Channel
Coastal water ecosystem
Planktonic biomass
Trophic efficiency
Impact

Manche
Écosystème côtier
Biomasse planctonique
Efficacités trophiques
Impact

Planktonic ecosystems in the Channel. Trophic relations

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ABSTRACT

Four planktonic coastal ecosystems from the western Channel to the southern part of the North Sea have been compared. The characteristics of the south of the North Sea are a very high planktonic biomass with an annual maximum value of 45 mg C m^{-3} h^{-1} for primary production, a maximum of 11 mg m^{-3} for chlorophyll *a* and 60 mg C m^{-3} for zooplanktonic biomass (expressed in term of carbon weight), linked with an oscillating ecosystem. In the western Channel primary production shows an annual maximum value of 8 mg C m^{-3} h^{-1}, the chlorophyll *a*, a maximum of 2.5 mg m^{-3} and zooplanktonic carbon weight of 14 mg C m^{-3} linked to a greater inertia in the system. Turnover is faster in the north. Trophic efficiency ratios have been calculated and linked to hydrodynamic conditions and currents. The impacts of a thermal perturbation from a nuclear power plant effluent (DT 11°-15°C) applied to ecosystems are compared.

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RÉSUMÉ

Écosystèmes planctoniques côtiers en Manche. Relations trophiques

Quatre écosystèmes planctoniques côtiers sont comparés entre la Manche Ouest et le sud de la Mer du Nord. Les caractéristiques du sud de la Mer du Nord sont une biomasse planctonique très élevée de 45 mg C m^{-3} h^{-1} pour la production primaire, un maximum de 11 mg m^{-3} pour la chlorophylle *a* et 60 mg C m^{-3} pour la biomasse zooplanctonique (exprimée en poids de carbone total), elle est liée aux conditions d'un système oscillant. En Manche Ouest, la production primaire montre une valeur maximale annuelle de 8 mg C m^{-3} h^{-1}, un maximum de chlorophylle de 2,5 mg m^{-3} et une biomasse carbonée zooplanctonique 14 mg C m^{-3} liée à une plus grande inertie du système. Le turnover est plus rapide au Nord. Les coefficients d'efficacité trophique ont été calculés et reliés aux conditions hydrodynamiques et courantologiques. Les impacts d'une perturbation thermique dont l'origine est le rejet de centrale nucléaire (DT de 11° à 15°C) appliqués aux écosystèmes sont comparés.

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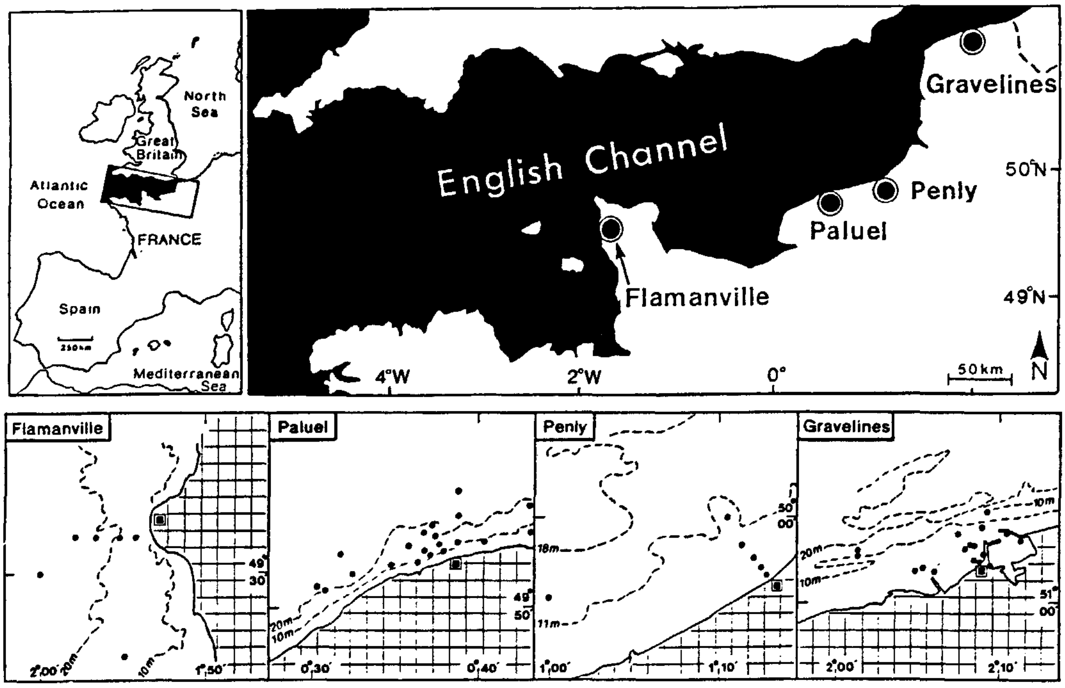
INTRODUCTION

Along the French coast of the Channel (Fig. 1) four nuclear power-plants have been built and come into operation over the last seventeen years. At each site, pelagic studies have been carried out, both before and after construction, as part of the environmental monitoring of the sites. Baseline information in the form of physical,

Figure 1

Map of area studies.

Carte des aires d'étude.



chemical and biological measurements was collected to describe a "reference state" with chronological series collected in the course of a long-term research programme. A second set of results is used to assess the impact of construction and to estimate effects on the system. For each study area data were collected on climatic conditions, currents, hydrology, chlorophyll biomass, primary production, phytoplankton species and zooplankton biomass and species.

