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## **Calculation of the Atlantic Mackerel (*Scomber scombrus* L.) Spawning Biomass from the Ichthyoplankton Surveys Conducted on the West Coast of Newfoundland in July 2007 and 2008**

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## ABSTRACT

Ichthyoplankton surveys for describing distribution and calculating the abundance of fish larvae, mainly herring (*Clupea harengus harengus*) and capelin (*Mallotus villosus*), are conducted on the west coast of Newfoundland since 2004. Atlantic mackerel (*Scomber scombrus*) eggs and larvae are also sampled during these surveys. In this report, the egg abundances of mackerel were converted into spawning biomasses using the Total Egg Production Method. For the entire study area, Atlantic mackerel spawning biomasses were estimated at 13,234 t in 2007 and 19,682 t in 2008. These biomasses are below those calculated in the southern Gulf of St. Lawrence, but suggest relatively high spawner densities within the smaller area on the west coast of Newfoundland.

## RÉSUMÉ

Des relevés d'ichtyoplancton visant à décrire la distribution et à calculer l'abondance des larves de poissons, principalement de hareng (*Clupea harengus harengus*) et de capelan (*Mallotus villosus*), sont réalisés sur la côte ouest de Terre-Neuve depuis 2004. Des œufs et des larves de maquereau bleu (*Scomber scombrus*) sont aussi récoltés lors de ces relevés. Dans ce rapport, les abondances d'œufs de maquereau ont été converties en biomasses reproductrices selon la Méthode de la Production Totale d'Oeufs. Pour toute la zone d'étude, les biomasses reproductrices de maquereau bleu ont été estimées respectivement à 13 234 t en 2007 et 19 682 t en 2008. Ces biomasses sont bien inférieures à celles mesurées dans le sud du golfe du Saint-Laurent mais elles suggèrent des densités relativement élevées de reproducteurs à l'intérieur d'une plus petite zone de la côte ouest de Terre-Neuve.

## INTRODUCTION

Since 2004, ichthyoplankton surveys were conducted on the west coast of Newfoundland in order to calculate the abundance and to describe eggs and larvae distribution of the fish species present in the study area. Several species were sampled during the surveys and larval communities were characterized by the occurrence of some dominant species (Grégoire et al. 2005, 2006a, 2006b, 2008a, 2009, 2010a, 2010b, and 2010c). Furthermore, catches for all species varied interannually.

One of the fish species sampled during these surveys was the Atlantic mackerel (*Scomber scombrus*). The presence of Atlantic mackerel eggs and larvae in the samples from the west coast of Newfoundland surveys was surprising since it is generally recognized that the species' main spawning ground is the southern Gulf of St. Lawrence (Sette 1943, Arnold 1970). Because the west coast of Newfoundland had never previously been covered by an ichthyoplankton survey (except for St. George's Bay), it is not known if mackerel spawns there annually or occasionally.

Spawning biomasses of Atlantic mackerel for the west coast of Newfoundland were calculated for the first time in 2008 from the eggs sampled in 2004 and 2005 (Grégoire et al. 2008b). Since then, two other surveys were conducted on the west coast of Newfoundland, in July 2007 and 2008. Therefore, the objective of this study was to calculate the spawning biomasses of Atlantic mackerel from the data collected in 2007 and 2008.

## MATERIAL AND METHODS

Spawning biomasses were calculated using the same analytical approach used for the abundance surveys conducted in the southern Gulf of St. Lawrence (NAFO Division 4T) (Grégoire et al. 2008c). The main steps of this approach are presented in the following sections.

### Sampling at Sea and Laboratory Analyses

Sampling at sea (deployment of the plankton nets and STD probe) and laboratory analyses have been described in details in Grégoire et al. (2005, 2006b, 2008a, and 2010b). After the lab analyses were completed and the data recorded and validated, the egg abundances (in numbers) per station for development stages 1 and 5 (Girard 2000) were standardized into numbers per m<sup>3</sup> and m<sup>2</sup> while accounting for the volume (m<sup>3</sup>) of filtered water and the maximum sampling depth (m).

### Incubation Time (hr) and Daily Egg Production (n/m<sup>2</sup>)

Incubation times (hr) were calculated based on the Lockwood et al. (1977) model for the Atlantic mackerel in the north-east Atlantic. The daily egg production (n/m<sup>2</sup>) per station was defined as follows:

$$\frac{\text{Abundance (stages 1 and 5) (n/m}^2\text{)}}{\text{Incubation time (hr)}} \bullet 24 \text{ hr}$$

The daily egg production for the entire sampled area, e.g. the average or **P** in the equation below, was calculated using ordinary kriging. The variogram selection and semivariance calculation were made using the GS<sup>+</sup> software (Robertson 1998). Kriging variances and means were calculated with EVA II (Petitgas and Lafont 1997).

### **Sampling Area (A)**

The sampling area was extended in 2007 and 2008 to St. George's Bay (Figure 1). In order to conduct the survey within the same time period, nine of the 39 stations sampled in 2004 and 2005 were removed from the sampling plan. This removal along with the addition of the stations of St. George's Bay led to a new estimate (using EVA II) of the sampling area. The area associated with the 2004 and 2005 survey increased from 2,470 km<sup>2</sup> to 3,214 km<sup>2</sup> in 2007 and 2008. The area occupied by the St. George's Bay stations was estimated at 1,512 km<sup>2</sup> for a total area of 4,718 km<sup>2</sup>.

### **Proportion of Eggs Spawned Daily (S)**

The proportion of eggs spawned daily and at the time of each survey (median date) (**S**) was calculated from a logistic model describing the daily changes of the gonadosomatic index (GSI) values. These GSI values were calculated from all the biological samples collected in the Gulf of St. Lawrence in 2007 and 2008. The same samples were used to calculate the mean weight (g) of a fish (**W**), female fecundity (**F**), and sex ratio (**R**). As the commercial fishery of mackerel starts only in September, it was not possible to collect biological samples directly from the survey area. Consequently, the proportions of eggs spawned daily were calculated from samples collected mainly in the southern Gulf.

### **Total or Annual Egg Production (nb) (P•A/S)**

The total or annual egg production was determined by the ratio between the product of the daily egg production (**P**) and the size of the sampling area (**A**), and the proportion of eggs spawned at the time of a survey (**S**).

