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Mussel (*Mytilus edulis*) culture management along the Normandy coastline (France): Stock assessment and growth monitoring.

by

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ABSTRACT: The Normandy region is presently a leading shellfish rearing area in France yielding 35,000 metric tons of oysters *C. gigas* and 11,000 metric tons of mussels *M. edulis* on a yearly basis. Preliminary studies were initiated in 1989, 1991 and 1992 to develop the sampling strategy for cultured mussel stock assessment. Comprehensive mussel stock assessment and concomitant growth monitoring were carried out in 1993 to study mussel population and optimize overall shellfish culture management.

A three-stage cluster sampling strategy combined with stratification was tested on the 278 kms 'bouchot' type culture with a sampling effort of 275 units. Stratification was based upon two criteria including geographical sector and tidal level. Overall biomass was estimated to be 15,721 metric tons (1,069 t on the eastern coast of Cotentin) with a 27.7% precision level, representing a total 13,992 t net weight.

Concomitant oyster growth monitoring on 36 sites prompted us to study spatial variability and establish relationships to maximize the current spatial management.

An empirical model is proposed to link overall growth performance to local stocking density, tidal distribution and distance from the main runoffs inputs. It aims to provide recommendations in support of decision-making to improve shellfish culture. This approach is discussed in view of assumptions inherent in the model and used as a basis for further research programs.

Keywords: Blue mussel, *Mytilus edulis* L., stock assessment, growth monitoring, model.

RESUME: La Normandie est actuellement un des principaux secteurs de production de bivalves avec un tonnage annuel de 35 000 t d'huîtres *C. gigas* et 11 000 t de moules *M. edulis*. Des études préliminaires ont été effectuées en 1989, 1991 et 1992 afin de mettre au point la stratégie d'échantillonnage des stocks de moules en élevage. Une évaluation complète des stocks et, simultanément, des performances de croissance a été réalisée en 1993 afin d'étudier la population de moules et d'optimiser l'aménagement des cultures de bivalves.

Une stratégie d'échantillonnage à 3 degrés combinée à une stratification a été testée sur les 278 kms de bouchots avec un effort d'échantillonnage de 275 unités. La stratification est basée sur les secteurs géographiques et le niveau intertidal. La biomasse brute a été estimée à 15 721 t dont 1 069 t sur la côte est avec une précision de 27,7%. La biomasse totale nette représente 13 992 t.

En parallèle, les suivis de croissance sur 36 sites nous permettent d'étudier la variabilité spatiale et d'établir des corrélations afin d'optimiser l'aménagement spatial actuel.

Un modèle empirique est proposé afin de corréler la performance de croissance à la biomasse en élevage, au niveau d'émersion et l'éloignement des élevages vis à vis des principales sources d'apports terrigènes. L'objectif est de proposer un outil d'aménagement afin de faciliter les choix d'options d'aménagement et d'optimiser les élevages en place. Cette approche est analysée en fonction des hypothèses du modèle et en tant que support pour le développement de programmes de recherches complémentaires.

Mots-clés : moule bleue, *Mytilus edulis* L., estimation de stocks, suivi de croissance, modèle.

Introduction:

Since 1965, shellfish culture has significantly increased along the Normandy coastline (Fig. 1). Historical trends of leasing grounds show a large increase of oyster leases during the 1970's with the concomitant introduction of the Pacific oyster *C. gigas* in France. Then, the mussel leases peaked, and since then, the km of bouchots has slightly decreased. Concomitant to the increased oyster leasing ground acreage, oyster farmers have reported decreasing growth rates and mussel farmers irregular landings raising the need for a comprehensive management plan for these shellfish grounds. The critical issue to address is the overstocking problem: Are these shellfish grounds saturated with regards to stocking biomass versus the ecosystem carrying capacity ? How the mussel and oyster culture interacts ?; and can we still extend the leasing grounds without effecting current culture productivity ? A 'saturated' rearing area classification would prompt the managers to stop any lease extension.

To address these issues, a comprehensive research program was initiated in 1989 to assess oyster and mussel stocks, and to characterize the current status of the shellfish populations so as to propose a global management plan and improve current shellfish productivity.

