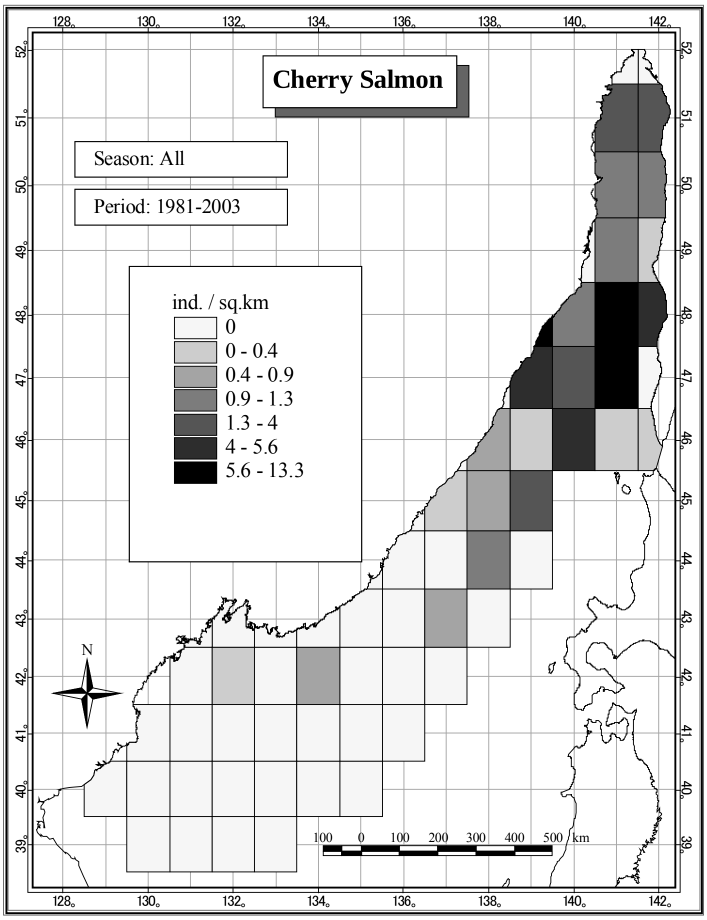

Fig. 16. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer irrespective of season. The data for the years 1981-2003

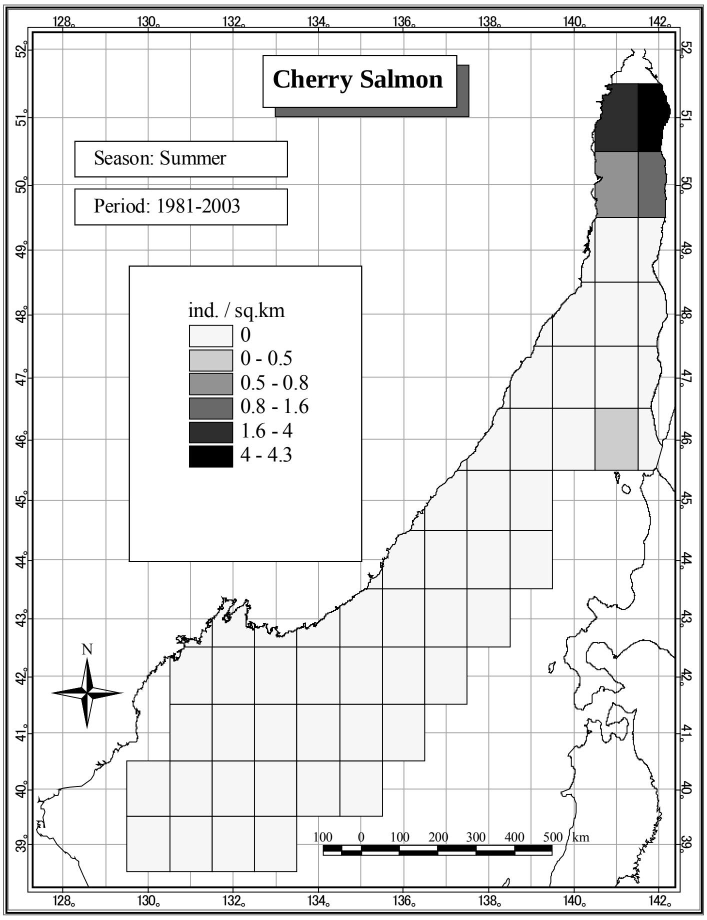

Fig. 17. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer in summer. The data for the years 1981-2003

