Synthesis on biology of Common European Cockle Cerastoderma edule.

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1 - Taxonomy

Phylum: *Molluscs*	Genus: ***Cerastoderma***
Class: *Bivalvia*	Species: ***edule***
Order: *Veneroida*	Description : Linné (1758)
Familiy: *Cardiidae*	Synonym (before 1950) *Cardium edule*

2 - Anatomy of the shell

- The two valves are quite similar, but inequilateral
- Broadly oval, up to 50mm long
- Shell with 22 to 28 conspicuous broad ribs, closely spaced
- External ligament, rubbery appearance, that is tends to open shell permanently (Fig.1)
- Two adductor muscle scars (these muscles serve to close the shell)
- Pallial line without sinus

Growth line

Fig. 1 The two valves of a closed Cockle. The broad ribs, the ligament and the hinge are conspicuous

broad ribes

ligament

Internal view of a right valve

Anterior adductor muscle scar

Posterior adductor muscle scar

Pallial line
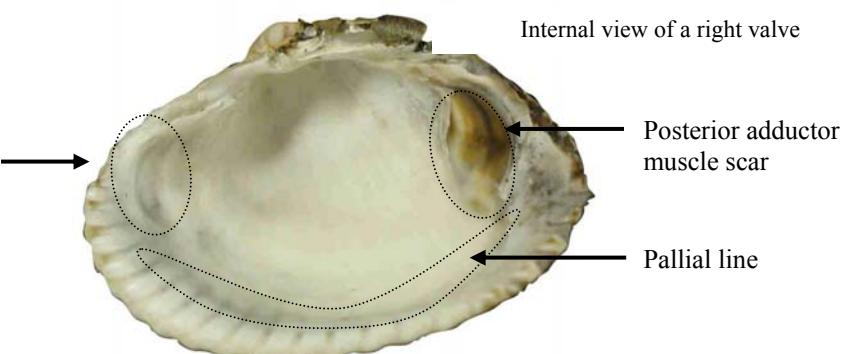
3 - Distribution

The Cockle (*Cerastoderma edule*) is one of the most common and widely distributed bivalve species on tidal flats along the coast of most of european countries. Its distribution area extends from Norway to Senegal. It's an ubiquist species which can be found in estuaries and sandy bays (Tebble, 1966), particulary in sandy mud, sand or fine gravel.

Main stocks are in Netherlands (Waddenze, Zeelande), United Kingdom (Wash, Thames estuary, Horecambe and Caenarfon bays), in Spain (Galice, Mediterranean coast). In France, Cockle is widely distributed along the coastline. From north to south, the more constant and regular stocks are: around Dunkerque, Bays of Canche, Somme, Seine, Veys, Mont Saint-Michel, Saint-Brieuc and many others bays of northern Britanny. Further south, Cockle can be found in Bay of Vilaine, Baule, Loire estuary, Bassin de Marennes-Oléron, Bassin d'Arcachon (Quéro & Wayne, 1998).

Fig. 2 : Main stocks of Cockle (*Cerastoderma edule*) in France (Quéro & Vayne, 1998)
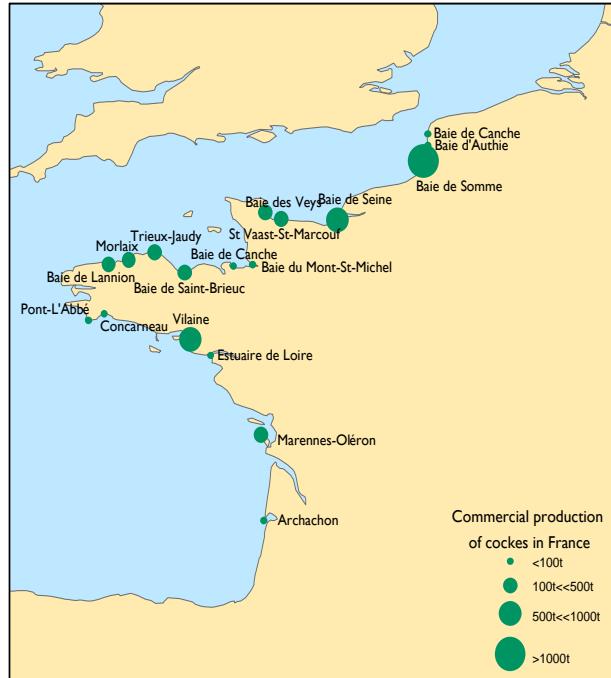
Cockle are found on a large part of the intertidal area. For a given geographical location, for example the scale of a bay, the distribution is aggregative (Fig.3) as for many endogean benthic species (Reys, 1971; Elliot, 1979; Downing, 1979). Densities can vary from a few individuals per square meters to thousands. For example, the maximum density observed in the Bay of Saint-Brieuc is 2752 individuals/m² in 2008. Densities of 5000 individuals/m² have been observed at Oostershelde in Belgium in 1985 (Coosen *et al.*, 1994). Higher densities are observed around the mid-tidal level (Fig.4).
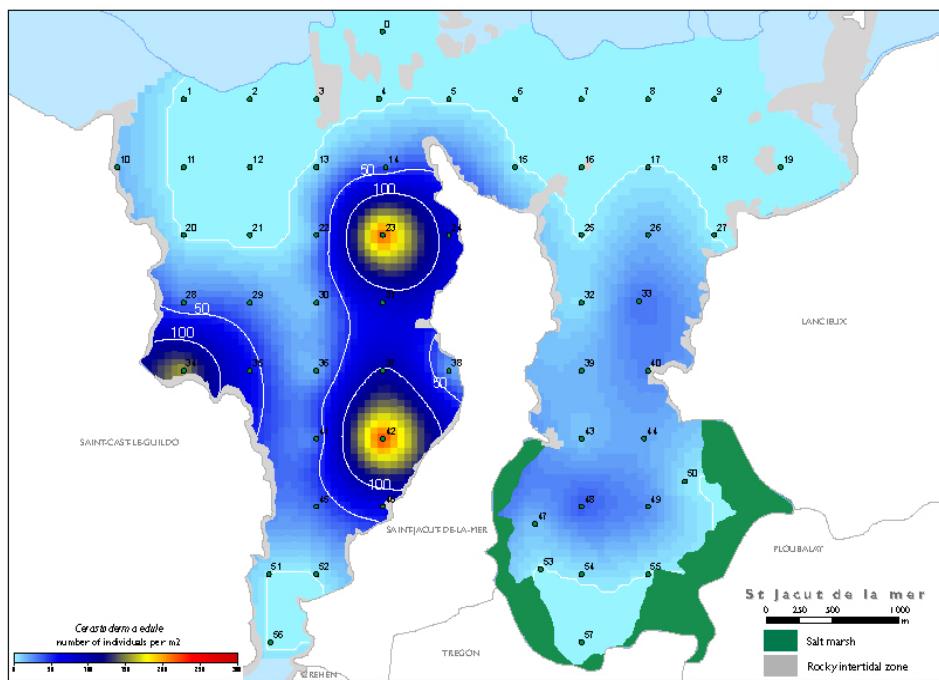
**Fig. 3**: Repartition of *Cerastoderma edule* at Saint-Jacut de la mer (Côtes d'Armor) in 2008.
(Datas and map not published: Vivarmor Nature, 2008)
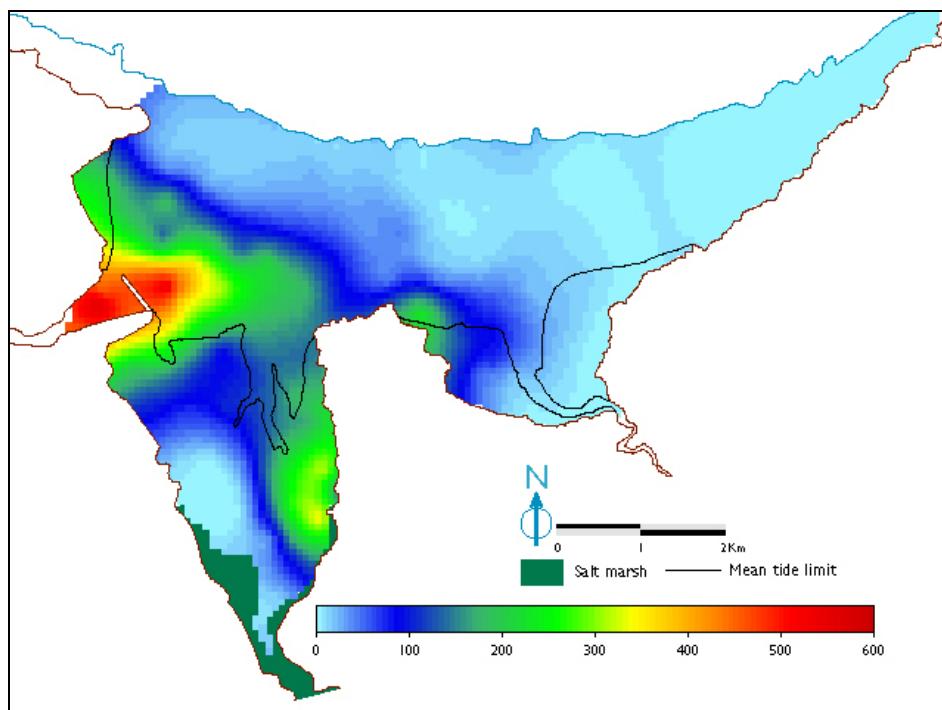
Fig. 4: Repartition of *Cerastoderma edule* in the Bay of Saint-Brieuc (average 2001-2008)