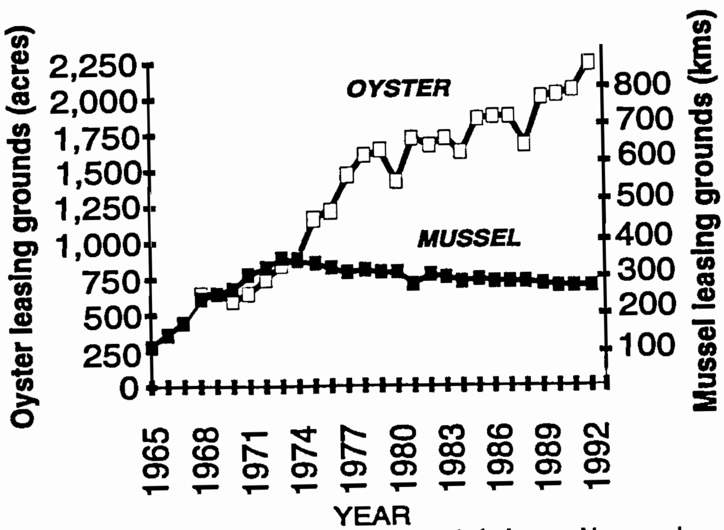

Fig. 1: Historical trends of leasing grounds in Lower Normandy (oyster and mussels grounds are in acres and kms of bouchots, respectively).

Materials and Methods:

Stock Assessment

The first component of the study aimed to stratify the shellfish grounds along the Normandy coastline using 2 geographical criteria: 1) a north-south gradient with respects to shellfish cultured areas boundaries (Fig. 2), and 2) vertical distribution within the intertidal area (i.e.: middle, and lower). The vertical distribution was established using an aerial photography coverage at low tide during spring and neap tides (Kopp and Joly, 1989). Therefore, 14 and 6 strata were specified along the western and eastern coast of Cotentin, respectively. This stratification aims to specify homogeneous sectors to minimize the within-stratum variance and then, optimize the overall precision of estimates (Cochran, 1977).

A preliminary study was carried out in 1989 to assess mussel stocks using extensive aerial coverage. Length of "bouchot" lines were measured to compare with official leasing ground acreage, and then, determine exploitation rate. A field monitoring survey provided a mean productivity coefficient per pole to calculate stocking biomass. Although the methodology provided valuable information to specify exploitation rates per area, mussel coverage variability per pole was not considered (e.g., mussel height) to assess mussel stocks, and precision of estimates unknown, therefore impeding further optimization. In 1991, a pilot study was carried out within the sector No 4 (Agon) to statistically design the sampling scheme based on a 3-stage cluster sampling strategy (Cochran, 1977; Mazurié and Dardignac-Corbeil, 1988; Trotin, 1991). The main objective is to assess the volume of cultured mussels per "bouchot" line (primary unit) using 1) the mean mussel height per pole (secondary unit), and 2) the mean surface of mussels per pole calculated by subtracting empty from filled pole mean girths. Three poles are individually sampled by "bouchot" line, with 3 girth lengths measured per pole. In April 1992, the sampling strategy was carried out along the western coast of Cotentin in 2 successive steps: 1) counting extensively exploited "bouchot" lines ('exploited' means that more than 10 poles per bouchot were covered with mussels), and 2) randomly sampling 220 "bouchot" lines with proportional allocation per stratum, representing 14.85% of the cultured population. Meanwhile, the coefficient volume-weight was estimated to convert estimates (m^3) into total and net weight by sorting mussels. In April 1993, the sampling scheme was carried out on the eastern and western coasts of Cotentin to assess the whole cultured biomass in Normandy. Sample size reached 267 "bouchot", of which 26 on the eastern coast, distributed among 17 strata. All the statistical data treatments were performed using the software "STOC" developed by Maurer (1991).