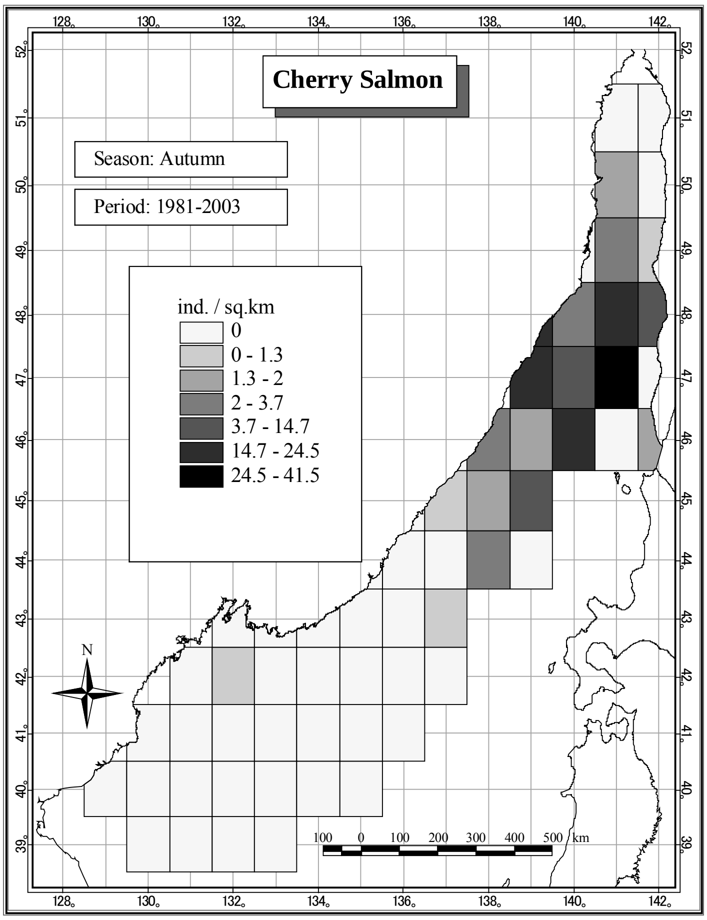

Fig. 18. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer in autumn. The data for the years 1981-2003

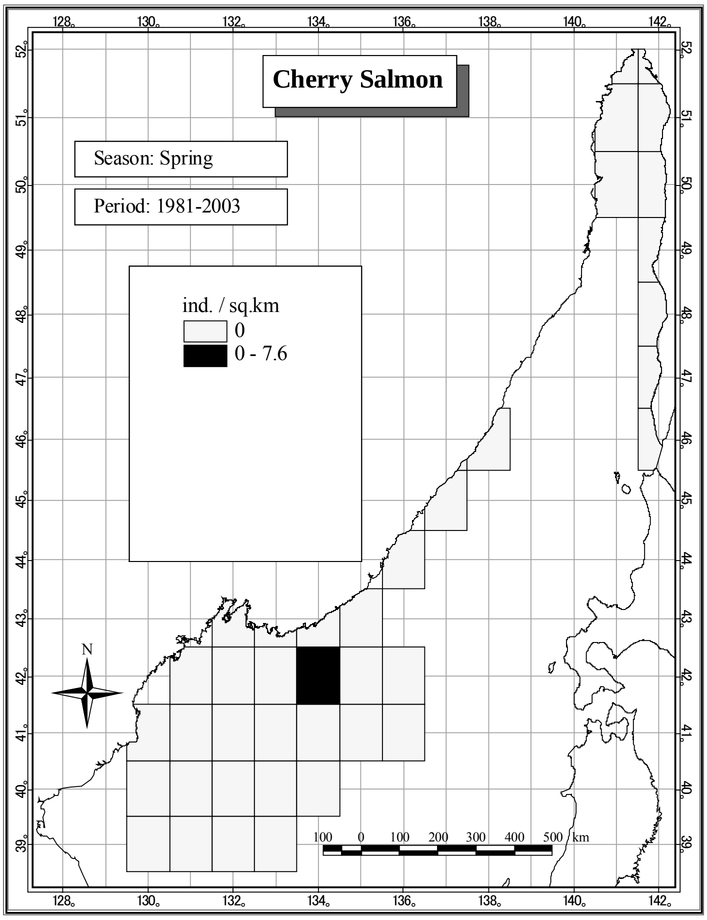

Fig. 19. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer in spring. The data for the years 1981-2003