In some previous papers (Crassous *et al.*, 1981; Laurec *et al.*, 1981; Le Fèvre-Lehoërff and Quintin, 1981; Le Fèvre-Lehoërff *et al.*, 1983; Ryckaert *et al.*, 1983; Gros and Ryckaert, 1983), seasonal and spatial variations of the planktonic species have been discussed for each site over different scales. In this paper a comparison is made between four ecosystems from the western Channel (Flamanville) to the southern bight of the North Sea (Gravelines). The differences observed in the Channel are discussed in terms of trophic relations in the pelagic ecosystem. We have selected the following global variables: nutrients, primary production and zooplankton biomass, carbon and nitrogen biomass. Two efficiency ratios - primary production : nutrients available, and zooplankton : phytoplankton - are calculated and interpreted with respect to the main natural and physical features of the coast. In a second part we describe how two ecosystems submitted to the impact of a power plants are dependent both on "plant effect" and on initial conditions.

METHODS

Sampling strategy

Sampling was determined according to the characteristics of each site (large tides, strong currents) with similar techniques used for each area (Belsher *et al.*, 1986); these included:

- long-term studies since 1975 to understand the characteristics of each site;

Table 1

Reference state. Number of observations. F: Flamanville (1976-1991), A: Paluel (1975-1991), Y: Penly (1977-1991), G: Gravelines (1975-1991).

État de référence. Nombre d'observations. F : Flamanville (1976- 1991), A : Paluel (1975-1991), Y : Penly (1977-1991), G : Gravelines (1975-1991).

Variable	Month	1	2	3	4	5	6	7	8	9	10	11	12
T° C													
	F	39	62	44	88	108	79	90	67	80	54	60	50
	A	69	80	79	61	59	68	79	58	92	66	46	62
	Y	21	24	8	53	36	28	51	25	62	22	28	21
	G	55	90	61	51	99	84	83	98	59	98	48	15
Nutrients (SiOH) μM l^{-1}	F	42	60	44	96	79	78	98	67	79	54	58	57
	A	63	35	86	70	58	119	101	55	85	28	48	4
	Y	22	26	8	80	39	27	93	30	40	31	29	21
	G	68	56	81	89	146	93	103	72	60	112	48	17
Chlorophyll a mg m^{-3}	F	43	62	45	92	127	74	105	65	78	52	68	57
	A	68	87	92	77	65	128	128	59	91	85	46	61
	Y	23	25	10	65	67	21	85	30	75	37	28	20
	G	66	100	84	90	152	99	100	90	90	118	71	20
Primary Production mg C m^{-3} h^{-1}	F	6	24	17	38	65	30	61	24	41	19	20	18
	A	18	9	10	15	4	14	17	8	20	14	9	4
	Y	3	6	0	27	26	3	80	7	49	12	6	10
	G	15	11	28	21	27	13	27	19	22	22	22	6
Zooplankton Dry weight mg m^{-3}	F	12	23	21	40	69	35	77	27	54	20	21	9
	A	22	23	31	24	26	25	50	19	41	32	20	8
	Y	4	4	5	19	14	6	25	15	19	14	10	4
	G	14	18	41	25	34	32	24	24	64	41	20	15

Table 2

Reference state. Variables: temperature, nutrients. Mean (M) and standard deviation (SD) for each month. F: Flamanville (1976-1991), A: Paluel (1975-1991), Y: Penly (1977-1991), G: Gravelines (1975-1991).

État de référence. Variables : température, nutriments. Moyenne (M) et déviation standard (SD) pour chaque mois. F : Flamanville (1976-1991), A : Paluel (1975-1991), Y : Penly (1977-1991), G : Gravelines (1975-1991).

N° month →			1	2	3	4	5	6	7	8	9	10	11	12
T° C														
	F	M	8.77	7.16	9.01	9.24	10.59	12.79	15.23	16.66	16.47	15.68	12.78	10.29
		SD	0.70	0.98	1.37	0.64	0.56	0.66	0.57	0.40	0.90	0.60	1.03	0.38
	A	M	6.27	6.48	7.30	9.22	10.89	13.85	16.69	18.28	18.52	17.51	12.49	9.07
		SD	0.93	1.51	1.44	0.94	1.57	1.63	0.64	1.37	1.68	1.69	0.90	0.75
	Y	M	4.13	4.78	7.66	8.04	10.36	13.46	15.45	17.19	17.28	15.47	12.80	8.78
		SD	0.58	0.39	0.34	0.74	1.31	0.52	0.87	0.54	0.82	1.24	1.32	0.78
	G	M	5.06	6.67	6.85	7.72	10.44	13.51	16.71	18.78	16.57	15.13	10.42	7.37
		SD	1.23	1.13	1.27	1.00	1.43	16.71	1.30	1.05	1.26	1.28	1.37	1.53
Σ (NO_3+NO_2+NH_4)														
µM l^{-1}	F	M	7.49	10.06	9.79	7.55	3.53	2.20	1.15	2.22	4.71	5.25	6.22	7.23
		SD	2.12	1.59	1.44	5.87	2.41	2.48	0.84	0.60	1.16	1.43	1.24	1.09
	A	M	26.83	24.10	23.95	28.02	12.19	6.75	5.79	11.53	13.75	21.75	27.28	27.71
		SD	2.97	4.29	7.86	4.62	6.04	5.85	2.92	1.53	3.88	4.94	4.82	8.60
	Y	M	16.76	23.26	11.33	22.32	13.38	7.21	2.17	1.66	5.18	9.12	11.76	13.22
		SD	3.75	4.65	1.33	5.45	7.02	4.85	1.57	1.07	2.33	2.76	5.46	3.56
	G	M	24.29	27.37	17.73	11.30	6.84	8.18	4.76	5.34	7.34	11.36	15.62	22.26
		SD	8.49	14.16	9.07	8.04	5.03	5.32	3.35	4.04	3.76	5.44	5.42	8.76
SiOH														
µM l^{-1}	F	M	3.35	3.34	3.39	1.83	1.31	1.49	1.31	2.10	2.97	3.14	3.00	3.40
		SD	1.03	0.78	1.05	1.32	1.43	0.89	0.77	0.93	0.73	1.13	1.05	1.02
	A	M	12.39	12.41	6.03	3.74	2.18	1.99	2.74	5.28	6.04	8.35	11.01	17.47
		SD	2.93	2.06	5.05	3.89	1.66	1.70	1.54	2.98	3.15	2.78	4.01	1.04
	Y	M	9.15	10.71	4.00	8.20	3.99	3.70	2.35	2.14	5.76	6.63	7.59	7.90
		SD	2.55	2.57	0.99	3.71	3.30	1.60	1.86	1.88	2.52	2.18	2.61	2.24
	G	M	8.42	8.26	3.94	1.52	2.04	1.69	2.00	0.99	3.31	5.01	10.59	9.53
		SD	2.47	2.88	3.95	1.14	1.45	1.60	1.43	1.64	1.42	2.03	3.57	3.69