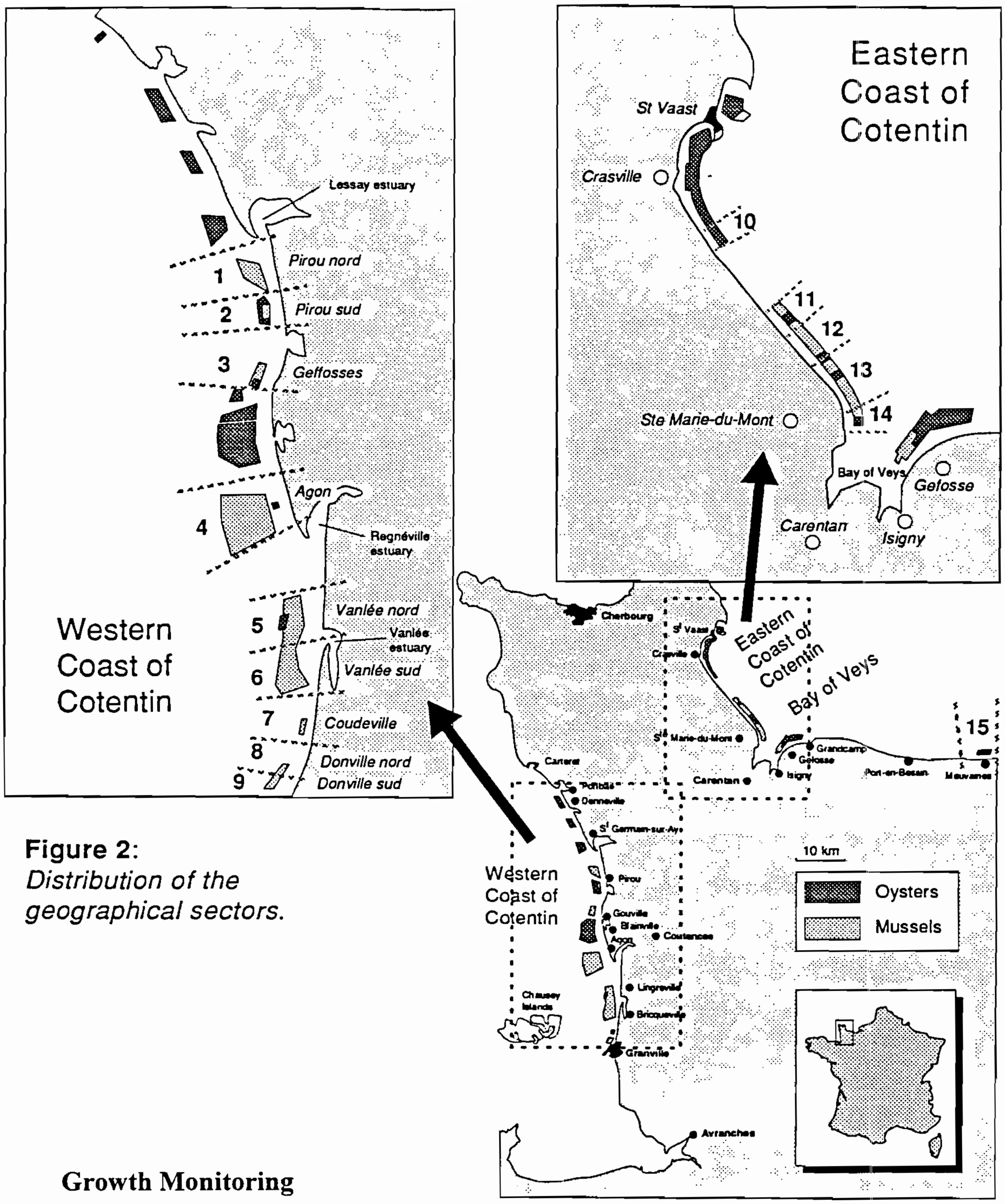

Figure 2:
Distribution of the geographical sectors.

Growth Monitoring

A population of mussel seed originating from Agon (sector 4) was sorted in February 1993 (length 35.1±0.2 mm; total weight 3.9±0.3 g; dry meat weight 161±13 mg) and, then equally distributed among 36 experimental sites for growth monitoring on each strata (Fig. 3). On each site, a subpopulation was attached around 3 wooden poles using traditional mussel culture techniques (Dardignac-Corbeil, 1989). In addition, a tubular net was deployed to avoid bird predation. The methodology aims to limit bias resulting from cultural practices and stock origin. The experimental populations were sampled in October 1993. Length and total weight were measured individually on 100 mussels to the nearest mm and 0.01 g, respectively. Mussels were shucked, and meat stored at -60°C, then freeze dried 36 hours before weighing.