4 – Lifestyle

The Cockle is a burrowing animal. By means of its muscular foot the cockle burrows rapidly in the sediment (Fig.5). Thus, cockle is protected from waves as many aquatic and terrestrial predators: crabs, waders, humans...

Diet: active suspension feeder
The Cockle filters actively water thanks to its two siphons (inhalant and exhalant) positionned on the surface of the sediment. Water is filtered through gills to keep phytoplancton, zooplancton and organic particles. These elements are grouped together into a mucus and make for the mouth thanks to cilias, like on a conveyor belt.
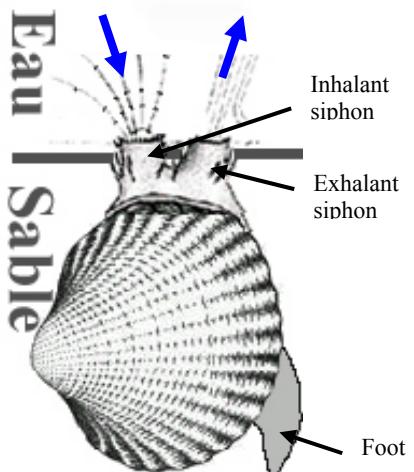

Fig. 5 : Cockle in the sediment

Digestion takes place in an intestine to enzymes and bacteria. The crystal-line style is translucent like a glass rod (fig.6). It's an enzyme reserve used progressively by the cockle during the digestion.
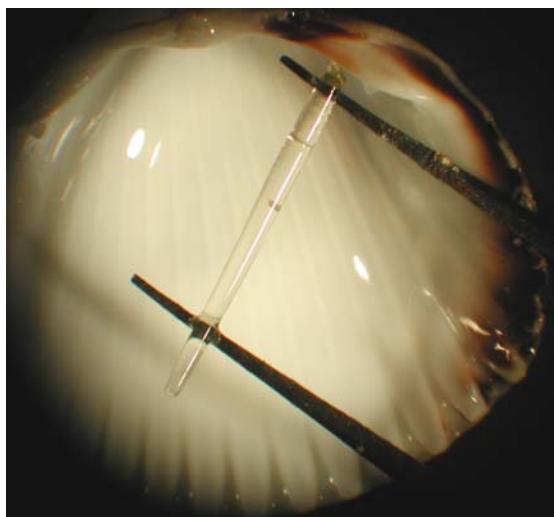
Fig. 6: enzymatic cristal-line style
(extrated from the digestive tract for the picture)

Fig.7: Cockle group on the surface of the sediment
(bay of Saint-Brieuc)

Alive cockles can be found on the sediment surface on the intertidal zone (Fig. 7). They generally represent a little part of the global population. These cockles themselves come back up to the surface of the sediment, or have come loose due to displacement of sediment, caused for example by modifications of the banks of the rivers which go all over the intertidal zone. These cockles are generally very weakened and have lost their burrowing capacities.

The burrowing capacity is here compared on an experimental basis. Cockles are placed on the sediment (5cm deep) under 5cm of water, and spaced out a few centimeters from each other. Burrowed cockles are counted 2 hours later. Results are shown fig. 8.
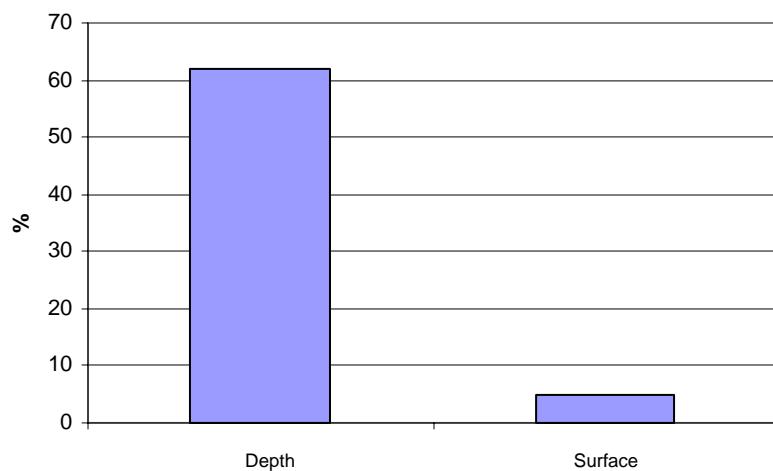
Fig. 8: The burrowing capacity of cockles from deep (n=127) and cockles found on the surface of the sediment (n=139), in percent of burrowed cockles after two hours (U.C.O., june 2003, not published)

To confirm that these cockles are weakened and not capable to burrow, a condition index (Ic) is calculated to get valuation of the state of their health. The IC is the flesh-to-shell ratio. It enables to bring out the loss of weight (fig. 9). Cockles found on the surface of the sediment weigh 25% less than ones found burrowed in the sediment (dry weight). These cockles are very weakened, probably dying.
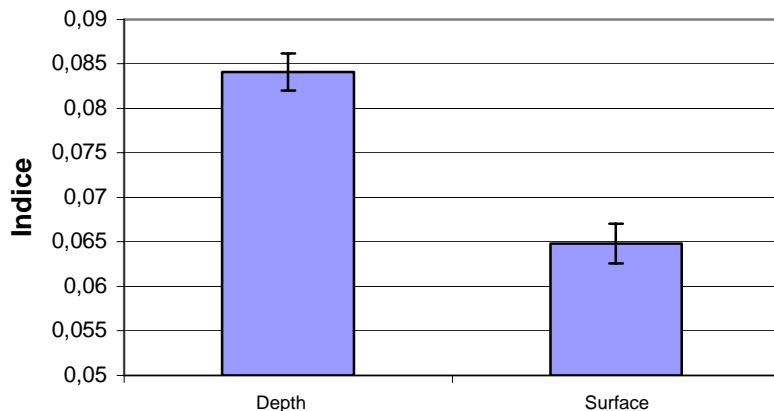
Fig. 9: condition index (IC= ash free dry mass of flesh / dry mass of shell) ± standard-Error of Cockles found burrowed in the sediment (n=60) and on the surface (n=61), (Anova test p<0,01).
(U.C.O., june 2003, not published)

5 – Reproduction

Cockles generally live two to four years on average, but they can exceptionally reach ten years old. The phenomena of reproduction are clearly influenced by the physical environment, notably the increase of the temperature, more than an absolute value of it. The sexual maturity is generally reached during the second year (size between 13 and 16 mm, 15 to 18 months). Some authors have noticed a reproduction during the first year if cockles grow very fast (Seed & Brown, 1977). It seems that, sexual maturity depends on the size more than the age of individuals (Kristensen, 1957; Handcock & Franklin, 1972; Sauriau, 1992). Sexual maturity can be reached in a few months in the bay of Sommes (Lemoigne *et al.*, 1988) and up to 2 years in Northern Ireland (Seed & Brown, 1977).