### **Spawning Biomass (t)**

Spawning biomass (t) was calculated based on the Total Egg Production Method (TEPM) which is defined as follows:

$$B = \frac{P \cdot A \cdot W}{S \cdot F \cdot R \cdot 10^6}$$

where :

- P** = Daily egg production for the entire sampling area (n/m<sup>2</sup>) (kriging average)
- A** = Sampling area (m<sup>2</sup>) (3.214 x 10<sup>9</sup> m<sup>2</sup>, 1.512 x 10<sup>9</sup> m<sup>2</sup>, and 4.718 x 10<sup>9</sup> m<sup>2</sup>)
- W** = Mean weight (g) of a fish
- S** = Proportion of eggs spawned daily (median date of a survey)
- F** = Female fecundity (Pelletier 1986)
- R** = Sex ratio (proportion of females in the biological samples)
- 10<sup>6</sup>** = Conversion factor from grams to tons

## RESULTS

### Pattern of the Sampling Design

The 2007 survey was conducted between July 18<sup>th</sup> and 21<sup>st</sup>, and in 2008 between July 16<sup>th</sup> and 18<sup>th</sup>. The sampled area included the southern part of Bonne Bay, Bay of Islands, Port au Port Bay and St. George's Bay further south (Figure 1). In 2007, the stations in Bay of Islands and those located in the southern part of Bonne Bay and off Port au Port Bay were sampled first (Figure 2). The survey then moved to St. George's Bay, Port au Port Bay and finally Bay of Islands. In 2008, the stations in Bay of Islands were the first to be sampled (Figure 2). The vessel then moved overnight to St. George's Bay. The last sampled stations were those in Port au Port Bay and Bay of Islands.

In 2007, station 22 was not sampled due to a lack of time and in 2008 there were some problems with the nets at station 3. Problems with the STD probe were met at stations 5 and 28 in 2007 and at stations 26 and 29 in 2008.

### Sampled Depth (m) and Filtered Volume of Water (m<sup>3</sup>)

The water column was sampled at depths varying between 8 and 65 m, for averages of 38 m in 2007 and 31 m in 2008 (Table 1). The volume of filtered water varied between 171 and 653 m<sup>3</sup>, for averages of 253 m<sup>3</sup> in 2007 and 393 m<sup>3</sup> in 2008 (Table 1).

### Number of Eggs by Development Stage and by m<sup>3</sup> and m<sup>2</sup>

A larger number of Atlantic mackerel eggs were sampled in 2008 than in 2007 (Table 2). In 2007, the most abundant eggs were from development stage 1 compared to stages 3 and 1 in 2008. An average of 9.64 eggs per station from stages 1 and 5 was calculated in 2007 compared to 95.91 eggs in 2008 (Table 3). The average and maximum number of eggs per m<sup>3</sup> were respectively 0.04 and 0.26 in 2007 compared to 0.23 and 1.53 in 2008. The corresponding numbers of eggs per m<sup>2</sup> were estimated at 1.34 and 9.20 in 2007, and 5.95 and 34.32 in 2008.

In 2007, the highest abundances (n/m<sup>2</sup>) of eggs (stages 1 and 5) were found at the stations located on the east side of St. George's Bay (Figure 3A). In 2008, the highest abundances were found at most of the stations located between the south of Bonne Bay and Port au Port Bay (excluding the latter) and at the stations located on the east side of St. George's Bay (Figure 3B).

### Water Temperature (°C) in the 0-10 m Layer

The water temperatures of the surface layer (10 first meters) varied between 13.5 and 17.0°C with respective averages of 14.8°C in 2007 and 15.0°C in 2008 (Table 1). In 2007 and 2008, the highest temperatures were measured in St. George's Bay (Figures 3C and 3D).

## **Incubation Time (hr)**

The incubation times calculated in 2007 varied between 25.9 and 35.4 hours for an average of 30.9 hours (Table 4). In 2008, they varied between 24.5 and 35.2 hours for an average of 30.0 hours.

## **Daily Egg Production (nb/m<sup>2</sup>)**

The daily egg production for the entire sampled area (arithmetic mean) was estimated at 1.13 eggs/m<sup>2</sup> in 2007 and at 5.05 eggs/m<sup>2</sup> in 2008 (Table 4). The highest daily egg productions per station were recorded in St. George's Bay in 2007 and south of Bonne Bay and in Bay of Islands and St. George's Bay in 2008 (Figures 4A and 4B). The kriging maps of the daily egg productions per station (Figures 4C and 4D) reflected well the production values presented in Figures 4A and 4B.

A spherical variogram was used to kriging the egg productions (n/m<sup>2</sup>) per station recorded in 2007 (Table 5). For the entire sampled area, the daily egg production (kriging average) was estimated at 1.08 eggs/m<sup>2</sup>, with lower and upper limits (95%) of 0.79 and 1.37 eggs/m<sup>2</sup> (Table 6). A spherical variogram was also used to kriging the egg productions (n/m<sup>2</sup>) per station recorded in 2008. The average daily egg production was estimated at 4.68 eggs/m<sup>2</sup> with lower and upper limits of 3.33 and 6.04 eggs/m<sup>2</sup> (Table 6).

The daily egg productions for St. George's Bay were estimated at 0.46 eggs/m<sup>2</sup> in 2007 and 4.35 eggs/m<sup>2</sup> in 2008 (Table 6). For the sampled areas located between Bonne Bay and Port au Port Bay, the daily egg productions were estimated at 0.47 eggs/m<sup>2</sup> in 2007 and 4.30 eggs/m<sup>2</sup> in 2008.

## **Gonadosomatic Index and Proportion of Eggs Spawned Daily**

In 2007, the maximum values of the gonadosomatic index, which were around 14%, were observed around June 9<sup>th</sup> or day of the year (DOY) 160 (Figure 5A). After a rapid decline, the gonadosomatic index reached values under 2% after July 18<sup>th</sup> (DOY 199). Based on the corresponding logistic model, spawning would have lasted 23 days with a maximum around June 27<sup>th</sup> (DOY 178) (Table 7). The proportion of eggs spawned at the survey's median date, i.e. July 19<sup>th</sup> (DOY 200.5) (Figure 5B), was 0.0005 (Table 8).

In 2008, the maximum gonadosomatic index values were around 13% in early June (Figure 5C). Spawning would have lasted 22 days with a maximum around June 24<sup>th</sup> (DOY 176) (Table 7). The proportion of eggs spawned at the survey's median date, i.e. July 17<sup>th</sup> (DOY 199) (Figure 5D) was estimated at 0.0015 (Table 8).

## **Total Egg Production (nb) and Biological Parameters**

Total egg productions of  $1.24 \times 10^{11}$  and  $2.85 \times 10^{11}$  eggs were calculated for the area covered by the 2004 and 2005 surveys (Table 9) (Grégoire et al. 2008b). Following the changes made to the calculations of the size of the sampled area, the productions increased respectively to  $1.53 \times 10^{12}$  and  $6.07 \times 10^{12}$  eggs (Table 10). In 2007 and 2008, they were estimated at  $3.28 \times 10^{12}$  and  $9.52 \times 10^{12}$  eggs.



For the entire sampled area, the total egg productions were estimated at  $1.11 \times 10^{13}$  eggs in 2007 and  $1.52 \times 10^{13}$  eggs in 2008 (Table 10). For St. George's Bay only, they were estimated at  $1.52 \times 10^{12}$  and  $4.53 \times 10^{12}$  eggs.

From the samples collected in 2007, the proportion of females, mean weight and mean fecundity were respectively 0.51, 341.3 g and 554,931 eggs compared to 0.51, 338.9 g and 510,906 eggs for 2008 (Table 11).

### **Spawning Biomass (t)**

For the entire sampled area, the spawning biomasses were estimated at 13,234 t in 2007 and 19,682 t in 2008 (Table 10, Figure 6). For St. George's Bay, the spawning biomasses in 2007 and 2008 were estimated at 1,821 t and 5,865 t compared to 3,922 t and 12,321 t for the area located between Bonne Bay and Port au Port Bay.