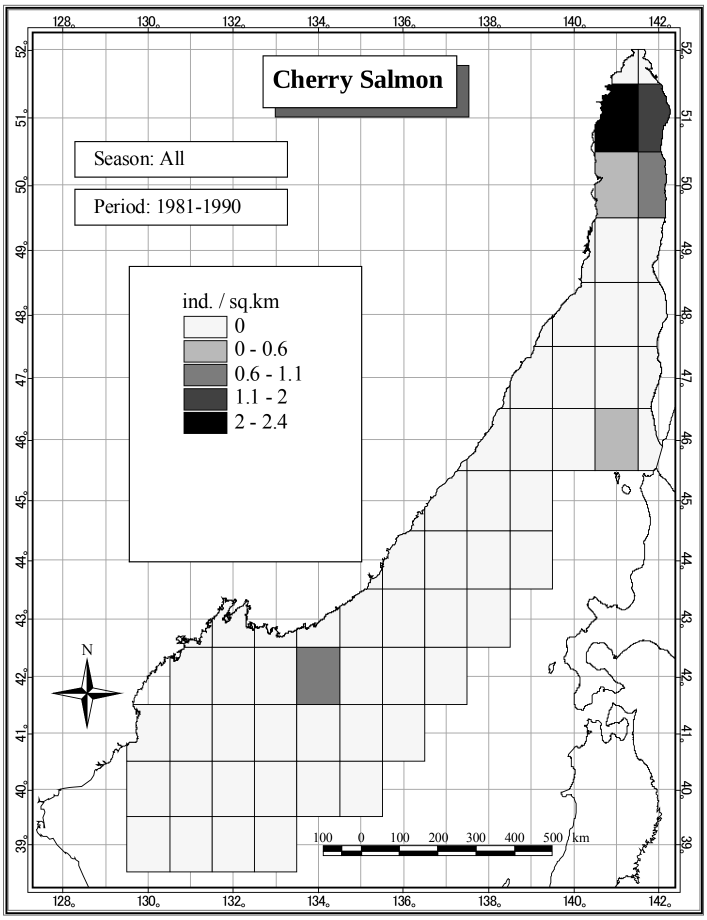

Fig. 20. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer irrespective of season. The data for the years 1981-1990

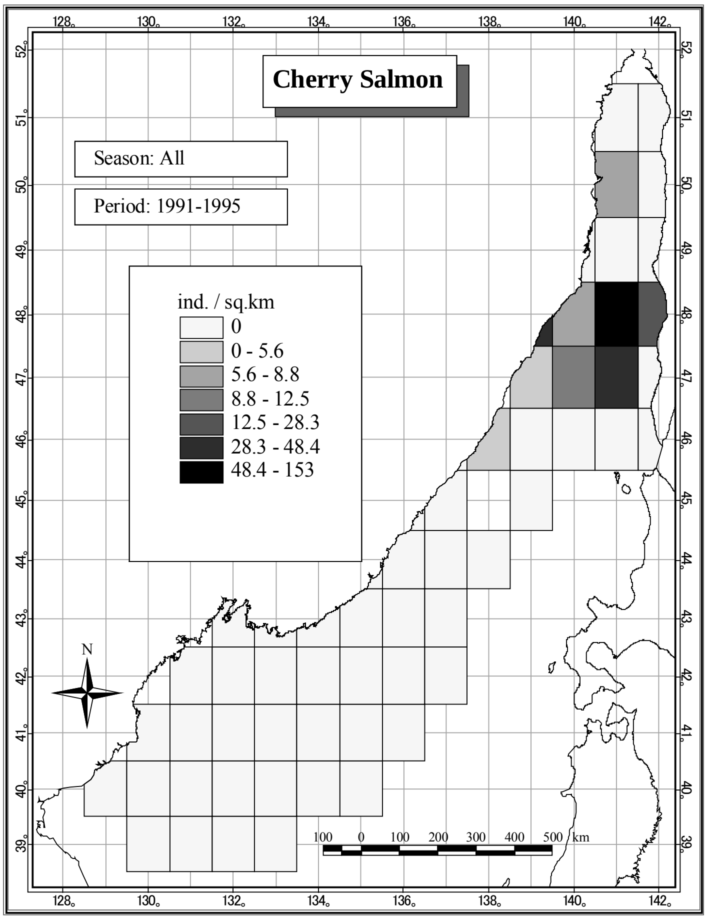

Fig. 21. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer irrespective of season. The data for the years 1991-1995