Cockles are gonochorics (sexes are distinct). On medium latitude, many phases of laying can be identified during the year:

- Early layings (frebruary-marsh), particularly for old individuals (Guillou *et al.*, 1990)
- Spring layings (april-june), generally the most important
- Summer layings, all the more important if the spring layings have been low
- Late autumn layings (end of September-November) not always intense

On more nordic latitude (higher than 55°N), only one reproduction period is observed. It's a short period, synchronised with the most favorable nutritive and thermic conditions. In the South, from Northern Ireland latitude, the strategy of reproduction is modified. Gametogenesis occurs in spring-summer but the repetitive characteristics of laying become more constant (Seed & Brown, 1978). For medium latitudes, up to Galice, it occurs earlier and earlier and layings are repetitive.

The intensity of laying is generally conversely linked with the intensity of the previous laying. Thus, the intensity of autumn laying is conversely linked with the intensity of the summer laying, as it has been observed in the bay of Somme (Desprez *et al.*, 1987). Literature is unanimous to say that a harsh winter stimulate reproduction, synchronising male and female emissions of gametes and insuring a better fertility (Handcock, 1973).

Ovocyt production depends on the size of individuals. For a female of about 18 to 38 mm, ovocyt production varies from 5600 to 52 000 ova (Kristensen, 1957). Gametes are emitted in the pallial cavity. Thanks to water currents created by gills, gametes will go into the sea water through the exhalant syphon. Sperm will then fecond ova and form eggs (50 to 60 μm). Eggs will develop to form a planctonic larva, named trocophore and Velliger (fig. 10). In 3 days, planctonic larvae will develop a minuscule shell and reach the size of 270 μm in 3 to 5 weeks (Creek, 1960). In three month, the larva measure 1mm.

Ciliated stomach

Mouth

Crown of cilia

Anus
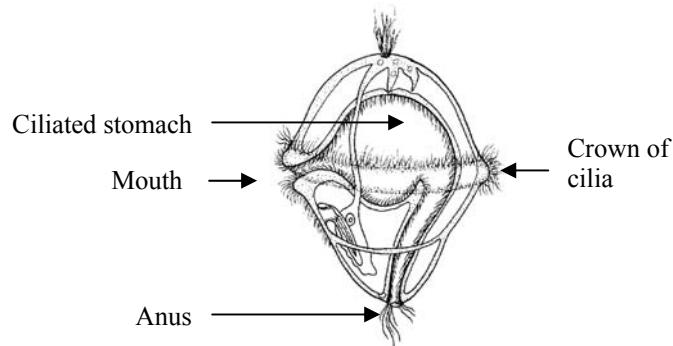
Fig. 10 schema of the trocophore larva (Biodidac, Ottawa University)

6 - Settlement

Settlement refers to the the settling of larvae in the sediment. Young larvae of 1 mm with small shells settle on the surface of the sediment and try to burrow using their foot. It occurs in May-June for most of cockles from medium latitudes, and to a lesser extent, up to September.

Bouma has shown that important densities of cockle settlement are correlated with areas where the silt is maximal during the tidal cycle, at the bathymetric and granulometric levels (Bouma *et al.*, 2001).

Sediment must have propitious granulometric characteristics for water fixing: between 50 and 200 μm in the Bay of Somme (Lemoigne *et al.,* 1988), between 100 and 125 μm in the bay of Saint-Brieuc, because the survival of youngs depends on a good water retention (humidity between 30 and 35% for settlement sites in the bay of Saint-Brieuc). Settlement areas are generally restricted. For example, they represent about 1000 ha in the bay of Saint-Brieuc. The global stock represents 3000 ha, and areas with a density of young cockles in

excess of 100 individuals/m² only represent 400 ha (excluding exceptional year with high settlement) (Ponsero *et al.*, 2009).

Temperature seems to be a primary factor for the survival of the planctonic larvae (Baggerman, 1953), particularly during the implantation in the sediment. If conditions are not combined, the young cockle can look for a better site. To find a new site, the young cockle makes some byssus, like proteic filaments, which makes its bearing surface increase to get hanging in water easier, and is transported by current to new sites. This displacement is named "bisso-pelagic migration" (Moutaudouin, 1997; Huxham & Richards, 2003).

An important or a very important settlement is generally followed by a low one the year after. For example, in the bay of Saint-Brieuc in 2005, the settlement was lower than 20% of the average observed between 2001 and 2008, after a very important settlement, rate of 220%, which occured in 2004 (Ponsero *et al.*, 2009).

Year	total	0	%
2001	1546	1156	74,81
2002	1355	393	29,00
2003	1619	1279	79,02
2004	5158	3972	77,00
2005	2051	380	18,53
2006	1870	968	51,76
2007	858	115	13,41
2008	6297	6067	96,34
mean	2594	1791	55
sd	1990	2109	31

Table 1: Total numbers ($*10^6$) of the cockles stock of the bay of Saint-Brieuc, and numbers ($*10^6$) of the first year cohort assessed by modelisation (kriging)

7 - Growth

Cerastoderma edule follow a very fast growth the first two years which then declines (fig. 11). Cockles growth modeling can be adjusted to the Von Bertalanfy model (1938). It's generally used to compare mollusc growth rate (Ramon, 2003).

The model of growth in length, at t time, has for equation: $L_t = l_\infty(1-e^{-k(t-t0)})$ with
l_∞ : asymptote of the curve (often called "maximal length")
k : initial growth coefficient
t_0 : theoretical date of birth

Sites	k	l_∞	t_0	ϕ'	source
Denmark (Langerak)	0.248	54	-0.2	2.86	(Brock 1980)
	0.386	40.7	-0.34	2.81	
Germany (Wadden sea)	0.404	40	-	2.81	(Ramon 2003)
England Wales (Llanrhidian sand)	0.59	31.5	-	2.77	(Hancock 1965),
Ireland (Dundalk bay)	0.4364	49.1	-.03995	3.02	(Fahy et al. 2005)
France (Saint-Brieuc bay)	0.64	34.36	-	2.88	
France (Marenne-Oleron)	0.068	30.87	-2.11	1.82	(Sauriau 1992)
north Spain (rias Altas)	1.609	26.5	0.104	3.05	(Catoria et al. 1984)
north Spain (rias Arosa)	0.951	41.226	0.083	3.21	(Pérez Camacho & Román 1984)
north Spain (Mundaca estuary)	0.026	28.27	8.998	1.32	(Iglesias & Navarro 1990)
south Spain (Algeciras bay)	0.18	36	-0.05	2.37	(Guevara & Niell 1989)