## **CONCLUSION**

The spawning biomasses estimated for the west coast of Newfoundland are well below those calculated for the southern Gulf of St. Lawrence (DFO, 2008). However, they present a net upward trend and the values estimated in 2008 are the highest of the series.

The west coast of Newfoundland surveys do not target the Atlantic mackerel. One of the initial objectives was to calculate the abundance of herring and capelin larvae. The end of July was selected as the best time to sample these larvae. The end of July is also a relatively quiet period in terms of fishing activities and probably the only period where it's possible to conduct a survey on a commercial vessel.

In the southern Gulf of St. Lawrence, the mackerel egg survey is conducted towards the peak of the spawning season (mid to end June). It was not possible to do the same on the west coast of Newfoundland because mackerel are not present in this region at that moment. This should not have any major impacts on the robustness of the method as far as the calculated proportion of eggs spawned daily is representative of the spawning condition of the fish that were present on the west coast of Newfoundland at the time of the survey.

To determine the full extent of the mackerel spawning area, the southern Gulf of St. Lawrence egg survey should be extended at least to the Scotian Shelf and southern Newfoundland. The detection of spawning activities outside the Gulf would improve the current understanding of migration and distribution.

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**Table 1.** Sampled depth (m), volume of filtered water (m<sup>3</sup>), and mean temperature (°C) of the first 10 meters of water for the stations of the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

STATION	LONGITUDE	LATITUDE	SAMPLED		VOLUME OF FILTERED		TEMPERATURE (°C)	
	°W	°N	DEPTH (m)		WATER (m <sup>3</sup> )		(0-10 m)	
	(degrees-minutes)	(degrees-minutes)	2007	2008	2007	2008	2007	2008
1	58° 12'	49° 09'	48	39	286	513	15.3	14.6
2	58° 12'	49° 12'	63	65	279	558	15.7	15.0
3	58° 12'	49° 27'	34	27	249	---	14.8	---
4	58° 12'	49° 33'	56	48	277	473	14.2	13.6
5	58° 18'	49° 06'	40	37	203	453	---	15.1
6	58° 18'	49° 11'	61	60	292	653	14.7	14.4
7	58° 18'	49° 15'	62	39	238	410	14.8	14.3
8	58° 18'	49° 20'	30	27	251	422	14.7	14.0
9	58° 18'	49° 27'	48	46	254	389	14.2	13.6
10	58° 24'	49° 11'	52	38	207	391	14.2	14.2
11	58° 24'	49° 15'	33	17	277	425	14.0	14.6
12	58° 24'	49° 20'	33	28	262	433	14.5	14.2
13	58° 30'	49° 03'	48	28	286	404	14.5	15.3
14	58° 30'	49° 07'	51	51	216	221	13.5	14.9
15	58° 30'	49° 12'	52	46	256	206	14.2	14.3
16	58° 36'	48° 51'	33	27	268	441	14.4	15.0
17	58° 36'	48° 57'	24	22	242	389	14.0	14.8
18	58° 36'	49° 03'	33	28	208	418	13.6	15.0
19	58° 36'	49° 07'	57	39	210	408	14.2	14.5
20	58° 42'	48° 39'	28	20	245	401	15.2	16.6
21	58° 42'	48° 45'	17	18	261	391	15.1	16.0
22	58° 42'	48° 51'	---	8	---	395	---	14.5
23	58° 42'	48° 57'	16	20	248	428	13.9	14.4
24	58° 48'	48° 36'	16	18	255	427	15.8	15.4
25	58° 48'	48° 39'	17	15	262	405	15.3	16.2
26	58° 48'	48° 42'	11	10	248	396	15.4	---
27	58° 48'	48° 48'	16	15	249	381	13.9	14.4
28	58° 48'	48° 51'	30	29	231	430	---	14.4
29	58° 54'	48° 39'	10	10	242	398	14.9	---
30	58° 54'	48° 45'	19	16	245	402	13.9	14.6
31	59° 06'	48° 39'	28	21	258	406	13.6	14.7
32	59° 18'	48° 30'	44	34	312	358	14.3	14.3
33	59° 06'	48° 28'	47	45	244	223	14.8	16.1
34	58° 54'	48° 28'	50	39	259	264	15.8	16.5
35	58° 42'	48° 30'	35	11	269	396	15.6	17.0
36	58° 36'	48° 30'	33	19	253	412	16.4	16.6
37	58° 36'	48° 27'	55	47	241	453	15.0	15.6
38	59° 12'	48° 24'	53	52	235	203	15.5	15.4
39	59° 00'	48° 24'	50	42	256	225	14.9	15.6
40	58° 48'	48° 24'	37	27	248	344	15.2	15.6
41	58° 42'	48° 24'	41	29	256	440	15.5	15.4
42	59° 06'	48° 18'	52	50	263	171	15.2	15.1
43	58° 54'	48° 18'	52	46	266	429	15.1	15.4
44	58° 48'	48° 18'	35	25	255	438	15.0	15.1
45	59° 00'	48° 12'	54	47	249	457	14.7	15.1
46	58° 54'	48° 13'	26	15	257	425	15.2	14.9
Min.:			10	8	203	171	13.5	13.6
Average:			38	31	253	393	14.8	15.0
Max.:			63	65	312	653	16.4	17.0

**Table 2.** Number of Atlantic mackerel eggs sorted by stage of development for the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