- simultaneous measurement of several elements to link the different trophic levels of the ecosystem;

- measurements to describe different temporal (seasonal, annual) and spatial scales. Samples were often replicated. This strategy was used to estimate different sources of variation, spatial, seasonal and microdistribution (Laurec *et al.*, 1981; Gros and Ryckaert, 1983; Chardy and Menesguen, 1984).

Investigation techniques

Field work and laboratory analyses used standard oceanographic methods (UNESCO, 1966 *a*; *b*; 1968; 1978; 1979; 1981; Aminot and Chaussepied, 1983). Samples were obtained using Niskin bottles and a WP2 (200 µm mesh width) plankton net. Sampling of zooplankton was based on vertical hauls from bottom to the surface. Mean depth at the Gravelines and Penly sites is 15 m and at Paluel and Flamanville 25 m. The volume of water filtered was measured using a TSK flowmeter set in the mouth area of the net (Le Fèvre-Lehoërff, 1985). Samples for nutrients, chlorophyll *a* and zooplankton biomass were frozen on board. Nutrients were analyzed with a Technicon autoanalyzer and expressed in µmole l^{-1} for each nutrients, NO_3^-, NO_2^-, NH_4^+ and total nitrogen (amount of NO_3^-, NO_2^- and NH_4^+). Primary production samples (light and dark bottles) were inoculated with 4 µCI of NaH C^{14} O_3 and incubated under fluorescent light for three-four hours according to the ^{14}C technique (Steeman-Nielsen, 1952; Brouardel and Rinck, 1963). Primary production was analyzed with a liquid scintillation counter (Betamatic I) and chlorophyll by fluorometry (Strickland and Parsons, 1972).

In the laboratory, zooplankton was oven-dried for 48 hours at 60°C and weighed (Lovegrove, 1966). Dry weight is expressed in mg dry weight m^{-3}. Dry zooplankton was then homogenized by a pulverizer and analyzed with a CHN Carlo Erba elemental analyzer. Results are given in percentage of total carbon and nitrogen in dry weight. We calculate carbon dry weight and nitrogen weight (mg C m^{-3} and mg N m^{-3}).

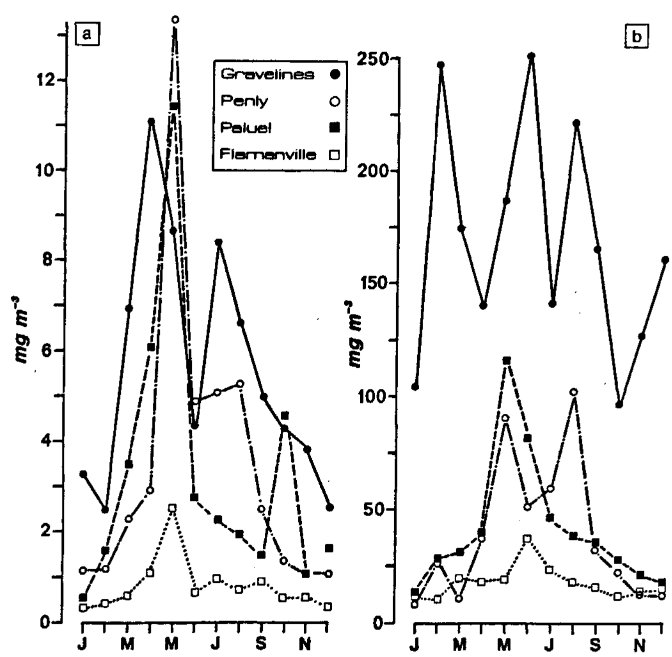


Figure 2

a) mean monthly variations of chlorophyll a *(mg m^{-3}); b) mean monthly variations of dry weight zooplankton (mg m^{-3}). G: Gravelines, Y: Penly, A: Paluel, F: Flamanville.*

a) variations moyennes mensuelles de chlorophylle *a* (mg m^{-3}) ; b) variations moyennes mensuelles du poids sec de zooplancton (mg m^{-3}). G : Gravelines, Y : Penly, A : Paluel, F : Flamanville.

Table 3

Reference state. Variables (mean): nitrate NO_3^-, nitrite NO_2^-, ammonium NH_4^+.

État de référence. Variables (moyenne) : nitrate NO_3^-, nitrite NO_2^-, ammonium NH_4^+.

	FLAMANVILLE			PALUEL			PENLY			GRAVELINES		
	NO_3^-	NO_2^-	NH_4^+	NO_3^-	NO_2^-	NH_4^+	NO_3^-	NO_2^-	NH_4^+	NO_3^-	NO_2^-	NH_4^+
January	7.14	0.17	0.18	23.64	1.08	1.51	15.28	0.25	1.22	19.02	0.74	4.49
February	8.61	0.19	1.26	21.99	0.79	1.32	21.48	0.46	1.32	24.82	0.56	1.99
March	8.58	0.16	1.05	20.86	0.36	2.73	10.22	0.33	0.78	15.05	0.30	2.38
April	5.91	0.14	1.50	19.01	0.37	8.64	21.36	0.37	0.59	9.38	0.29	1.63
May	3.38	0.05	0.10	6.64	0.29	5.26	11.98	0.26	1.14	5.75	0.24	0.85
June	1.13	0.07	1.00	1.51	0.16	5.09	6.05	0.21	0.95	2.28	0.47	5.43
July	0.51	0.04	0.60	4.06	0.20	1.53	1.52	0.07	0.58	2.97	0.48	1.31
August	1.07	0.17	0.98	5.60	0.22	5.71	0.69	0.07	0.90	3.86	0.10	1.38
September	3.02	0.23	1.46	8.58	0.37	4.81	3.59	0.16	1.43	5.02	0.36	1.96
October	3.90	0.44	0.91	14.94	0.77	6.40	7.48	0.28	1.36	5.51	0.37	5.48
November	4.56	0.38	1.28	17.83	1.34	8.11	9.36	0.57	1.83	8.50	0.63	6.49
December	6.39	0.11	0.73	24.22	1.18	2.31	12.41	0.21	0.59	13.00	0.84	8.42

Database analysis

We have distinguished two sets of data destined respectively for the reference state description and for the impact study.