Table 2: Comparison of cockle growth modelisation in different european sites (K: initial growth coefficient, $l\infty$ asymptote value, t_0 length to the origin. Some authors do not model this value and prefer the set to 0.
• growth index : • = 2 $\log_{10}$ ($l\infty$)+ $\log_{10}$(k) according to Pauly & Morgan, 1987)
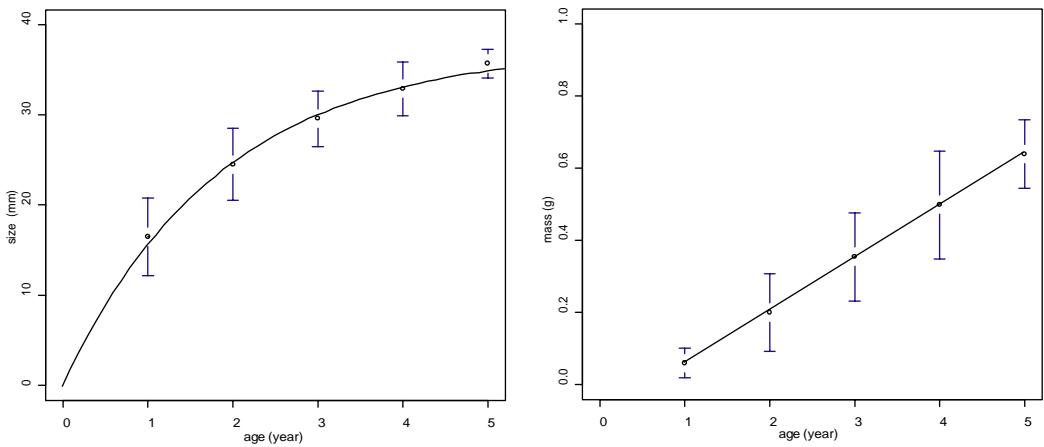
Fig. 11 : Growth of cockles in the bay of Saint-Brieuc:
On left: link between size and age according to the Von-Bertallanfy model (L∞=34.36, k=0,64, t_o=0); on right linear relationship between mass (dry mass) and age (Mass=0,13*age-0,06; R²=0,9892)

Many factors influence the growth of cockles : the season, the location (Hancock, 1967; Ducrotoy *et al.*, 1991), water temperature (Smaal *et al.*, 1997), food availability or cockle density (Jensen, 1993, Montaudoin & Bachelet, 1996).

In the bay of Arcachon Montaudoin & Bachelet (1996) have shown that the cockle growth was linked with their position on the intertidal area. On low foreshore levels, cockles grow faster because they suffer less tides and can spend more time filtering and feeding. Thus, growth rate depends as well on immersion time. In the bay of Saint-Brieuc, we show that the doubling of immersion time explains about 30% of the increase of growth for the first winter rings, 20% for the second winter rings, and 10% for the third winter ones. That can be brought to the fore with the comparison of the k parameter values (growth coefficient) of the Von Bertalanfy model estimated in stations characterised by different hypsometric levels.
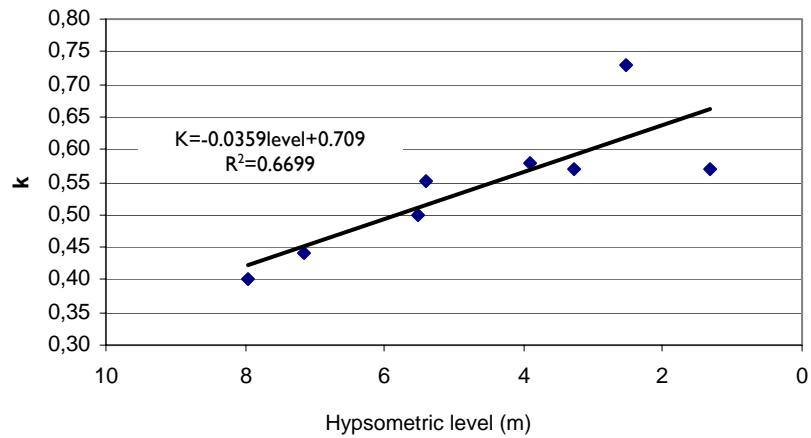
**Fig. 12** : K parameter value of the Von-Bertallanfy model in the bay of Saint-Brieuc modelised according to hyspometric level (m) (Ponsero *et al.*, 2009).

Seasonal growth starts in May in Wales, it reaches its maximum from June to August, and it's negligible after (Seed & Brown, 1977; Hancock & Franklin, 1972). Cockles generally lose weight during winter and support the theory of important mortality due to winter harshness.

In regions characterised by marked cycles of temperature, seasonal rhythms of growth are visible in mineralised tissues.

The fluctuation of growth speed causes an alternation of fast growth zones and slow growth on shells. Sometimes, the growth can stop, waiting for better conditions. This seasonnal growth causes rings of growth on shells (fig. 13). Thus, it became possible to determine the age of the cockle reading and counting these rings, and analyse the differencial growth of populations in a second time (Richardson *et al.*, 1980; Jones & Baxter, 1987). However, rings reading remains difficult because of additional rings caused by growth variations during the same year (Ramon, 2003), all the more when winter temperatures remain high (low latitudes).


First winter

Second winter

Third winter
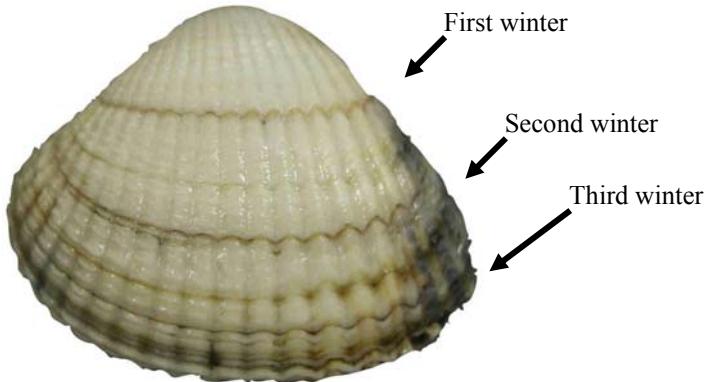
Fig. 13: Growth rings (cockle size: 4,2 cm)

Relationships which link individual size (mm) with the mass of living matter produced (mass of ash free dry mass) can be analysed in this form: $W = aL^b$.
W: ash free dry mass $(g.m^{-2})$
L: size of individuals (mm)
a and b: parameters of the equation establied for the site

Sites	a	b	source
Baie de Somme (France)	$3*10^{-6}$	3.0969	(Triplet et al. 1999)
Baie de Saint-Brieuc (France)	$4*10^{-6}$	3.3504	Ponsero and al 2009
Saint-Jacut (France)	$4*10^{-6}$	3.3381	Vivarmor Nature, 2008
Pays de Galles	$3.2*10^{-6}$	3.083	(Sutherland 1982)

Table 3: Comparison of the modeling parameters of the size-mass relationship in different sites.

8 – Biomass and production

Cockles can represent up to 60% of the benthos biomass (Ramon, 2003) and play an important role in the intertidal ecosystem functioning (Beukema and Dekker, 2006). In the bay of Saint-Brieuc, cockles represent 62% of the bivalves biomass (2007).
The producted biomass (grams of dry matter per square meter ou $g.AFDW. m^{-2}$) is about from 10 to 40g, and can reach up to 100 $g.AFDW. m^{-2}$). In the bay of Marennes-Oléron, biomass is evaluated to 32,5 $g.AFDW. m^{-2}$ (Sauriau, 1992). In the Wadden sea, the production varies from 7,6 to 101,6 $g.AFDW. m^{-2}$ (Beukema & Dekker, 2006). In the bay of Saint-Brieuc the biomass average of the site, varies in function of year between 6,01 $g.AFDW. m^{-2}$ and 14,52 $g.AFDW. m^{-2}$ (average $10,349 \pm 2,713$), with maximums that vary from 43 to 388,55 $g.AFDW. m^{-2}$. To sum up, production depends on many factors and strong year-to-year variations are usually observed.