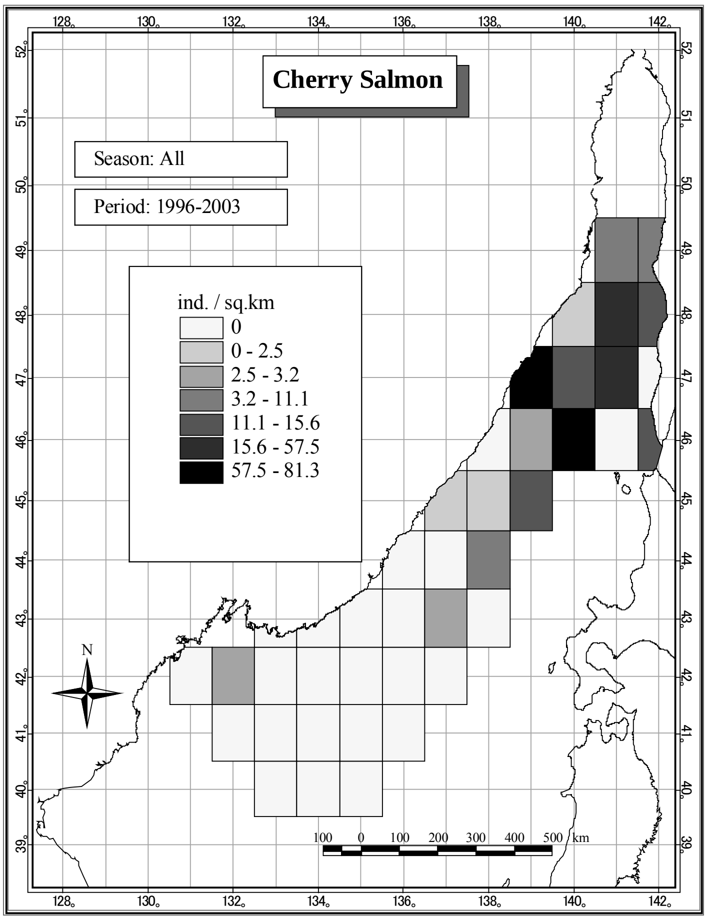

Fig. 22. Density of Cherry Salmon *Oncorhynchus masou* in the upper epipelagic water layer irrespective of season. The data for the years 1996-2003

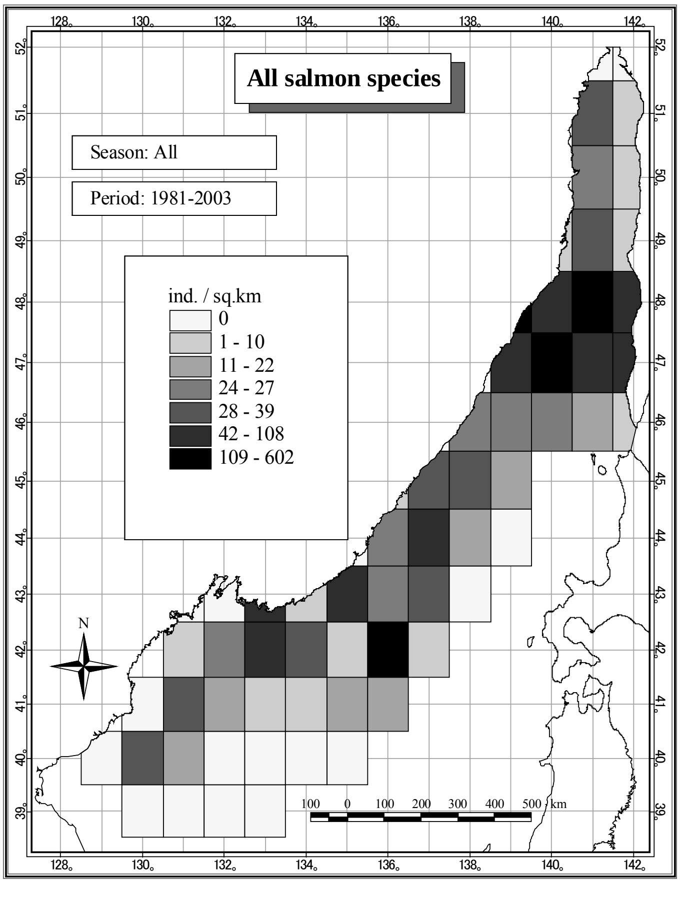

Fig. 23. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer irrespective of season. The data for the years 1981-2003