Reference state data (Tab. 1)

In a previous paper (Le Fèvre-Lehoërff and Woehrling, 1991), the reference state was defined. For each site the reference state is the state calculated with all data collected without impact. The reference state, for each site, presents a dynamic notion over the study period including all data before plant construction and the data collected after plant operation at the unimpacted stations. In the reference state of a site we take into account natural variation, especially differences between years over a long period (fifteen years in Gravelines). A comparison is made between the reference state for the four sites.

Impact study data

Data selected are collected at sampling sites where there is evidence of an effect after plants started operation. Each site is a small area under the influence of the cooling discharge (thermal plume). The data of the impact study area are compared to reference state data for two sites (Flamanville and Gravelines).

RESULTS

Reference state

For each variable selected, for each month and for each site we have calculated a mean value and a standard deviation (Tab. 2 and 3).

Table 4

Reference state. Variables (mean): chlorophyll a*, primary production, zooplankton biomass, carbon percentage, nitrogen percentage zooplankton. F: Flamanville (1976-1991), A: Paluel (1975-1991), Y: Penly (1977-1991), G: Gravelines (1975-1991).*

État de référence. Variables (moyenne) : chlorophylle *a*, production primaire, biomasse zooplanctonique, pourcentage de carbone et pourcentage d'azote du zooplancton. F : Flamanville (1976-1991), A : Paluel (1975-1991), Y : Penly (1977-1991), G : Gravelines (1975-1991).

Month	1	2	3	4	5	6	7	8	9	10	11	12
Chlorophyll a $mg.m^{-3}$												
F	0.31	0.43	0.57	1.10	2.51	0.68	0.99	0.77	0.92	0.54	0.55	0.34
A	0.52	1.55	3.47	6.05	11.43	2.74	2.21	1.98	1.50	4.58	1.14	1.68
Y	1.15	1.17	2.25	2.90	13.33	4.81	5.07	5.26	2.53	1.35	1.14	1.15
G	3.27	2.48	6.95	11.09	8.64	4.31	8.43	6.68	5.00	4.32	3.88	2.56
Primary production $mg\ C\ m^{-3}\ h^{-1}$												
F	0.55	1.85	1.97	5.11	7.91	3.49	4.28	4.48	4.42	4.15	3.06	1.55
A	1.23	3.45	9.49	12.54	65.35	11.47	16.30	3.87	15.66	10.17	3.09	6.76
Y	0.87	6.67	-	7.38	23.88	24.62	18.59	2.84	8.84	4.02	4.18	2.55
G	3.26	6.64	20.63	42.80	45.52	23.06	27.58	43.81	15.81	12.32	9.58	7.49
Zooplankton Dry weight $mg\ m^{-3}$												
F	12.5	12.2	18.8	17.4	19.4	37.9	23.6	19.2	17.0	11.9	14.1	15.8
A	14.0	29.4	31.4	40.0	115.8	82.8	46.9	39.4	36.2	27.8	21.6	17.9
Y	7.9	28.3	10.9	38.1	90.4	52.1	59.8	102.5	32.1	22.4	13.5	12.4
G	105.5	248.2	175.5	139.9	186.6	251.5	142.1	222.4	167.2	96.3	127.8	160.5
Zooplankton % carbon												
F	17.8	23.5	23.0	24.6	34.6	32.7	35.0	35.6	34.0	35.5	23.4	15.9
A	19.1	17.9	23.5	27.8	31.3	20.5	23.6	22.5	18.4	21.6	17.0	16.2
Y	19.5	26.6	32.2	28.8	33.8	25.7	30.5	30.6	34.6	27.1	26.5	27.2
G	12.3	10.9	12.8	19.9	21.1	23.1	23.7	14.9	17.2	16.2	17.3	16.6
Zooplankton % nitrogen												
F	4.0	4.9	4.1	5.0	7.5	8.0	7.9	8.8	8.0	7.8	4.9	3.7
A	4.1	3.6	5.9	6.6	7.3	12.1	5.5	5.6	4.2	4.7	3.9	3.8
Y	3.9	5.6	7.5	6.9	8.5	7.5	6.9	7.5	8.3	6.4	6.1	5.6
G	1.6	2.5	2.2	3.8	4.4	5.1	5.5	2.9	3.1	2.7	2.3	2.6

Biomass, chlorophyll a *and dry weight zooplankton (Tab. 4)*

Major differences appear between sites (Fig. 2 *a*, *b*). The first concerns the level of values (chlorophyll *a* x 6 between the two furthest sites) and annual variation, both increasing from the western Channel to the North Sea. The second is the precocious pelagic production, more than one month earlier in the North Sea compared with the western Channel (Ryckaert *et al.*, 1983). Lastly we observed numerous blooms in a single year (Le Fèvre-Lehoërff and Quintin, 1981; Le Fèvre-Lehoërff *et al.*, 1983). Average data collected over a fifteen-year period since 1975 shows a constant pattern at the scale of the Channel. Moal (1980) for chlorophyll data and Razouls (1980) for dry weight zooplankton obtained in the Ecomanche survey (May 1978, May 1979) similar data for the central Channel with 2-5 $\mu g\ l^{-1}$ for chlorophyll and 30-80 mg m^{-3} dry weight mesoplankton. In a regional study of the Gulf of Saint-Malo from 1980 to 1983 similar data was obtained by Arnal (1981; 1983) and Arzul *et al.* (1986).