STATION	2007						2008					
	STAGE					TOTAL	STAGE					TOTAL
	1	2	3	4	5		1	2	3	4	5	
1	1	1	5	4	0	11	28	40	236	44	52	400
2	0	1	2	1	1	5	28	48	124	48	28	276
3	10	3	2	0	0	15	---	---	---	---	---	---
4	0	0	0	0	0	0	45	2	7	0	7	61
5	2	5	15	9	0	31	17	2	26	21	5	71
6	5	0	4	3	0	12	24	0	104	96	8	232
7	2	0	0	2	0	4	120	88	152	88	56	504
8	10	3	0	1	1	15	108	8	34	20	8	178
9	3	0	1	1	0	5	93	5	2	1	0	101
10	0	0	0	1	0	1	18	16	54	48	8	144
11	2	0	0	2	1	5	104	2	78	80	0	264
12	6	0	0	1	1	8	146	10	66	38	4	264
13	4	2	5	0	1	12	336	360	704	112	160	1 672
14	0	0	0	0	0	0	3	15	18	7	3	46
15	2	0	3	2	0	7	2	0	4	1	0	7
16	2	2	10	4	0	18	44	44	132	48	16	284
17	1	0	0	2	0	3	388	24	28	40	4	484
18	0	0	0	0	0	0	36	36	228	152	16	468
19	0	0	0	1	0	1	19	10	49	31	3	112
20	5	5	10	6	0	26	5	1	15	26	1	48
21	3	1	15	9	2	30	92	24	66	44	0	226
22	---	---	---	---	---	---	94	20	64	72	2	252
23	0	0	0	0	0	0	22	5	2	0	0	29
24	7	7	9	8	0	31	4	2	20	18	0	44
25	17	3	16	24	0	60	9	1	11	23	4	48
26	1	2	11	17	1	32	30	2	7	3	6	48
27	0	0	0	0	0	0	54	26	102	36	6	224
28	0	0	0	0	0	0	17	7	8	1	1	34
29	43	24	3	2	3	75	22	0	24	0	0	46
30	2	0	2	0	0	4	115	13	147	69	11	355
31	18	0	0	0	0	18	29	19	75	18	0	141
32	10	2	3	0	0	15	3	0	0	0	0	3
33	17	3	10	6	0	36	5	1	9	5	0	20
34	12	14	60	9	0	95	26	18	112	70	0	226
35	9	8	20	36	0	73	320	120	152	384	48	1 024
36	25	4	15	66	0	110	616	24	496	160	16	1 312
37	23	8	8	5	0	44	186	32	136	24	8	386
38	11	1	3	6	0	21	7	2	20	8	0	37
39	13	2	1	0	0	16	2	4	6	2	2	16
40	8	3	6	7	0	24	7	3	47	23	0	79
41	57	31	11	13	1	113	120	38	104	96	6	364
42	5	1	0	0	0	6	6	7	7	0	0	20
43	10	2	1	1	0	14	4	2	4	3	4	17
44	58	18	9	4	7	96	270	22	86	22	4	404
45	2	0	0	1	0	3	80	19	30	13	2	144
46	9	0	0	0	0	9	104	0	138	80	10	332
Σ:	415	156	260	254	19	1 104	3 807	1 122	3 934	2 075	509	11 446
Min.:	0	0	0	0	0	0	2	0	0	0	0	3
Average:	9.2	3.5	5.8	5.6	0.4	24.5	84.6	24.9	87.4	46.1	11.3	254.4
Max.:	58	31	60	66	7	113	616	360	704	384	160	1 672

**Table 3.** Total number and abundance (nb/m<sup>3</sup> and nb/m<sup>2</sup>) of Atlantic mackerel eggs of stages of development 1 and 5 for the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

STATION	EGGS OF STAGES 1 AND 5					
	Total		Abundance (nb / m <sup>3</sup> )		Abundance (nb / m <sup>2</sup> )	
	2007	2008	2007	2008	2007	2008
1	1	80	0.00	0.16	0.17	6.03
2	1	56	0.00	0.10	0.23	6.56
3	10	---	0.04	---	1.36	---
4	0	52	0.00	0.11	0.00	5.28
5	2	22	0.01	0.05	0.39	1.80
6	5	32	0.02	0.05	1.04	2.95
7	2	176	0.01	0.43	0.52	16.77
8	11	116	0.04	0.27	1.32	7.48
9	3	93	0.01	0.24	0.56	11.07
10	0	26	0.00	0.07	0.00	2.56
11	3	104	0.01	0.24	0.36	4.04
12	7	150	0.03	0.35	0.89	9.85
13	5	496	0.02	1.23	0.83	34.32
14	0	6	0.00	0.03	0.00	1.38
15	2	2	0.01	0.01	0.41	0.45
16	2	60	0.01	0.14	0.25	3.62
17	1	392	0.00	1.01	0.10	21.69
18	0	52	0.00	0.12	0.00	3.51
19	0	22	0.00	0.05	0.00	2.12
20	5	6	0.02	0.01	0.57	0.30
21	5	92	0.02	0.24	0.33	4.19
22	---	96	---	0.24	---	2.04
23	0	22	0.00	0.05	0.00	1.03
24	7	4	0.03	0.01	0.43	0.17
25	17	13	0.06	0.03	1.07	0.48
26	2	36	0.01	0.09	0.09	0.91
27	0	60	0.00	0.16	0.00	2.37
28	0	18	0.00	0.04	0.00	1.21
29	46	22	0.19	0.06	1.96	0.55
30	2	125	0.01	0.31	0.15	4.90
31	18	29	0.07	0.07	1.96	1.48
32	10	3	0.03	0.01	1.41	0.29
33	17	5	0.07	0.02	3.27	1.01
34	12	26	0.05	0.10	2.30	3.85
35	9	368	0.03	0.93	1.17	10.15
36	25	632	0.10	1.53	3.31	29.55
37	23	194	0.10	0.43	5.24	19.94
38	11	7	0.05	0.03	2.46	1.80
39	13	4	0.05	0.02	2.55	0.74
40	8	7	0.03	0.02	1.20	0.53
41	58	126	0.23	0.29	9.20	8.44
42	5	6	0.02	0.03	0.99	1.76
43	10	8	0.04	0.02	1.95	0.86
44	65	274	0.26	0.62	8.95	15.52
45	2	82	0.01	0.18	0.43	8.45
46	9	114	0.04	0.27	0.90	3.98
Min.:	0	2	0.00	0.01	0	0.17
Average:	9.64	95.91	0.04	0.23	1.34	5.95
Max.:	65	632	0.26	1.53	9.20	34.32

**Table 4.** Incubation time (hr) for Atlantic mackerel eggs of stages of development 1 and 5 and daily egg production (nb/m<sup>2</sup>) by station for the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

STATION	INCUBATION TIME (hr)		DAILY EGG PRODUCTION (nb / m <sup>2</sup> )	
	2007	2008	2007	2008
1	29.1	31.2	0.14	4.63
2	27.8	30.1	0.19	5.24
3	30.6	---	1.06	---
4	32.6	35.0	0.00	3.62
5	---	29.8	---	1.45
6	31.0	32.1	0.81	2.20
7	30.7	32.4	0.41	12.41
8	31.1	33.6	1.02	5.34
9	32.9	35.2	0.41	7.54
10	32.8	32.6	0.00	1.88
11	33.4	31.3	0.26	3.09
12	31.6	32.8	0.68	7.21
13	31.7	28.9	0.63	28.46
14	35.4	30.4	0.00	1.09
15	32.6	32.2	0.30	0.33
16	31.9	30.1	0.18	2.89
17	33.3	30.7	0.07	16.96
18	35.0	30.0	0.00	2.81
19	32.6	31.7	0.00	1.61
20	29.2	25.5	0.47	0.28
21	29.6	26.9	0.27	3.74
22	---	31.6	---	1.55
23	33.7	31.9	0.00	0.78
24	27.7	28.7	0.37	0.14
25	29.1	26.6	0.89	0.43
26	28.8	---	0.08	---
27	33.8	32.1	0.00	1.77
28	---	31.9	---	0.91
29	30.2	---	1.56	---
30	33.8	31.4	0.11	3.75
31	35.2	31.1	1.33	1.14
32	32.4	32.2	1.05	0.21
33	30.5	26.8	2.57	0.90
34	27.4	25.7	2.01	3.60
35	28.1	24.5	1.00	9.95
36	25.9	25.4	3.07	27.95
37	29.8	28.2	4.22	16.97
38	28.4	28.7	2.08	1.50
39	30.3	28.0	2.01	0.63
40	29.5	28.1	0.97	0.45
41	28.3	28.7	7.80	7.07
42	29.5	29.6	0.81	1.43
43	29.7	28.7	1.57	0.72
44	29.9	29.6	7.18	12.58
45	31.0	29.6	0.33	6.85
46	29.4	30.3	0.74	3.16
Min.:	25.9	24.5	0.00	0.14
Average:	30.9	30.0	1.13	5.05
Max.:	35.4	35.2	7.80	28.46