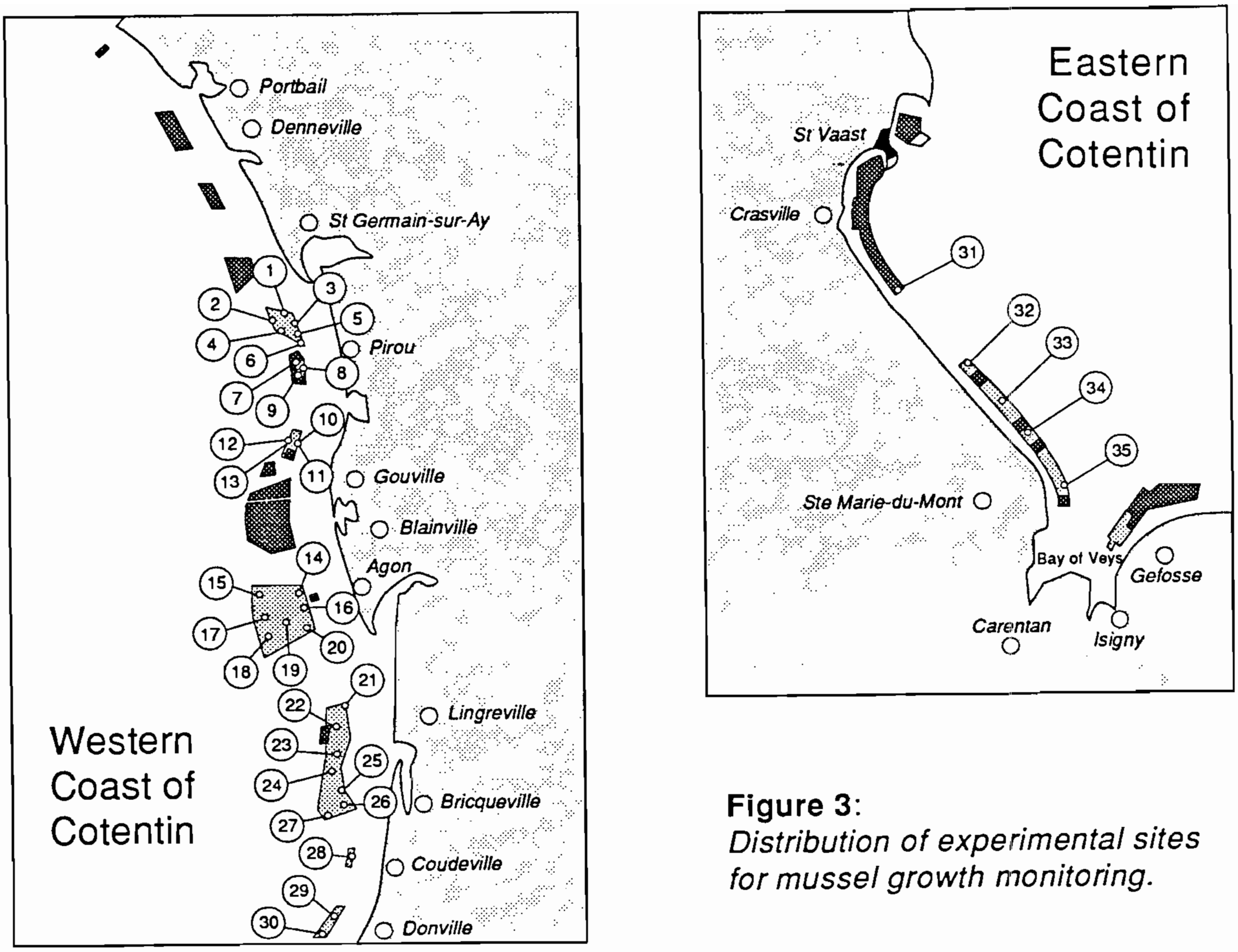

Figure 3:
Distribution of experimental sites for mussel growth monitoring.