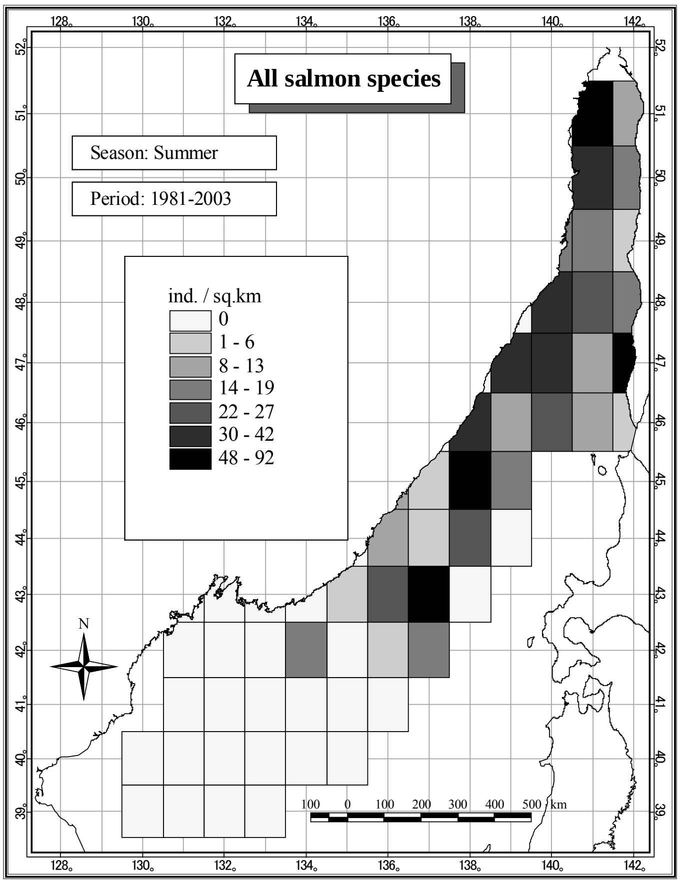

Fig. 24. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer in summer. The data for the years 1981-2003

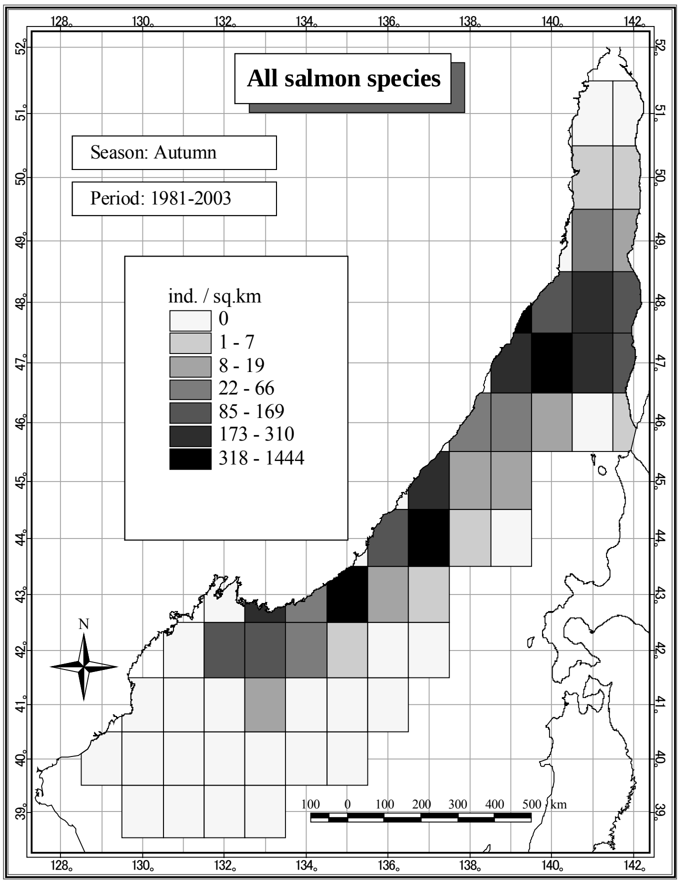

Fig. 25. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer in autumn. The data for the years 1981-2003