Nitrogen and carbon zooplankton percentages

In coastal shallow waters, zooplankton samples (200 µm mesh size net WP2) are contaminated with large phytoplankton species and by mineral particles. The counting of species in samples preserved in 8 % formaldehyde shows the degree of contamination by phytoplankton at the station. Elemental analysis of nitrogen and carbon is estimated in the dry weight and expressed in percentage. Moreover, mineral and organic (MO) percentages in total dry weight are both estimated.

At all four sites, the percentages of nitrogen (Fig. 3) and of carbon show a normal seasonal development, increasing in spring to reach a maximum in late summer (Tab. 3). Values are in accordance with values noted in other regions (Le Borgne, 1975; 1977; Razouls, 1985; Checkley *et al.*, 1992; Leakey *et al.*, 1992). Lower percentages were measured at Gravelines (Tab. 3) as a consequence of the high mineral

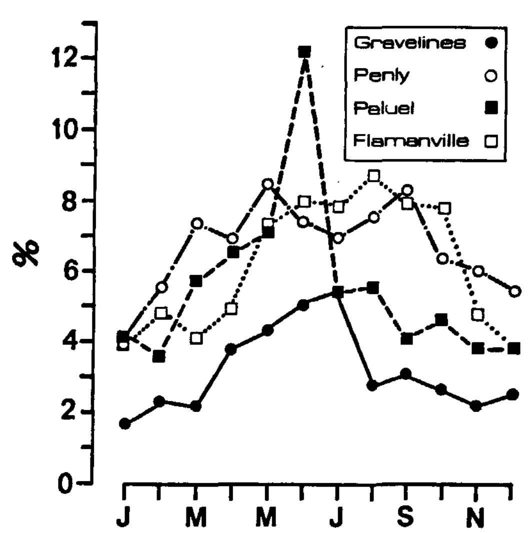


Figure 3

Nitrogen zooplankton percentage variations (mean monthly).

Variations du pourcentage d'azote zooplanctonique (moyenne mensuelle).

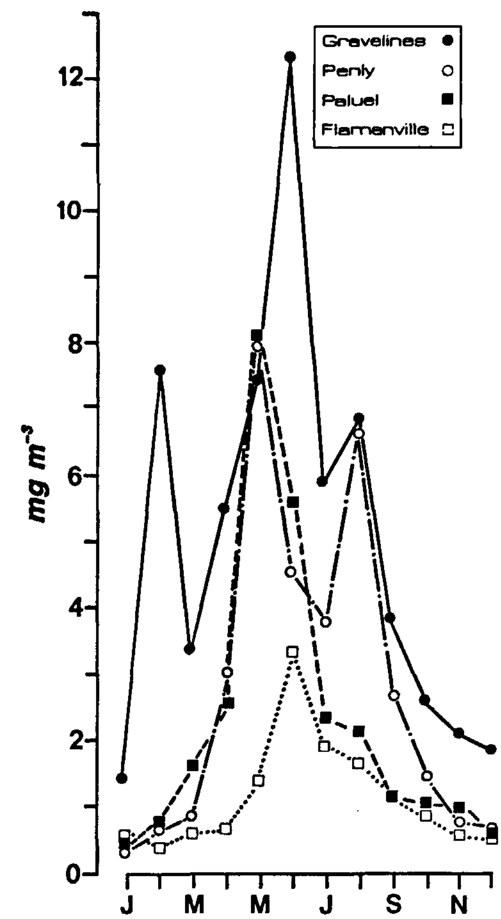


Figure 4

Nitrogen zooplankton dry weight variations (mean monthly).

Variations du poids sec d'azote zooplanctonique (moyenne mensuelle).

content of suspended particulates. Total organic matter (MO) represents 65 % of total dry weight. Consequently, in terms of carbon and nitrogen biomass, it seems important to consider both the percentage (Fig. 3) and the weight (Fig. 4). The differences observed between sites are reduced but the main conclusions noted for total dry weight zooplankton are still valid for nitrogen and carbon weights.

Environmental conditions

Two geographically adjacent sites in the eastern Channel, Paluel and Penly, appear to have a different form of pelagic production. Paluel is influenced by the Seine river. Seasonal variations of salinity and nutrient concentrations are influenced by the flow of the Seine. River flow reaches a maximum of 2000 $m^{-3}\ s^{-1}$ in spring, inducing low salinity water and high nutrient concentration at the Paluel site (Fig. 5 *a*, *b*, *c*). In summer, during the period of low Seine flow, Paluel is influenced by central Channel water. This conclusion is confirmed by zooplankton species in the samples. Conversely, Penly is less influenced than Paluel in spring by the Seine river and is submitted to low salinity water later in the summer. The duration of pelagic production during the year is shorter at Paluel, limited especially by the time of flow of the Seine.