**Table 5.** Parameters of the isotropic variograms used for kriging for the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

YEAR	MODEL*	NUGGET (C0)	SILL (C0 + C)	RANGE (A <sub>0</sub> )	R <sup>2</sup>	RSS (residuals sum of square)
2007	Spherical	0.00	2.93	35.50	0.90	6.45E-01
2008	Spherical	0.10	53.78	22.40	0.92	1.58E+02

\* Spherical model 
$$\gamma(h) = C0 + C \left[ 1.5 \left( \frac{h}{A_0} \right) - 0.5 \left( \frac{h}{A_0} \right)^3 \right] \text{ if } h \leq A_0, \text{ and } C0 + C \text{ otherwise}$$

where  $h$  is a vector of distance having a value and a direction

**Table 6.** Atlantic mackerel daily egg production (nb/m<sup>2</sup>), variance, CV, and confidence intervals (95%) calculated by kriging for the areas covered by the ichthyoplankton surveys conducted on the west coast of Newfoundland since 2004.

AREA*	YEAR	DAILY EGG PRODUCTION (nb / m <sup>2</sup> )	VARIANCE**	CV	95% CONFIDENCE INTERVAL	
					Lower Limit	Upper Limit
<b>2004-2005</b>	2004	1.74	0.07	0.15	1.23	2.25
	2005	4.31	0.16	0.03	3.53	5.08
	2007	0.47	0.04	0.41	0.10	0.84
	2008	4.30	0.74	0.20	2.62	5.99
<b>SGB</b>	2004	---	---	---	---	---
	2005	---	---	---	---	---
	2007	0.46	1.10	2.26	-1.59	2.52
	2008	4.35	12.34	0.81	-2.53	11.24
<b>2007-2008</b>	2004	---	---	---	---	---
	2005	---	---	---	---	---
	2007	1.08	0.02	0.14	0.79	1.37
	2008	4.68	0.48	0.15	3.33	6.04

\* 2004-2005: From south of Bonne Bay to Port au Port Bay; SGB: St. George's Bay;  
2007-2008: From south of Bonne Bay to St. George's Bay

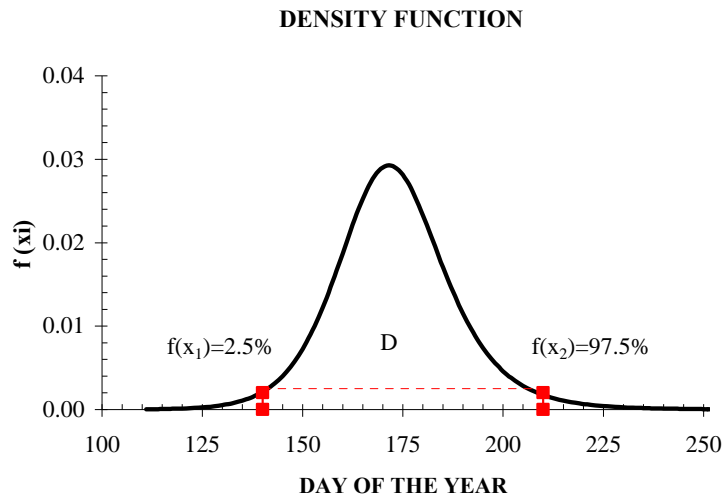
\*\* According to Petitgas and Lafont (1997)



**Table 7.** Characteristics of the Atlantic mackerel spawning seasons estimated from the logistic models describing the daily changes in the gonadosomatic index values.

YEAR	DAY OF THE YEAR			
	$f(x_1)=2.5\%$	$f(x_i)$ Max.	$f(x_2)=97.5\%$	Spawning duration (D) *
<b>2004</b>	169	175	199	30
<b>2005</b>	166	173	199	33
<b>2007</b>	172	178	195	23
<b>2008</b>	171	176	193	22
<b>Min.:</b>	166	173	193	22
<b>Average:</b>	170	176	197	27
<b>Max.:</b>	172	178	199	33

\* Spawning duration (D):  $x_{i=97.5\%} - x_{i=2.5\%}$



**Table 8.** Parameters of the logistic models used to describe the daily changes in the gonadosomatic index values and proportion of eggs spawned daily.

YEAR	PARAMETERS -LOGISTIC MODEL- *				SEE**	r <sup>2</sup> (adjusted)	PROPORTION
	a	b	x0	y0			
2004	10.55	29.09	175.60	0.51	0.991	0.938	0.0036
2005	16.03	26.66	173.70	0.46	0.949	0.962	0.0023
2007	12.34	38.25	176.99	0.53	0.623	0.979	0.0005
2008	10.35	39.53	176.68	0.50	0.768	0.963	0.0015

$$* \quad y = y_0 + \frac{a}{\left[1 + \left(\frac{x}{x_0}\right)^b\right]}$$

\*\* Standard error of the estimate

**Table 9.** Atlantic mackerel total egg production (nb) and spawning biomass (t) from the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2004 and 2005.

YEAR*	TOTAL EGG PRODUCTION	TOTAL EGG PRODUCTION METHOD (TEPM)		
	NUMBER	SPAWNING BIOMASS (t)	95% CONFIDENCE INTERVAL Lower Limit	Upper Limit
2004	1.24E+11	1 466	1 213	1 720
2005	2.85E+11	5 692	4 793	6 590