9 – Structure of the population

Class size histograms are generally polymodal (fig. 14) with an overlapping of different cohorts for the highest age classes (Ramon, 2003; Ponsero *et al.*, 2009). To differentiate the membership probability of cockles of one cohort or other, the probability of each cockle being linked with a cohort can be calculated using its size and consulting the normal curve of different cohorts obtained with the analysis of growth rings (Ponsero *et al.*, 2009). Parameters of cohort composing the demographic structure established each year are optimized by the maximum of likely methods (Hasselblad, 1966).
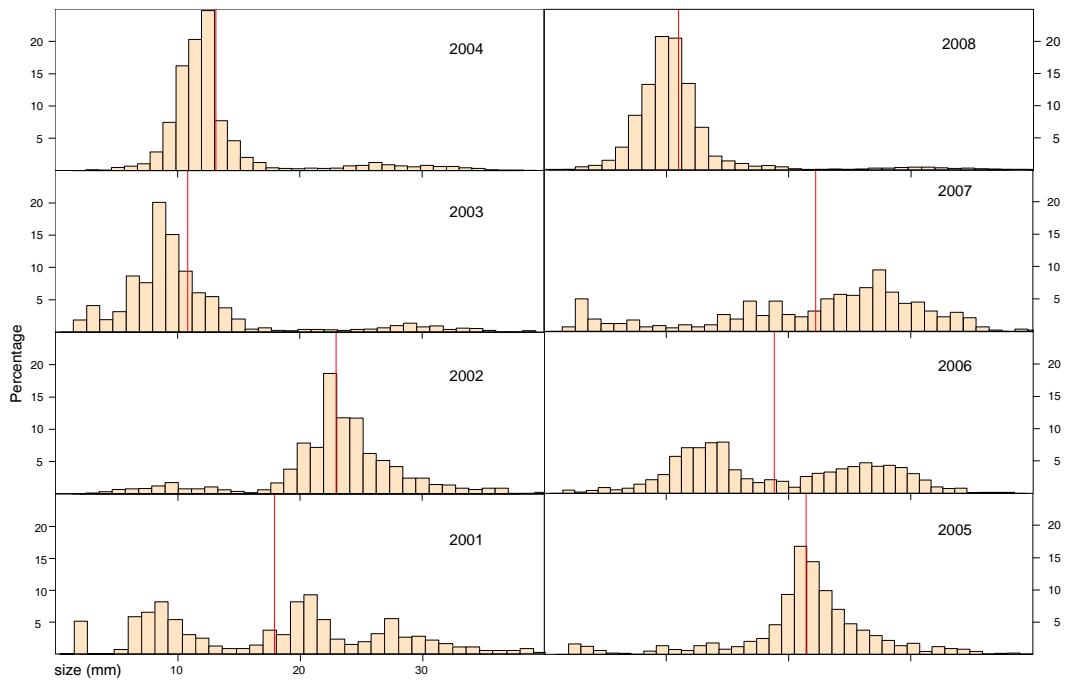
Fig. 14 : Size-frequency bar charts observed in the bay of Saint-Brieuc from 2001 to 2008, expressed as a percentage of total

For example, an important settlement can be observed in 2003, 2004 and 2008; an old population in 2002 and 2005; and different cohorts well represented in 2001. It shows strong   year-to-year variations of the population structure which depend on the settlement of the year and the years before.

One of the cockle particularity is certainly the flexibility of its demographic strategy (Seed & Brown, 1978; Sauriau, 1992). That's why biologic parameter assessment of a population must be realised with a sampling protocol adapted to the spatial scattering and the year-to-year variations.

10 – Spatial distribution

A spacial segregation of generations can be observed, as this has been highlighted in many sites for *Macoma balthica* (Bachelet, 1979; Hiddink & Wolf, 2002) and *C. Edule* (Sutherland, 1982). Spacial distribution varies with the size of individuals. Higher class sizes are at lower bathymetric levels. A correlation exists between the medium size of cockles per station and the bathymetric level of stations.

Generally, cockle stocks are characterized by a strong spacial heterogeneity of densities and biomasses (Farrow, 1974). Unlike what is observed in the bay of Somme (Desprez *et al.*, 1989) or in Scotland (Farrow, 1974), this spacial structuring is quite constant in the bay of Saint-Brieuc under eight years of monitoring. Settlement areas are geographically well defined and localized at mid-tide level in limited areas (excepted during exeptional settling phases). Cohorts 4+ and 5+ are below this level (fig. 15).
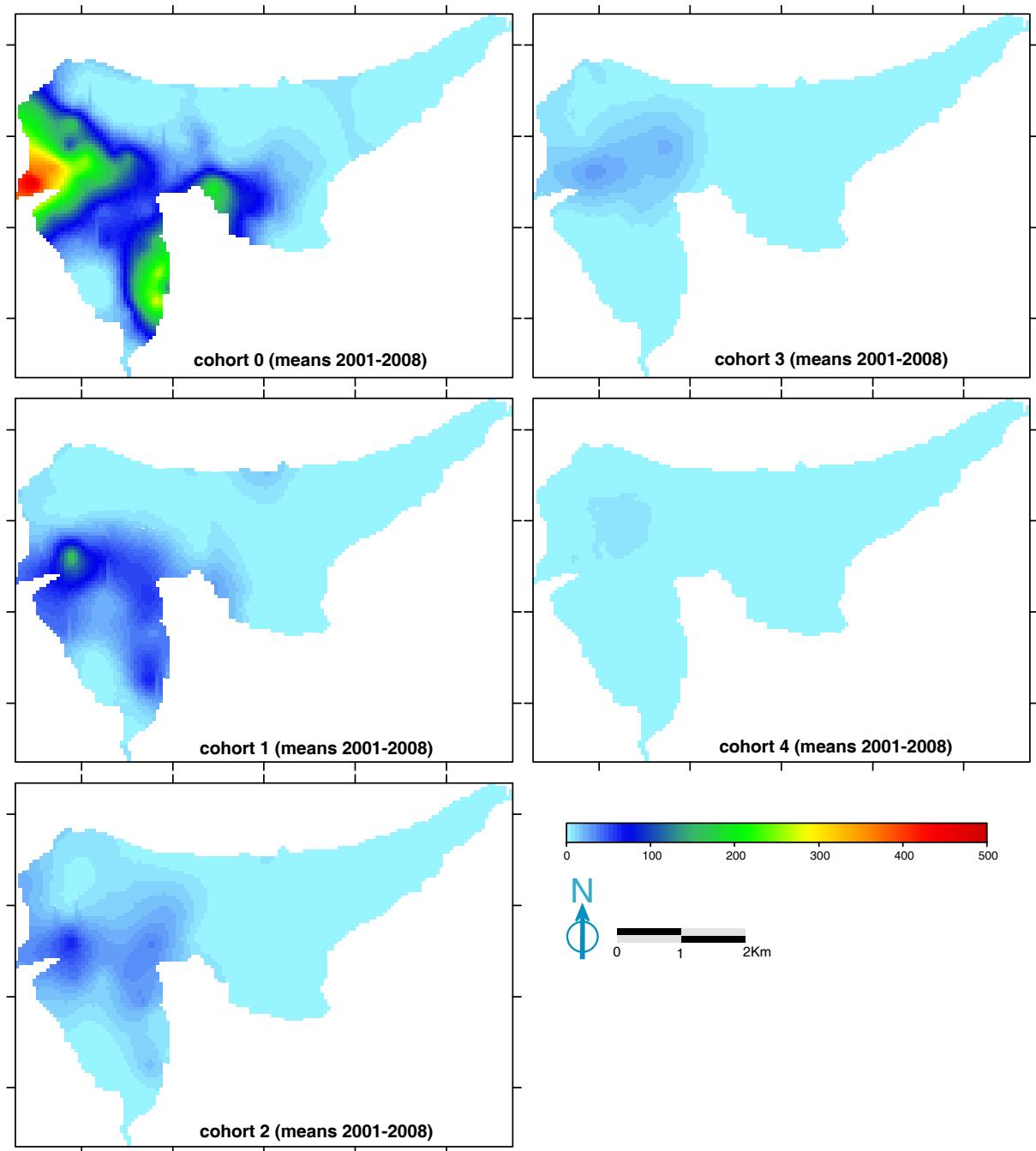
Fig. 15 : Spacial distribution map of the different cohorts in the bay of Saint-Brieuc (average values modeled from 2001 to 2008 by Kriging)