RESULTS

Mussel Stock Assessment

Exploitation rate

The exploitation rates of leasing grounds were estimated using the extensive 1989 aerial coverage, and the 1992-1993 field samplings (Table 1). The 1989 results showed clearly several overexploited strata (e.g., No 93, 122, 133, 182, 183), while 3 areas were almost unexploited (i.e., No 142, 143, 162). No mussel culture was reported during the 1992-1993 samplings in strata 152 and 162. On table 1, the field samplings provide information regarding the number of exploited poles per bouchot line, without taking into account its length or total bouchot number. Actually, the bouchot number exploited on the western coast increased from 1,481 (1992) to 1,770 (1993). Moreover, we note a significant increase of exploited poles on the western coast in 7 strata to 12 between 1992 and 1993. In contrast, this number decreased in one of the largest rearing area (Agon). However, the mean exploitation rate was not significantly different between the 2 surveys (80.3%±24.8 in 1992- 83.8±24.3 in 1993).

EXPLOITATION RATE					
STRATUM		Geographical sector	Length of bouchot line (exploited/leased) (%)	Exploited wooden poles/bouchot line (%)	
NAME	No*	No	1989	1992	1993
Eastern Coast					
Crasville Center	93	-	140		
Crasville South	83	10	104		88.1
Utah Beach	70	11	80		
"North	63	12			63.3
"Middle	53	13			89.5
"South	42	14			100
Western Coast					
Pirou North	122	1	111	90.8	80
	123	1	108	100	71.3
Pirou South	132	2	84	85	99.8
	133	2	123	56.9	87.8
Gefosse	142	3	38	79.5	74
	143	3	25	71.7	96.9
Gouville	152	-	114	-	-
Blainville	162	-	38	-	-
Agon	172	4	75	86.7	81.8
	173	4	48	87.8	79.8
Vanlée	182	5	131	73.1	85.4
	183	5	112	74.2	94.7
Donville	192	7-9	87	74.9	98.7
	193	7-9	96	60	86.4

Table No 1: Exploitation rate of the leasing grounds estimated by aerial coverage (1989), and field sampling (1992, 1993) (*, the last stratum number indicates the intertidal distribution: 2-middle, 3- lower) .

Cultured Mussel Stock Assessment

The main results concerning the mussel stock assessment are presented on table 2. The 1992-1993 data were directly converted from m^3 to metric tons using the 620 kg/m^3 coefficient, which was estimated on 18 wooden poles' production in Agon (sector No 4). Moreover, the total net weight in 1992 and 1993 can be estimated to 7,076 and 13,994.41 t, respectively. The biomass estimates tend to demonstrate a large stocking density increase between 1992 and 1993, as previously reported by the exploitation rates in several strata.

		1989		1992		1993	
STRATUM		BIOMASS (t)	BOUCHOT exploited (m)	BIOMASS (t)	BOUCHOT (n)	BIOMASS (t)	BOUCHOT (n)
NAME	N°	Mean		Mean		Mean	
Côte EST							
CRASVILLE Center	93	70	1,400	-	-	0	
CRASVILLE South	83	51.8	1,036	-	-	29.72	2
UTAH BEACH	70	1,068.3	21,366	-	-		
north	63					244.91	4
middle	53					208.6	10
south	42					586.02	10
Côte OUEST							
PIROU north	122	1,670	33,400	1,262.4	26	2,352.96	32
	123	114	2,280	137.02	2	180.08	3
PIROU south	132	185	3,700	217.99	7	303.48	8
	133	12,3	246	4.03	1	15.73	3
GEFOSSE	142	39	780	40.3	3	130.78	10
	143	47	940	38.19	3	95.02	5
GOUVILLE	152	22,8	456	0		0	
BLAINVILLE	162	22,5	450	0		0	
AGON	172	800.15	16,003	703.14	14	1,416.55	22
	173	2,059.55	41,191	3,262.25	61	4,716.67	55
VANLEE	182	2,929.35	58,587	1,202.43	61	2,416.97	61
	183	1,485.15	29,703	713.56	28	2,053.76	23
DONVILLE	192	111.6	2,232	79.55	3	135.51	2
	193	604.55	12,091	289.73	11	837.3	17
TOTAL		11,293.05 t (E+W)		7,950.59 (W)	220	15,724.06 (E+W)	267
PRECISION (%)		?		35.5		27.7	

Table No 2 : Mussel stock assessment estimates (t), sample size (n), and precision (%) based on aerial coverage (1989) and field sampling (1992, 1993). In 1989, the exploited "bouchot" line length is specified in meter.