We understand better the differences between Penly and Paluel if we take into account the geomorphological environment. Paluel is located on a convex coast with very strong (2.9 m s^{-1}) currents, erosion features and turbulent conditions. On the other hand, Penly is in a concave part of

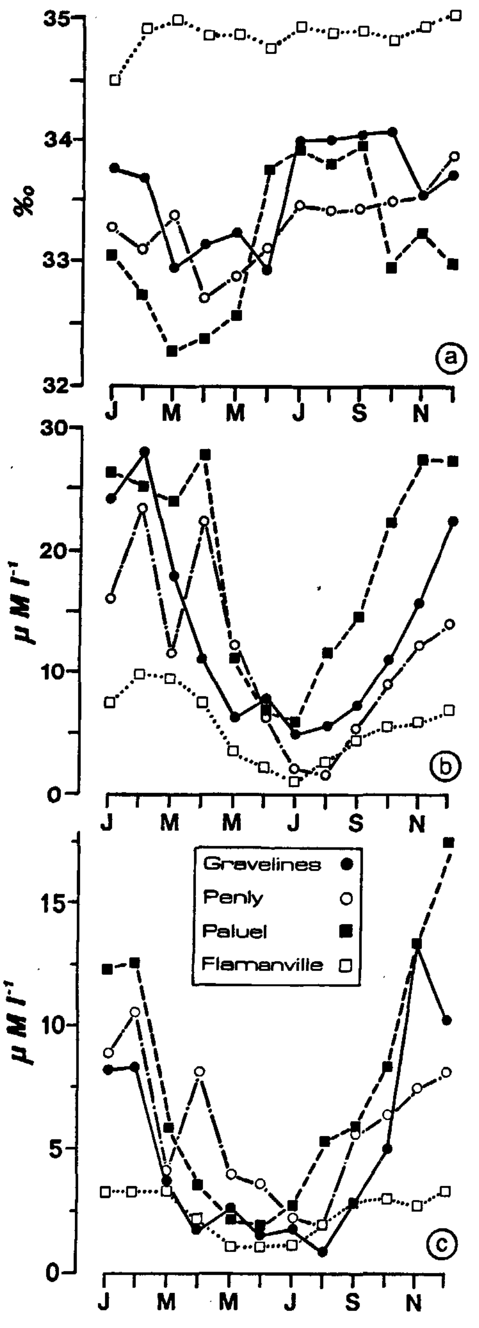


Figure 5

a) mean monthly variations of salinity; b) mean monthly variations of nitrogen nutrients (µ M of total N); c) mean monthly variations of SiOH nutrients (µ M of Si).

a) variations de la salinité (moyenne mensuelle) ; b) variations des nutriments azotés (moyenne mensuelle en µ M de N total) ; c) variations des silicates (moyenne mensuelle en µ M de Si).

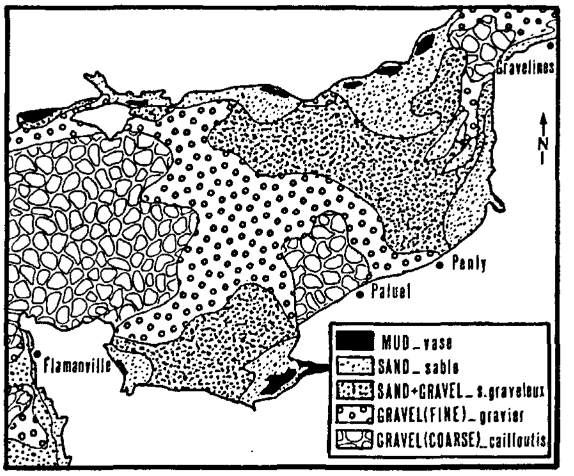


Figure 6

Map of bottom sediments in the Channel (LCHF-EPSHOM).

Carte des fonds sédimentaires de la Manche (LCHF-EPSHOM).

the coast with low current < 1 m s^{-1} speed, sedimentation and gradients in hydrological structure. Pelagic production and species patterns are determined as for the sediment on the bottom (Fig. 6) by residual currents. We believe that differences observed between sites in the pelagic biomass produced are not linked directly to initial stocks of nutrients as seems generally to be the case if we consider a mean area far from the coast (Agoumi, 1985). In this study, physical properties along the coast are estimated to be important factors determining local pelagic production and trophic level transfer.

Correlation coefficients. Trophic efficiency ratios (Tab. 5)

It is evident that the differences observed in primary and secondary biomass are linked both to the physical environment and to nutrient enrichment. Correlations were calculated on data to determine the best ratio between two trophic levels in the food chain. From the nutrient level to primary production the best transfer was observed at the Gravelines north site. Moreover correlation is better with SiOH than nitrogen nutrients, the latter seem "in excess" in the eastern Channel. Primary production linked especially with diatom species is better correlated with SiOH.

Table 5

*Some examples of correlation coefficients between nutrients-chlorophyll a-primary production and zooplankton carbon weight. * 95 % level confidence, ** 99 % level confidence. F: Flamanville, A: Paluel, Y: Penly, G: Gravelines.*

Quelques exemples de coefficients de corrélation entre les sels, la chlorophylle, la production primaire, le poids de carbone zooplanctonique. * niveau de confiance 95 %, ** niveau de confiance 99 %. F : Flamanville, A : Paluel, Y : Penly, G : Gravelines.

	F	A	Y	G
Chlorophyll a : Total nitrogen	- 0.40*	- 0.17	- 0.22	- 0.62**
Chlorophyll a : SiOH	- 0.69**	- 0.52	- 0.58*	- 0.75**
Primary P : Total nitrogen	- 0.57*	- 0.40	- 0.24	- 0.72**
Primary P : SiOH	- 0.75**	- 0.50	- 0.57*	- 0.83**
Zooplankton carbon : Chl a (1) (of same month)	+ 0.30	+ 0.86**	+ 0.91**	+ 0.23
Zooplankton carbon : Chl a (2) (of month before)	+ 0.89**	+ 0.63*	+ 0.43	+ 0.71**