\* For a sampling area of 2.47E+09 m<sup>2</sup>

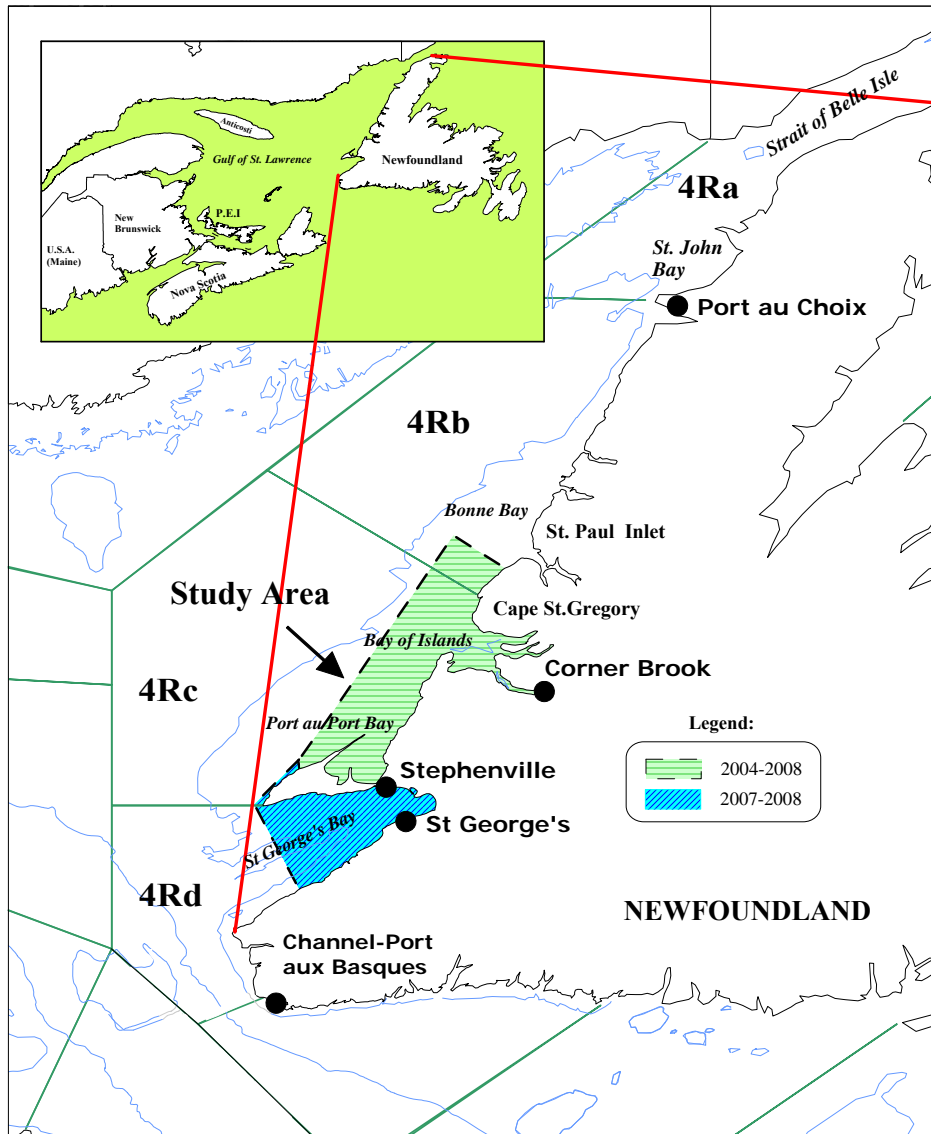
**Table 10.** Atlantic mackerel total egg production (nb) and spawning biomass (t) for the ichthyoplankton surveys conducted on the west coast of Newfoundland since 2004.

AREA*	YEAR	TOTAL EGG PRODUCTION NUMBER	TOTAL EGG PRODUCTION METHOD (TEPM)		
			SPAWNING BIOMASS (t)	95% CONFIDENCE INTERVAL	
				Lower Limit	Upper Limit
<b>2004-2005</b> (3.214E+09 m <sup>2</sup> )	2004	1.53E+12	1 911	1 580	2 241
	2005	6.07E+12	7 417	6 246	8 588
	2007	3.28E+12	3 922	2 768	5 076
	2008	9.52E+12	12 321	9 491	15 151
<b>SGB</b> (1.512E+09 m <sup>2</sup> )	2004	---	---	---	---
	2005	---	---	---	---
	2007	1.52E+12	1 821	-347	3 989
	2008	4.53E+12	5 865	3 146	8 583
<b>2007-2008</b> (4.718E+09 m <sup>2</sup> )	2004	---	---	---	---
	2005	---	---	---	---
	2007	1.11E+13	13 234	10 355	16 113
	2008	1.52E+13	19 682	15 372	23 991

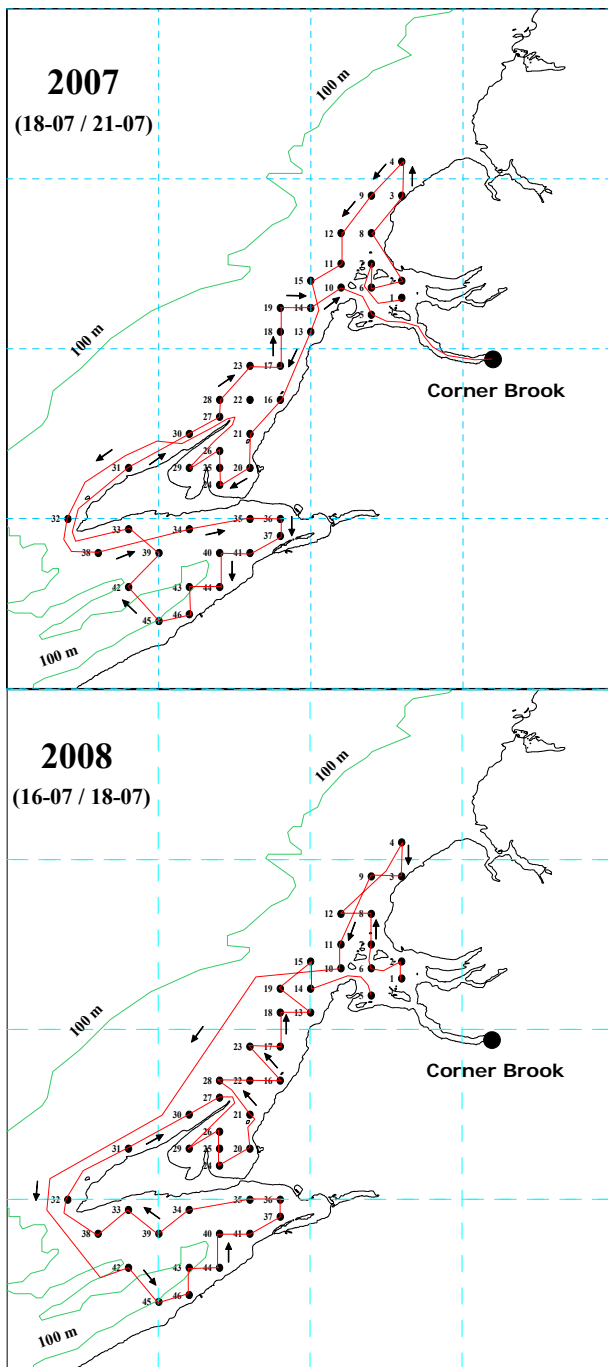
\* 2004-2005: From south of Bonne Bay to Port au Port Bay; SGB: St. George's Bay;  
2007-2008: From south of Bonne Bay to St. George's Bay

**Table 11.** Biological parameters used in the calculation of the Atlantic mackerel spawning biomass from the ichthyoplankton surveys conducted on the west coast of Newfoundland since 2004.