Besides the stocks estimates, the sampling time is of particular interest since the surveys were carried out early during the growing season (April 1992-1993), underestimating therefore the yearly total landings. Although the sampling time was similar in 1992 and 1993, a delay in growth resumption occurring between the 2 years and resulting from various environmental conditions, could be partly responsible for the estimates discrepancy.

The 1991 pilot study was carried out in only one part of the Agon sector and provided insights for the final sampling strategy. Since the main variable affecting the variance was the number of exploited wooden poles per bouchot line, varying from 56 to 400, we increased the sample size in 1992. However, the 1992 and 1993 surveys represented the first extensive field implementation of the sampling strategy on the western coast and, on eastern and western coasts, respectively. Therefore, it can explain the low precision level (1992, 35.5%; 1993, 27.7%) and be considered as a pre-sampling to estimate the within-stratum variance in order to optimize further field implementation. Actually, the precision improvement (8%) was obtained by increasing the sample size, and more significantly, by assessing the less variable eastern coast population.

Growth monitoring

Final mean total weight and dry meat weight were highly variable and compared using analysis of variance (ANOVA) and analysis of covariance (ANCOVA), respectively (Fig. 4). Highly significant differences of total weight were observed between the results at two emersion levels, in favor of mussels spending more time filtering ($F=262$; $P<0.0001$). Moreover, ANOVA results demonstrate significant differences among sectors ($F=55.17$; $P<0.0001$): growth rates tend to increase from northern to southern sites on the western coast, and except the isolated sectors 10 and 15, growth rate increase from north to south on the eastern coast. Similarly, ANCOVAs for the dry meat weight with the shell weight as a covariate, estimated significant difference between intertidal distribution ($F=753$; $P<0.0001$) and among sectors ($F=49.6, P<0.0001$). Multiple range analysis (Newman-Keuls' test) on the latter resulted in 4 homogeneous groups: (sectors 3, 1, 2); (15, 6); (7, 4, 5, 9); (12, 10, 14, 13); and (8).

Shellfish Management Model

Similarly to previous study on oyster management (Goulletquer et al., 1994), a stepwise regression model was carried out using the final total weight as the dependant variable, and local stocking density, emersion time, north-south gradient, and distance from