r correlation coefficient : * 95 % confidence level, ** 99 % confidence level

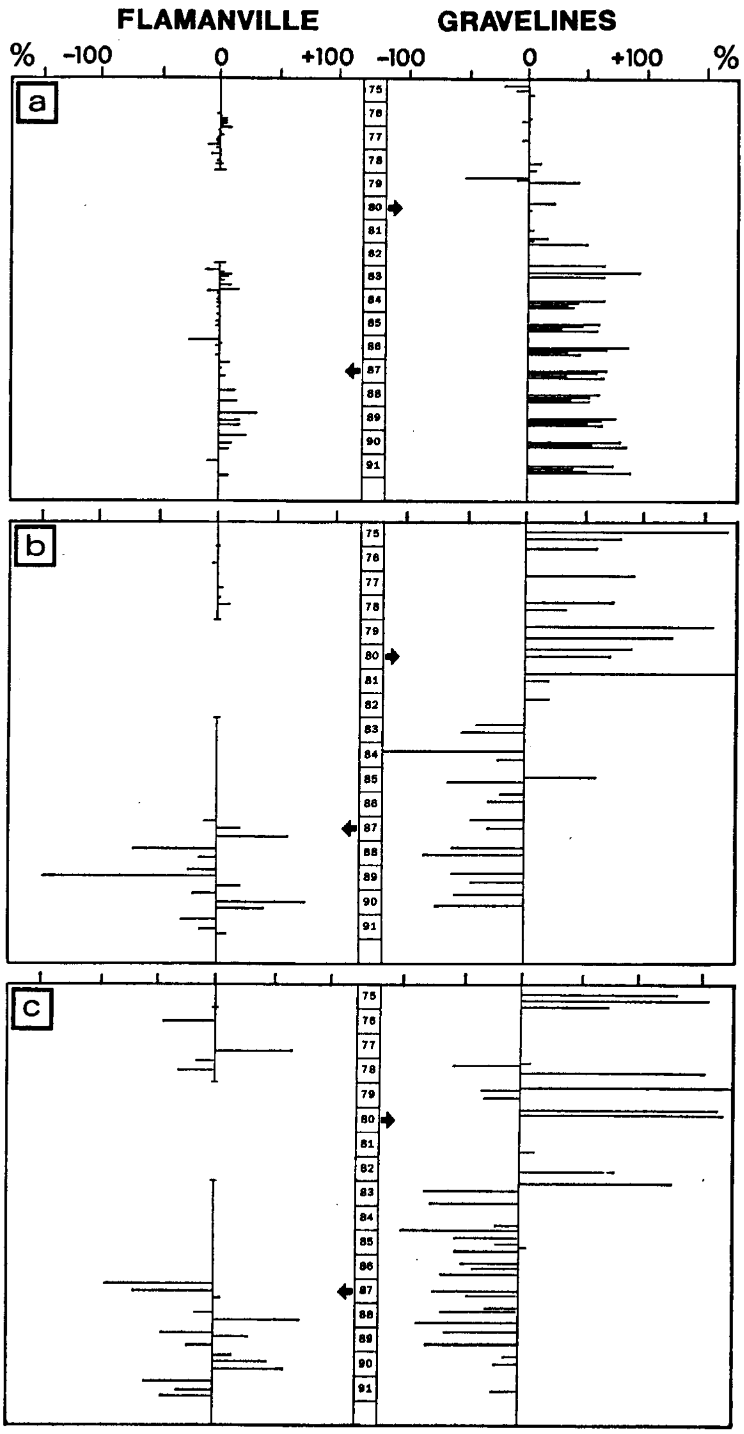
Table 6

Trophic efficiency ratios. R1 chlorophyll: nutrients; R2 zooplankton: chlorophyll. F: Flamanville, A: Paluel, Y: Penly, G: Gravelines.

Rapports de rendements trophiques. R1 chlorophylle/sels nutritifs; R2 zooplancton/phytoplancton. F : Flamanville, A : Paluel, Y : Penly, G : Gravelines.

		F	A	Y	G
Chl a : N	R1	18 10^{-3}	17 10^{-3}	50 10^{-3}	47 10^{-3}
Chl a : Si	R1	17 10^{-3}	33 10^{-3}	34 10^{-3}	91 10^{-3}
D.W. zooplankton : Chl a	R2	29	17	13	38
Carbon zooplankton : Chl a	R2	7.3	3.3	3.3	5.7
Nitrogen zooplankton : Chl a	R2	1.7	0.8	0.8	1.6

Differences appear between the sites not only in the level of total nitrogen nutrient but also in different components of nitrogen nutrients (Tab. 3) and in particular levels of ammonium between the Paluel and Gravelines sites. The complexity of many phenomena should encompass macro and microzooplankton excretion, nitrogen uptake of phytoplankton and the role of bacterial biomass production (Båmsted, 1985; Van Wambeke and Bianchi, 1985; Le Borgne, 1978; Harris and Malej, 1986).



Zooplankton (ZB)-phytoplankton (PB) biomass correlations differ if we correlate ZB with PB of the same month (1) or PB for the preceding month (2). Correlations in the same month were better in the eastern than in the western Channel. These correlations are in relation with the turnover of pelagic production. The increase of zooplanktonic population is faster in the eastern than in the western Channel.

The following trophic efficiency ratios have been calculated for all parameters in mg m^{-3} units. R1 chlorophyll/nutrients; and R2 zooplankton/chlorophyll (Tab. 6). Trophic efficiency ratios are average yearly values and a global approach to transfer in different trophic compartments.

In terms of carbon and nitrogen, the overall trophic efficiencies are presented (percentage). The terms of conversion C: chlorophyll and N: chlorophyll differ according to various authors, *viz*. Moloney and Field (1991), Moloney *et al.* (1991), Strickland and Parsons (1972), Herbland *et al.* (1985), Moal (1980). For Moloney, C: chlorophyll is 50 and N: chlorophyll is 10; for Strickland the term of conversion C: chlorophyll is = 20 and N: chlorophyll is 4; and for Moal, C: chlorophyll is 40 and N: chlorophyll is 7.

In our coastal planktonic studies the phytoplankton C and N values have not been directly measured. However organic values could be estimated from

Figure 7

Comparison of impact in Gravelines area and in Flamanville area. Vertical axis = temporal axis (years of studies). Horizontal axis = value of parameter: this is the difference observed between the reference state value and the value for the impacted area expressed as a percentage. Percentage observed = 100 x Δ (non impacted area value-impact area value)/non impacted area value. a: parameter temperature of water, b: chlorophyll a *biomass, c: zooplankton nitrogen dry weight.*

Comparaison de l'impact à Gravelines et à Flamanville. Axe vertical = axe temporel (années d'études). Axe horizontal = valeur du paramètre : c'est la différence observée entre la valeur de la zone sans impact et la valeur dans la zone impactée, exprimée en pourcentage. Pourcentage observé = 100 x Δ (valeur zone sans impact-valeur dans l'aire impactée)/valeur zone sans impact. a : paramètre température, b : biomasse chlorophyllienne, c : azote zooplanctonique (poids sec).