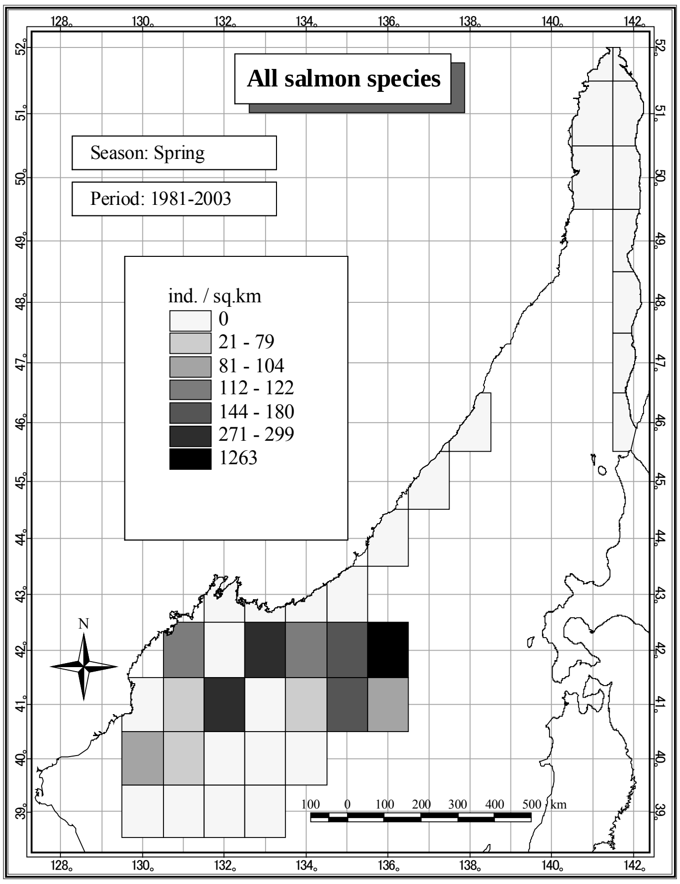

Fig. 26. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer in spring. The data for the years 1981-2003

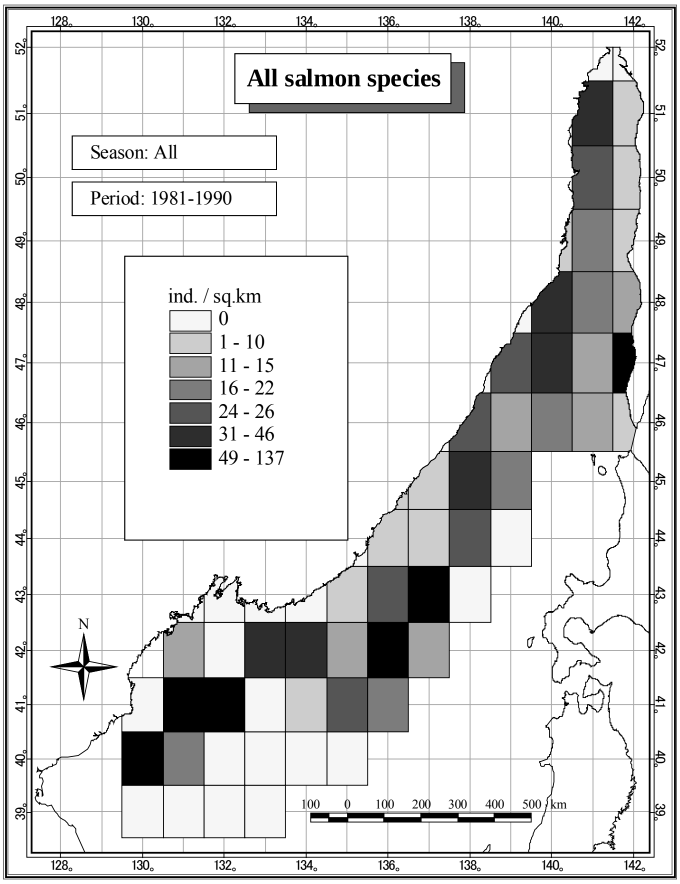

Fig. 27. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer irrespective of season. The data for the years 1981-1990