11 – Population dynamic

Cockle numbers can vary year-to-year on some sites or keep constant during larger periods on others. Different factors are described as acting on settlement, growth and natural population mortality. The diagram below, extracted from the thesis of Montaudouin (1995), shows the synthetic (fig. 16).
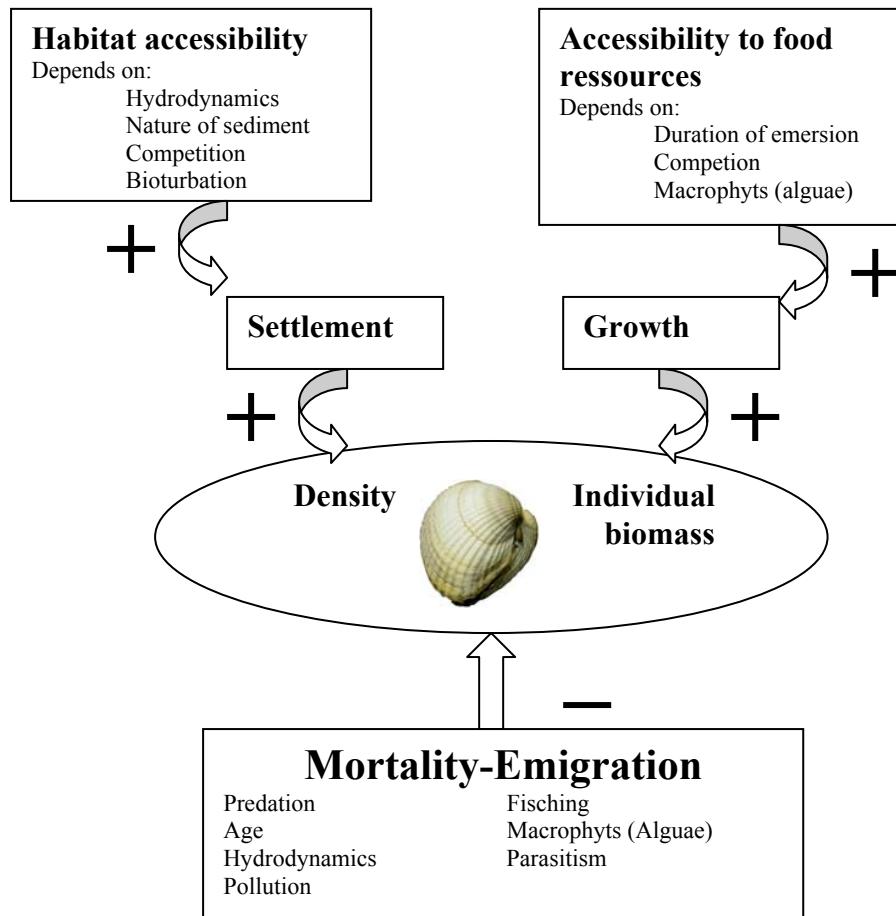
Fig. 16: Factors regulating the population dynamics of cockles (Montaudoin, 1995).

12 – Mortality

The long-term monitoring of the population dynamics of the cockles in the bay of Saint-Brieuc shows that the medium mortality from one year to another is an overall constant during the cockle life: between 50% and 70% of the number of the previuous year before (Ponsero *et al.*, 2009).
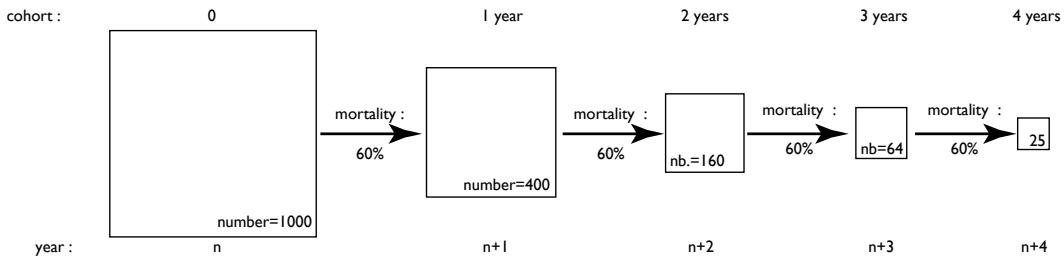

Fig. 17: Diagram shows the variations of an hypothetic cohort over time (with a constant medium interannual mortality of 60%).

In this case, the mortality is considered complete because it includes all of the anthropic or natural causes. Many authors have been interested in the predation that occured on juveniles. Reise (1985) shows clearly that the pression of predation is focused on first stages of growth and then decreases with cockle growth. For example, predation by the European flounder (*Platichthys flesus*) on the cockle seed (Wolf *et al.*, 1981), and the shore crab (*Carcinus maenas*) (Brock, 1980; Sanchez-Salazar *et al.*, 1987a,b) have been highlighted. Predation by waders, particularly by European oystercatcher (*Haematopus ostalegus*) occurs on individuals of about 2 cm long, either on one year and half old cockles (Triplet, 1996; Triplet *et al.*, 1999a) or between 15 and 30mm according to West *et al.* (2007). Leftover cockles were found in the faeces of waders, as Dunlin *Calidris alpina* (Durell & Kelly, 1990; Le Drean Quenec'hdu & Maheo, 1997; Cabral *et al.*, 1999), Red knots *Calidris canutus* (Dekinga & Piersma, 1993), Bar-tailed Godwit *Limosa lapponica* (Goss-Custard *et al.*, 1977; Scheiffart, 2001), Eurasian curlew *Numenius arquata* (Le Drean Quenec'hdu & Maheo, 1997), Avocet *Recuvirostra recuvirostra* (Moreira, 1995).

Extreme temperatures play an important role in the mortality of different age classes. The winter mortality particularly affects the smallest individuals (Sauriau, 1992). Populations can be affected when the temperature of the sediment decreases below 7°C. Kristensen (1957) showed that the tolerance of cockle is about 34°C with a lethal step at 36°C, and that seed resists better to high temperature than adults.

It's difficult to assess the impact of professional or recreational harvesting. However, these activities can have a significant impact on population dynamics (next chapter). The impact of parasitism is rarely mentionned in studies focused on the population dynamics of bivalves. Chapter 14 highlights the importance of this phenomenon without assessing the impact. Note that an accidental or diffuse pollution can weaken individuals which will become less resistant, and more sensitive to attacks by parasits or predators. Thus, the impact of these interacting factors is more important than the sum of the two.

13 – Harvesting and managment of the bed

In all european sites studied where an important harvesting activity occurs, a demographic structure truncated beyond the commercial size is observed, whatever the growth rate of individuals of these populations (Hancock, 1965; Franklin 1972; Gordo, 1982). Sauriau (1992) mentions that the demographic structure of a stock under heavy harvesting pressure presents less than 5% of individuals measuring 30mm.

In France up to 2006, the harvesting impact (professional or recreational) occurs on class sizes greater than or equal to 30mm, corresponding to 3 years old individuals and over. One can hypothesize that the increase of mortality of this class age could be attributed to harvesting. In autumn 2006, the legal harvesting size has changed from 30mm to 27mm (corresponding to two and a half years old individuals). It is possible that this decision had an impact on the demographic structure of the population. In the future, this modification of the harvesting size will probably influence the 1∞ modelised value, as it has been highlighted by Hancock in 1967, and that, whatever the growth rate of individuals of population. This harvesting size decrease, that seems negligible, causes a doubling of harvestable stock (Ponsero *et al., 2009*).