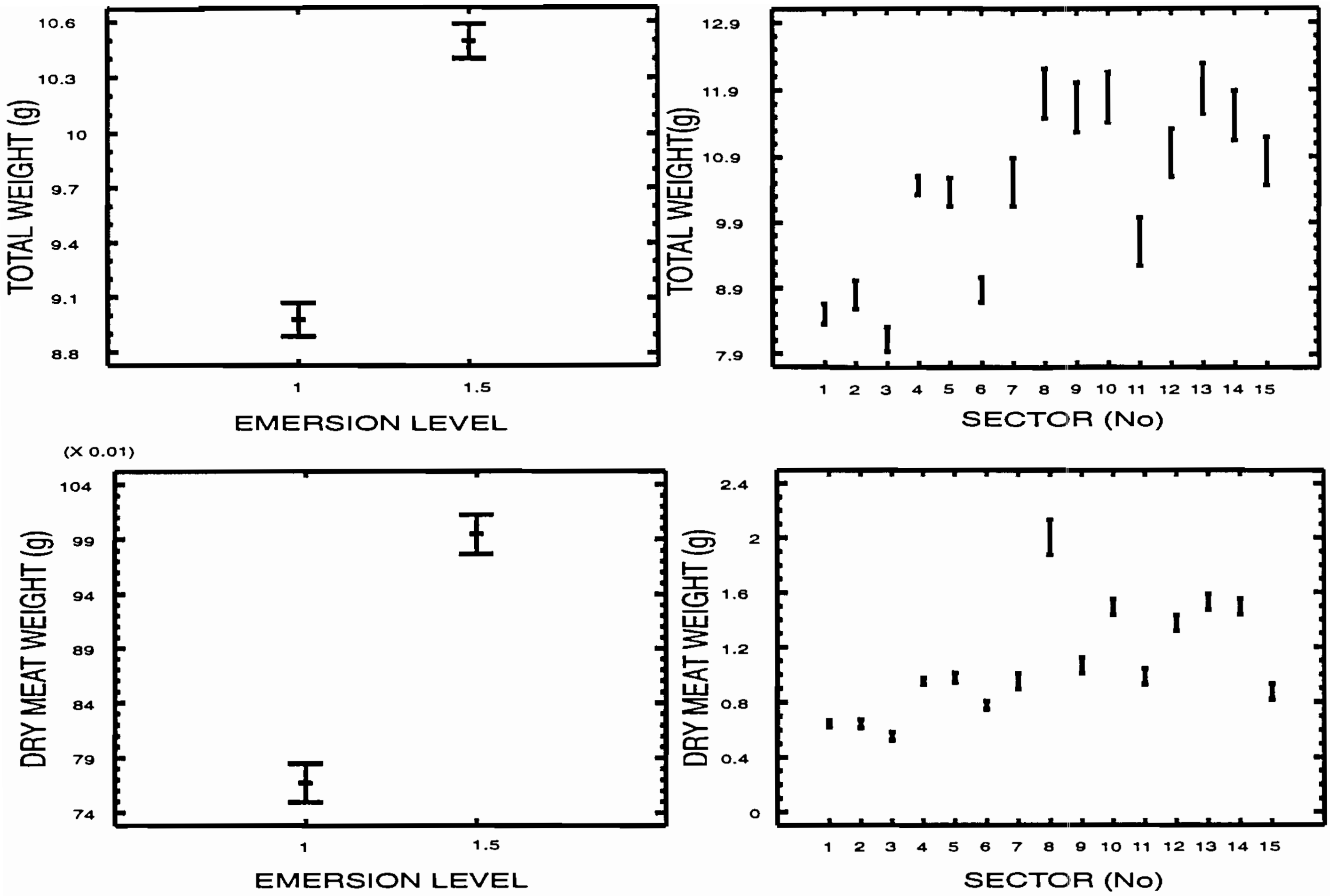

Fig. 4: ANOVA' and ANCOVA's results on total weight and dry meat weight, respectively, by emersion level (2, middle, 3, lower intertidal area) and by geographic sector.

several estuaries weighted by river fluxes coefficients as independent variables. Only the 3 variables were selected by the model which explained 68% of the variability. Component effect and the plot of predicted values are presented on Fig. 5. In contrast to the oyster management model, the mussel stocking biomass was removed from the final model. As previously reported, the most significant component effect is the north-south distribution of mussel population, probably linked to a food availability gradient.

Discussion

This study is part of a larger project aiming to 1) assess the cultured shellfish stocks as well as the current status of these populations in Normandy, and 2) propose an optimized spatial management plan to maximize the rearing productivity on the western coast of Cotentin.

Combined to oyster stock assessment carried out between 1989 and 1992, shellfish culture in Normandy represents 35,000 t of Pacific oysters *C. gigas* and 15,000 t of blue mussels *M. edulis* on a yearly basis (Kopp et al., 1991; Jeanneret et al., 1992; Goulletquer et