Table 7

Trophic efficiency (%): N phytoplankton: N nutrients; N zooplankton: N phytoplankton; C zooplankton: C phytoplankton. 1 mg C = 40 chl a and 1 mg N = 4 chl a.

Rendement trophique (%) : N phytoplancton : N nutriments ; N zooplancton : N phytoplancton ; C zooplancton : C phytoplancton. 1 mg C = 40 chl *a* and 1 mg N = 4 chl *a*.

	N Phyto : N nutrients	N Zoo : N Phyto	C Zoo : C Phyto
Flamanville	13 %	25 %	18 %
Paluel	12 %	12 %	8 %
Penly	35 %	11 %	8 %
Gravelines	33 %	23 %	14 %

1 mg C = 40 chla and 1 mg N = 4 chla (MOAL, 1980).

the chlorophyll *a* data using the relationship, C: chlorophyll = 40 and N: chlorophyll = 7 determined by Moal (1980) in the same area. These rough evaluations, calculated from the annual average, allow good appreciation of the trophic efficiency ratios. Table 7 summarizes the ratios of calculated estimated values and gives the following observations:

- low ratios of N phytoplankton: N nutrient at Paluel and Flamanville in relation to high water turbulence which limits the proliferation of the phytoplankton;

- high ratio values (C zoo: C phyto and N zoo: N phyto) at Flamanville and Gravelines which point to an efficient assimilation of phytoplankton by herbivorous populations. The same observations could be deduced from the ratios D.W. zoo: chl *a*.

In conclusion, comparison of the four area studies has shown:

- the passage from an unstable ecosystem (Gravelines) to a system with a greater inertia (Flamanville). We observe in the course of the year several periods of pelagic production. The number of these periods is higher in the north-eastern than in the south-western part of the study area and the amplitude of the production decreases;

- the turnover of is shorter durations in the north than in the south;

- the trophic efficiency ratio is linked both to the initial stock of nutrients or food and to physical environmental features.

Impact of plant. Comparison between the Flamanville and Gravelines areas (Fig. 7 *a*, *b*, *c*)

The starting up of the nuclear plants at Flamanville and Gravelines induced a perturbation in the initial system. The main source of disturbance was the sea water cooling system. At the Gravelines site the flow is 240 m^{-3} s^{-1}, $\Delta T = + 11°C$ and at Flamanville the flow is 80 m^{-3} s^{-1}, $\Delta T = + 15°C$. The chlorine injected at the intake point is 0.8 ppm when the temperature is higher than 10°C at the entrance point. The impact evaluation is linked to the stress characteristics of the flow, at Gravelines 240 m^{-3} s^{-1}, at Flamanville 80 m^{-3} s^{-1} and to the initial characteristics of the system. We show in Figure 7 *a*, *b*, *c* the impact of the cooling system observed at two sites in the thermal plume (Fig. 7 *a*), for the chlorophyll biomass (temperature and chlorine effects) (Fig. 7 *b*) and zooplankton nitrogen weight (Fig. 7 *c*).

In Figure 7, the vertical axis is a temporal axis and represents the period of study 1975-1991, continuous at Gravelines, interrupted at Flamanville (between 1978-1982). The horizontal axis represents in percentage, differences observed between impacted area and non impacted area [** (** = % observed = 100 x Δ (non impacted area value-impacted area value/non impacted area value)]. Before 1980 at Gravelines and 1987 at Flamanville, oscillations of values are natural seasonal variations. After the plants became operational, an impact was more evident at Gravelines than at Flamanville, corresponding to a difference in the sensitivity of the ecosystem. Examples of the impact at Gravelines after 1980: $\Delta T°$ positive value = outfall water $\Delta T = + 11°$. D chlorophyll value is positive before 1980, negative thereafter.

The differences observed at the two sites are also linked to the dates of entry into operation of the plants: 1980 for Gravelines, 1987 for Flamanville. Balance sheet: the deficit of the biomass crossing the cooling system is at Gravelines 50 tons $year^{-1}$ chl *a* and 40 tons $year^{-1}$ zooplankton nitrogen; at Flamanville: 2 tons $year^{-1}$ chl*a* and 3 tons $year^{-1}$ zooplankton nitrogen. Assessment of the impact of plant must consider both the natural "reference state" of the ecosystem and the "plant effect".

CONCLUSION

Flamanville shows low values of planktonic biomass and low levels of nutrients. The physical features are a good mixing of the water column, strong currents with a good coastal offshore dilution.

Paluel is a complex site. The planktonic biomass is high in spring and linked to the influence of the flow of the Seine, and low in summer, under the influence of central Channel water. The physical features are a high turbulence and strong currents. The erosion of this convex coast produces high values of suspended material which reduces phytoplankton production. The trophic efficiency ratios for a mean year is low.

Penly shows high values of planktonic biomass with oscillating system over the year. The physical features are weak currents, concavity of coast sedimentary facies. The trophic efficiency ratio (TER) phytoplankton: nutrients is moderate, while the TER zooplankton: phytoplankton ratio is poor. We interpret this last result to competition by predation between the benthos (annelida) and herbivorous zooplankton.

Gravelines is an oscillating system showing many cycles of production during the year. The planktonic biomasses are very high. Trophic efficiency ratios show good value with a rapid turnover.

This comparison shows:

- great differences in pelagic production from the western Channel and the North Sea, with a more inertial system in the western Channel and an oscillating system in the north;
- trophic efficiency ratios are related to the local hydrological conditions.

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