14 - Cockles parasitism

Cockles are, as other animals, a living environment for other organisms which depend totally on the first. This phenomenon is called parasitism. The parasit lives in its host, in this case the cockle, and reduces more or less the fitness of the host. Many parasits are known for the cockle. Can find ciliated protozoa living in the water-intake valves, crustaceans in the intestin, and several flatworms attached to the plathelminth phylum (digenian trematodes) in different bodies. These flatworms follow very complex biologic cycles.

A - Digenian trematode parasits

The adult of the parasit lives in vertebrates (bird or fish which is named definitive host (DH)) and lays eggs that will join the water by the faeces of the vertebrate. A small larva (miracidium) is born from this egg and immediately looks for a second host (intermediate host 1, IH1) to multiply, usually a mollusc. Cockle can be this PH1. A large numbers of larvae is produced by asexual reproduction, and then runs into water.
A third host (intermediate host 2, IH2) is used by larvae to join the definitive host easily. By feeding PH2, the DH swallows the parasite at the same time, and becomes contaminated. At this moment, the larval form of the parastite is different because it aims to wait and does not try to multiply as in PH1. Thus, the parasite lives in three different hosts (Fig. 18).

Definitive host (DH)
Sea bird for example

Intermediate host 2, (IH2)
Cockle

Intermediate host 1, (IH1)
An hydrobia gasteropod (3mm) for example
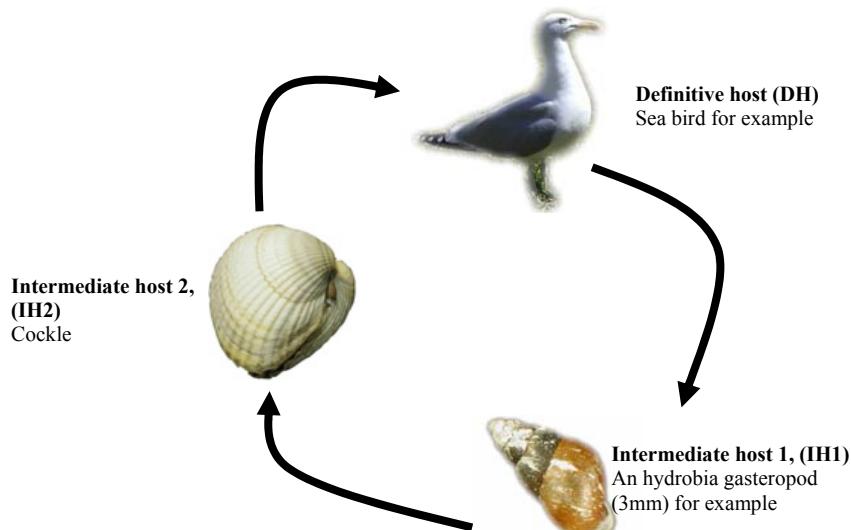
Fig. 18: Example of three successive hosts which enable to close the biological cycle of a digenian trematode parasite

According to a recent synthesis (Montaudoin *et al.,* 2009), 16 digenian species use cockle as intermediate host on all the East-Atlantic facade. Four examples of these parasits found in the bay of Saint-Brieuc are presented here (Fig. 19 to 22).

Gymnophallus choledocus
IP1: Cockle
IP2: ringed worms (annelid polychaete, for example *Nereis*)
DH.: seabird
Low prevalence in cockle. Intensive asexual reproduction that makes the cockle die. Cercariae, second type of mobile larva, left the dying cockle to join the IH2.
.
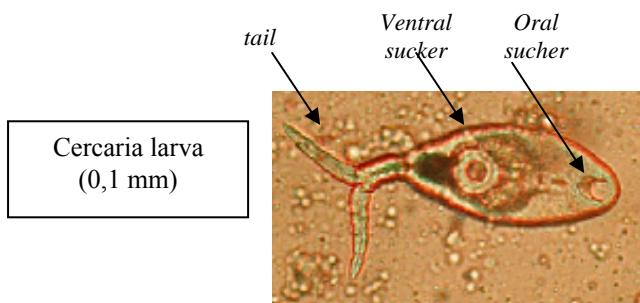
sporocyst larva (0,5mm) with cercariae

tail

Ventral sucker

Oral sucher

Cercaria larva (0,1 mm)

Fig. 19 : *Gymnophallus choledocus* sporocyst larva and cercaria

Labratrema minimus (Bucephalus minimus)
IH1: Cockle
IH2: fish, Gobby (*Pomatoschistus sp.*)
DH: fish, European sea bass (*Dicentrarchus labrax*)
Generally low prevalence in cockle, but can reach 50% at Arcachon. In the bay of Saint-Brieuc, prevalence varies from 2 to 20% depending on sites (Montaudouin *et al.*, 2009). Intensive multiplication in hemolymph (blood), gonad or digestive gland of the cockles which dies. Note on the right picture, high concentrations of parasits for only one cockle. Cercariae leave cockle and look actively for a gobby (PH2) to penetrate it by the base of fins or gills (Malek, 2001). These larvae, then, are stored in the fish's liver. When an infested gobby is consumed by a Sea bass, it is infested in turn and the parasite takes its adult form.
.
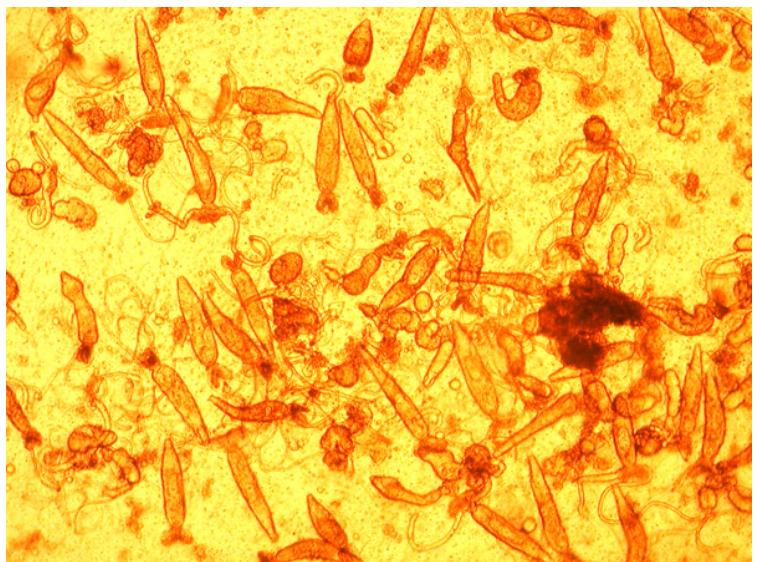
Fig. 20: *Labratrema minimus larvae of 0,2mm with 2 longs tentacles used to adhere to gobby mucus.*

Himasthla ssp

IP1: Hydrobia, a gasteropod (*Hydrobia ulvae*)
IP2: Cockle
DH: a sea bird (gull or European oystercatcher)

High prevalence from 84% to 100% at Arcachon ((Montaudouin et al. 2000); (Montaudouin et al. 2009)) and 100% in the bay of Saint-Brieuc (Montaudoin and al., 2009).
In foot cockle, the parasite makes a cyst (metacercarian stage) to wait, several months if it's necessary, that the cockle is eaten by an European oystercatcher. These cysts do not seem adverse for cockles. Indeed, the parasit's interest is for the cockle to live a long time. It will increase the probability of the parasite being eaten by the DH