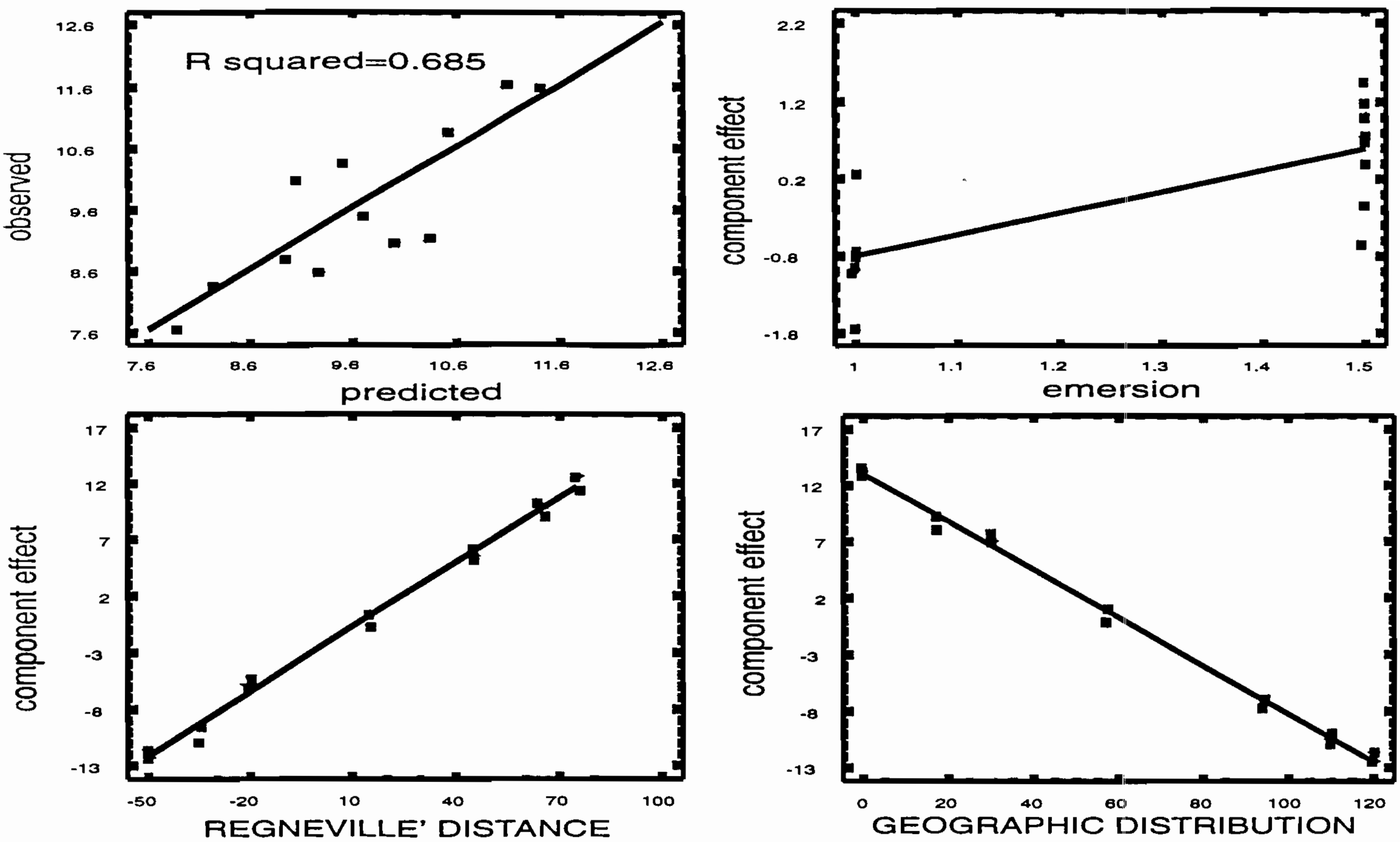

Fig. 5: Multiple regression model of mussel total weight function of emersion level, north-south distribution, and distance from Regneville' estuary. Observed and predicted values are presented on the top left figure.

al., 1994). Stratified sampling strategies for both oyster and mussel populations will be optimized using the Newman' allocation to likely improve the overall precision for the 1995 surveys. Stock assessment carried out before the growing season to limit effect of yearly variability of environmental conditions is also likely to improve the overall sampling strategy (Dardignac-Corbeil, 1994).

Similarly to oysters and particularly on the western coast of Cotentin, mussel growth rates have shown a large variability (6.9-12 g) mainly linked to spatial distribution (north-south gradient), therefore confirming previous results (Goulletquer et al., 1994). These results are particularly important to develop a global model incorporating simultaneously oyster and mussel populations so as to develop a spatial management plan. The north-south growth gradient is likely linked to food availability but should be confirmed by further studies involving hydrological surveys.

However, in contrast to the oyster management model, local stocking density does not improve significantly the model-fitting. Several hypothesis can be proposed to explain this result: the native mussel population might be less susceptible to stocking density than the exotic Pacific oyster species; mussel stocking density per stratum has not yet reached an upper threshold limiting food availability at this spatial scale; spatial distribution of the bouchot structure might be appropriate to locally limit the stocking density effect; and more likely, the distribution of mussel leases, mostly located at the mouth of estuaries, maximizes the food availability for mussel population therefore limiting the stocking density effect.

Moreover, the emersion time has opposite effects with regards to oyster and mussel growth. Lower growth rate on lower intertidal oyster distribution was linked to increased wake effect, breaking fresh shell in oyster bags (Goulletquer et al., 1994). Mussel cultural practices therefore appear more appropriate for these environmental conditions.

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