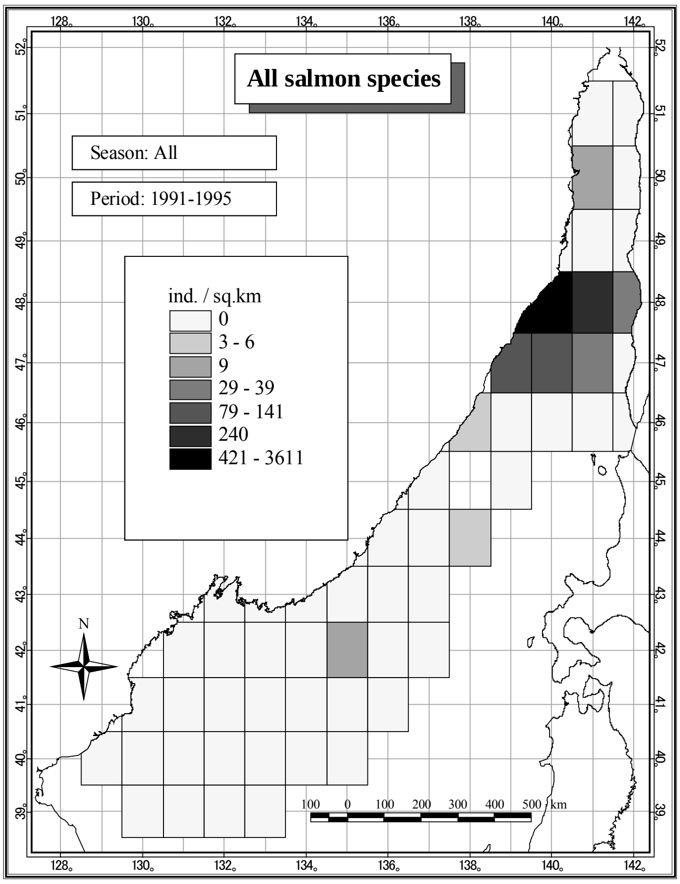

Fig. 28. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer irrespective of season. The data for the years 1991-1995

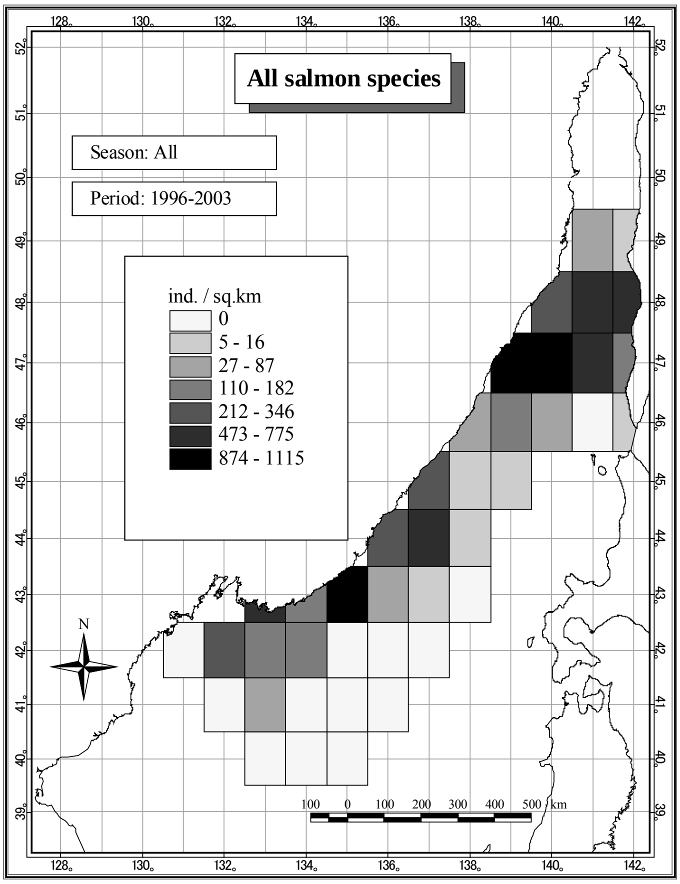

Fig. 29. Total density of all Salmon species *Oncorhynchus spp.* in the upper epipelagic water layer irrespective of season. The data for the years 1996-2003

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