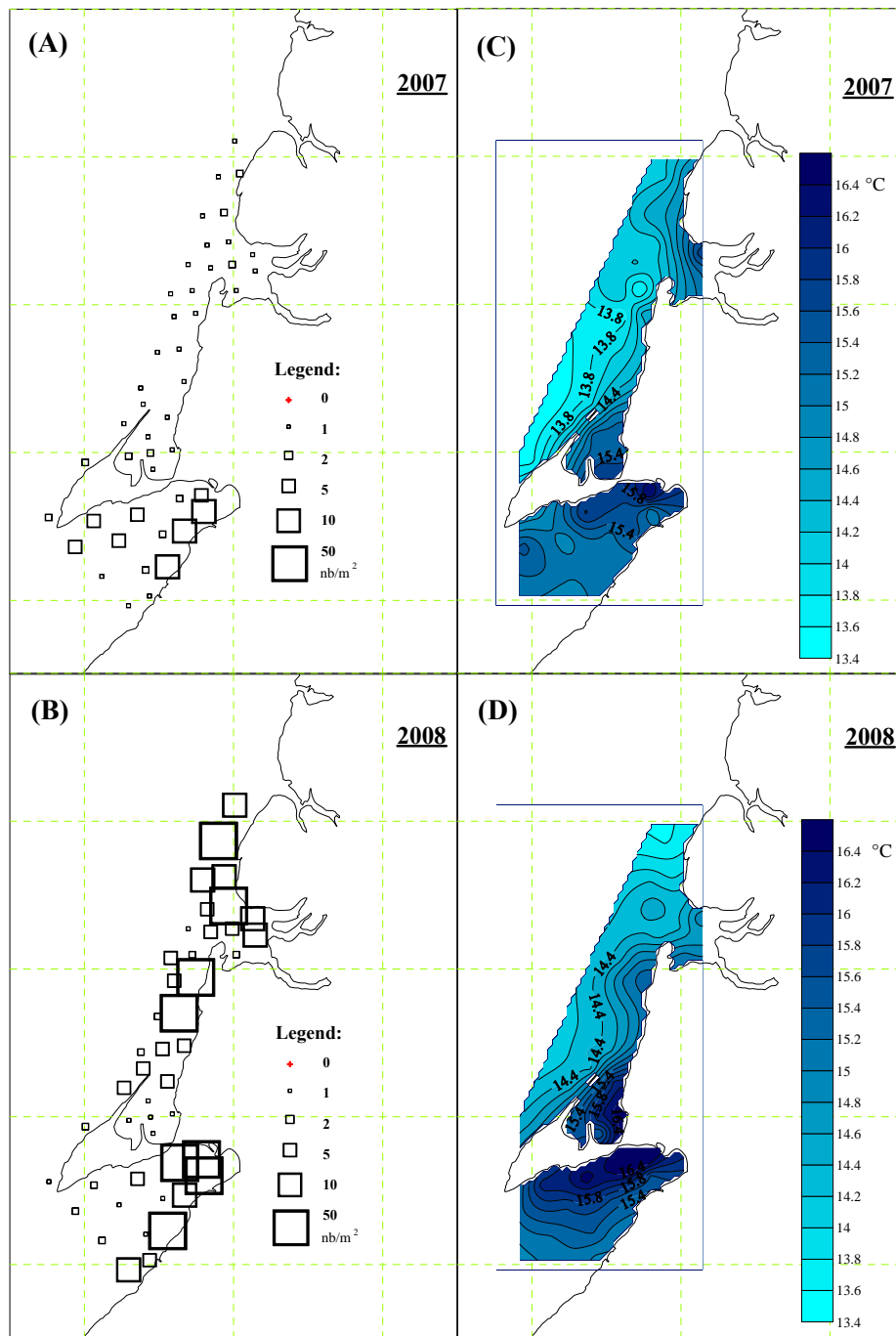
YEAR	PROPORTION		WEIGHT (g)		FECUNDITY	
	Female	Variance	Average	Variance	Average	Variance
<b>2004</b>	0.52	0.00	352.70	3 524	546 061	1.63E+10
<b>2005</b>	0.51	0.00	354.31	10 519	569 694	1.43E+05
<b>2007</b>	0.51	0.00	341.31	10 642	554 931	1.97E+10
<b>2008</b>	0.51	0.00	338.92	10 821	510 906	1.59E+10



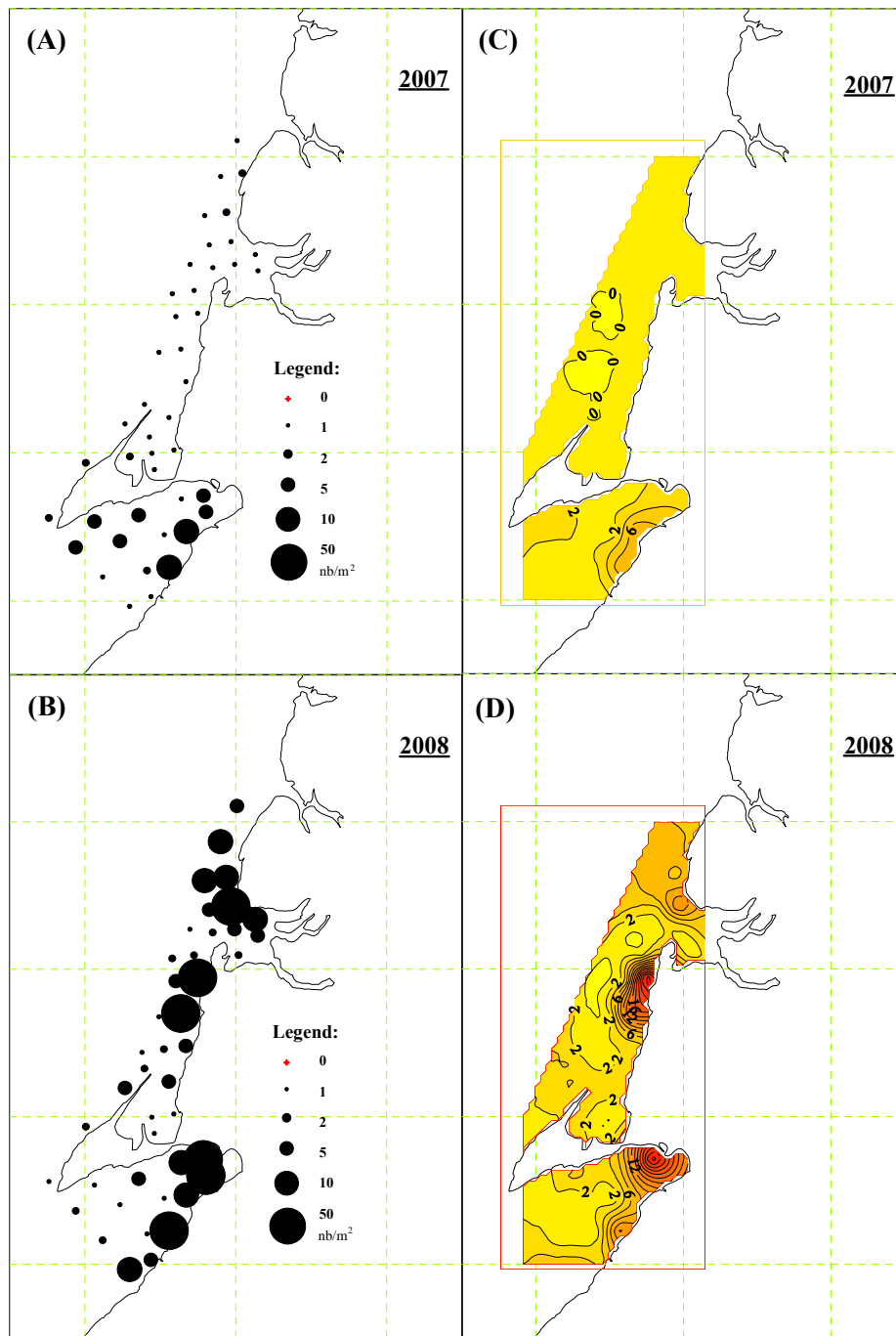
**Figure 1.** Map of the west coast of Newfoundland and the area sampled by the ichthyoplankton surveys since 2004.



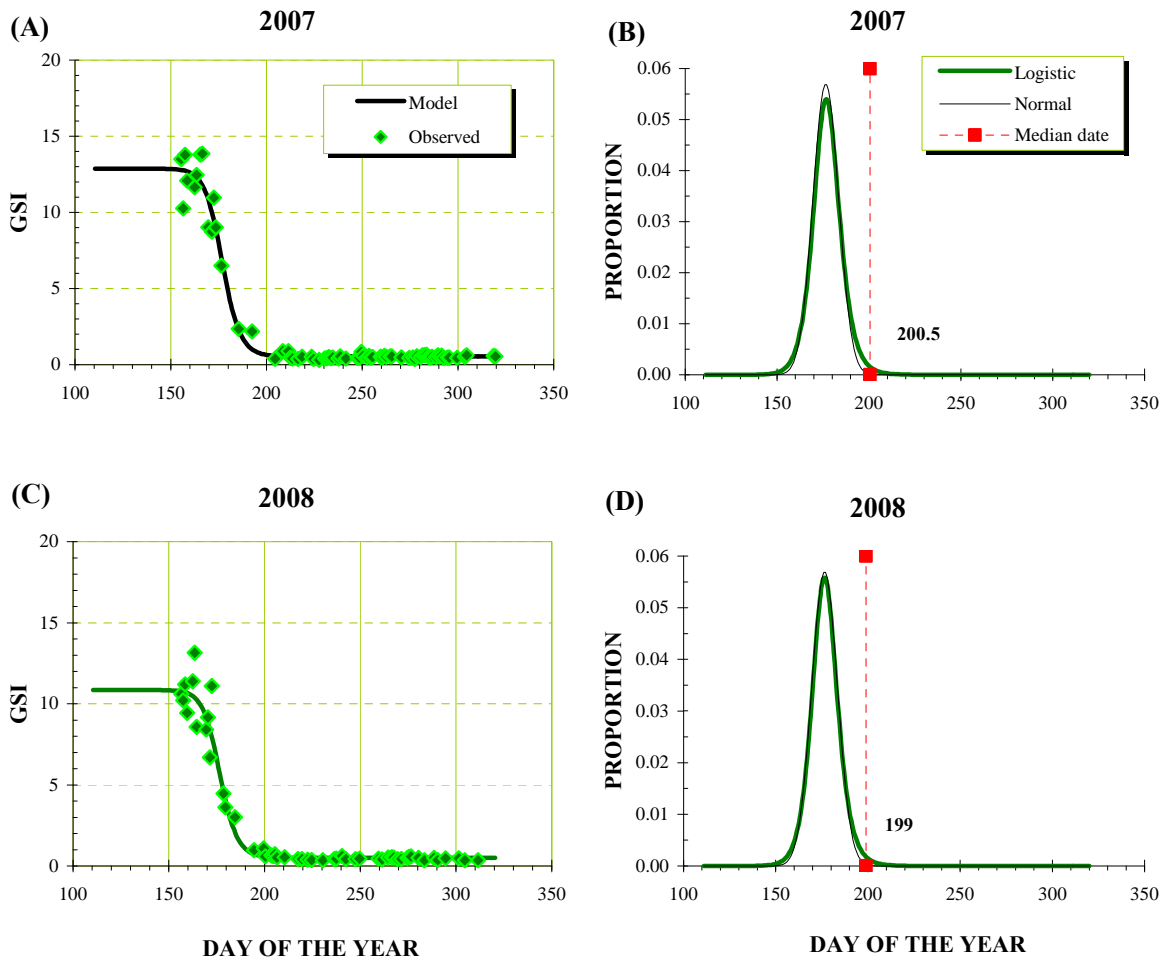
**Figure 2.** Maps of the sampled stations and of the cruise tracks for the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.



**Figure 3.** Maps of the Atlantic mackerel egg (stages 1 and 5) abundance (nb/m<sup>2</sup>) distributions (A and B) and mean water temperatures (°C) (0-10 m) (C and D) calculated from the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.

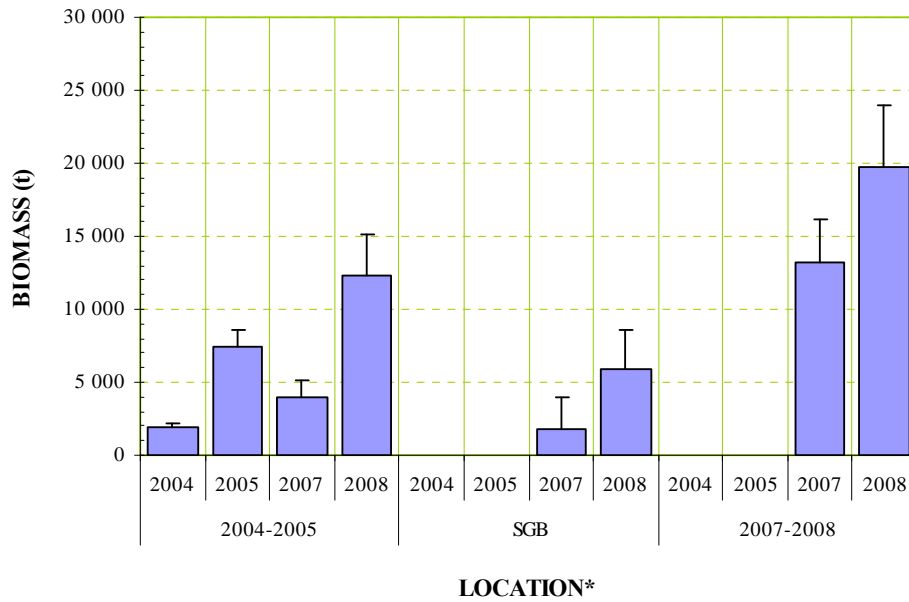


**Figure 4.** Maps of the Atlantic mackerel daily egg (stages 1 and 5) productions (nb/m<sup>2</sup>) observed (A and B) and kriged (C and D) from the ichthyoplankton surveys conducted on the west coast of Newfoundland in July 2007 and 2008.



**Figure 5.** Gonadosomatic indices (GSI) (observed and expected values) (A and C) and density curves (B and D) describing the daily proportion of the egg production in the Gulf of St. Lawrence in 2007 and 2008 (in B and D, the median dates of the surveys are indicated).





\* 2004-2005: from south of Bonne Bay to Port au Port Bay; SGB: St. George's Bay; 2007-2008: from south of Bonne Bay to St. George's Bay

**Figure 6.** Spawning biomass (t) (with 95% confidence intervals) of Atlantic mackerel calculated from the ichthyoplankton surveys conducted on the west coast of Newfoundland since 2004.