Muscle of the foot cocke
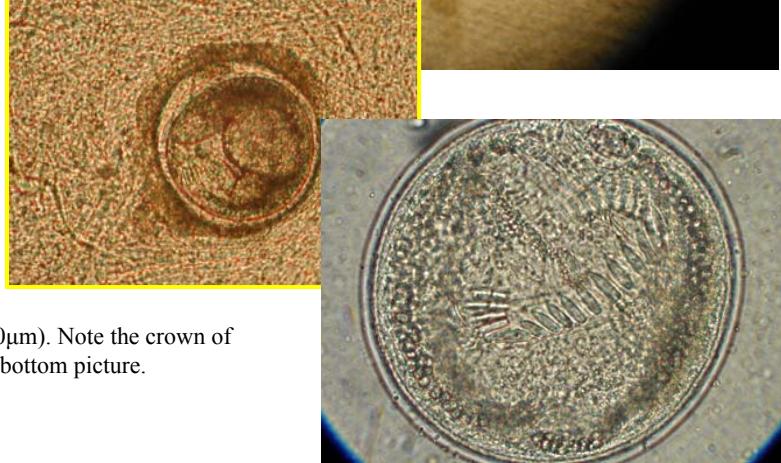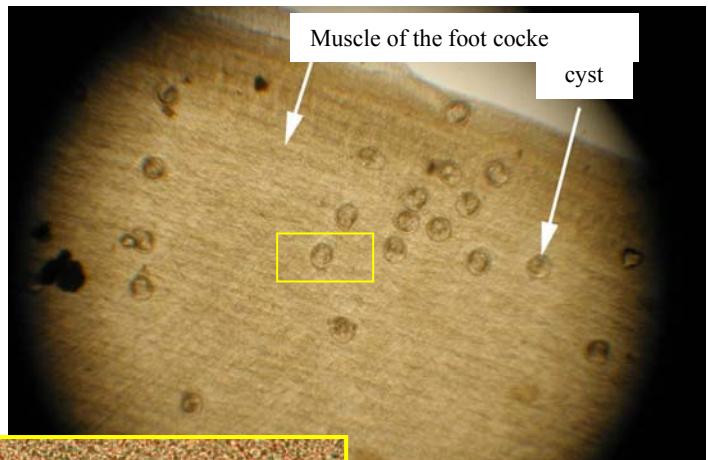
cyst

Fig. 21 : Cysts of *Himasthla* (200µm). Note the crown of thorns on the head on the bottom picture.

Monorchis parvus
IP1: Cockle
IP2: several bivlaves
DH : a marine fish

Low prevalence
Strong multiplication in the form of sporocysts in the cockle. Cercariae, second type of larvae, will leave the cockle to join IH2.

Sporocyst larva (0,5mm) with 4 germinal balls

tail

Oral sucker

Ventral sucker

cercaria (0,1 mm) in sporocyst

Fig. 22 : *Monorchis parvus,* sporocyst larva and cercaria

B - Other parasites found

 – **Turbellarias (free flatworms(not in a parasite stage)**

Paravortex cardii
This small 2mm long flatworm, highly mobile thanks to cilia spread all over the animal. It lives in the intestine of different bivalves including cockle. It's very frequent but rarely in high numbers, and seems harmless.
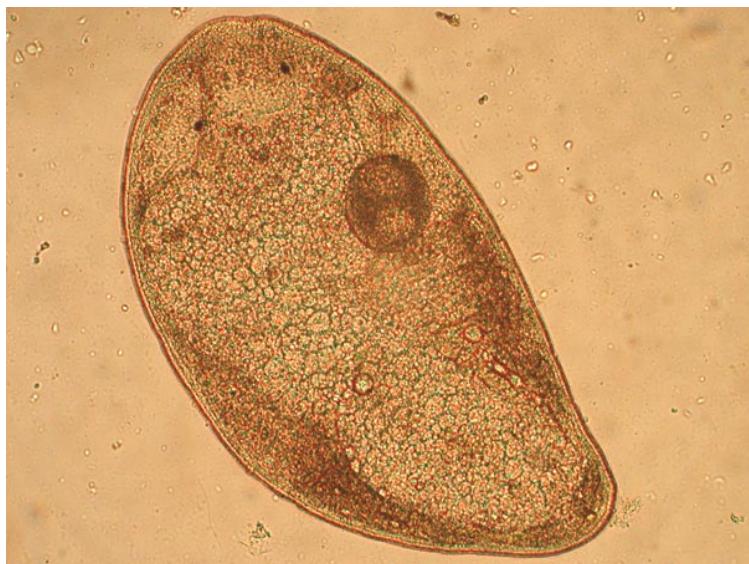
Fig. 23: *Paravortex cardii* (2 mm)

- **Crustacean**

A small elongated crustacean (2mm long) can be found, again in the intestine: *Mytilicola intestinalis*. As its name indicates, it particularly likes the intestine of mussels ("*cola*": which likes; "*mytili*": mussel; "*intestinalis*": intestine). It's also possible to find a closely related species (*Mytilicola orientalis*) in large numbers in farms of Pacific cupped oyster (*Crassostrea gigas*). It lives in an environment rich in food (phytoplancton, organic matter), so it just takes what it needs. In farms, this parasitism can cause a decrease of the growth rate of parasited individuals.
It is regularly found in low numbers in the intestine of cockle. It does not seem to cause damages on cockle populations.

Fig. 24 : *Mytilicola intestinalis* (3 mm) Mytilicolidae cristacean copepode.

17

- Ciliated protozoan

Ciliated protozoans are animals made of only one cell, therefore very small and invisible to the naked eye. The cilia that characterize the phylum of ciliates can be easily observed under the microscope.

Trichodina sp. particularly likes the company of cockles. It lives in water-intake valves near gills and may cling to them. *Trichodina sp.* is found in all the cockles of the bay of Saint-Brieuc, sometimes in large numbers. This species is little known. It seems that it is harmful to weakened young cockles, by drawing the hemolymph of gills, and promotes secondary bacterial infections (Lauchner, 1983).

Fig. 25 : *Trichodina sp* (50 μm)
Long cilias around the animal can be observed.

C - To conclude

Others macroparasites have been found in the cockles of the bay of Saint-Brieuc, for example: *Meiogymnoplallus minutus*. This species is located at the hinge in a vesicule tissue of the host. It is present in large quantities and with a high prevalence. The first intermediate host is the Peppery furrow shell (*Scrobicularia plana*), very common in the bay of Saint-Brieuc. The definitive host can be the European oystercatcher or some anatidae.

The impact of parasitism generally depends on the numbers of parasites present in the host. In scientific literature, several cases of weakening effects are mentioned. Strong mortality can occur (Jonnsson & André, 1992), and sometimes a destruction of gonads which causes the castration of some individuals, and thus decreases the stock of breeding (Boyden, 1972).

When cockle is the first intermediate host, there is an outbreak that causes the death of the host, but with a relatively low prevalence. IH1 is used to multiplicate asexually intensively the parasite and provide a very large number of infective forms that will stay in the second intermediate host.

When cockle is the second intermediate host, it serves to convey parasites and send them to the definitive host. In this case, the virulence of the parasite is low because it must not cause the death of the host, which will cause its own at the same time. There is a low pathogenecity, but a high prevalence, which will increase the probability that the definitive host becomes infested by eating IH2.

We observed in the bay of Saint-Brieuc that the cockles found on the surface of the sediment (ascending cockles) were more infested by cysts of *Himasthala* (Fig. 26). That indicates a nefast effect of the parasite on the weakened animal. Some authors interpret this as a strategy of the parasite. Indeed, it is not by chance if the parasite is in the foot of the cockle. We can suppose that it causes a decrease of its burrowing capacities. It thus becomes more accessible to the bird (definitive host). This phenomenon is called "favorisation" mechanism (Combes, 1995).
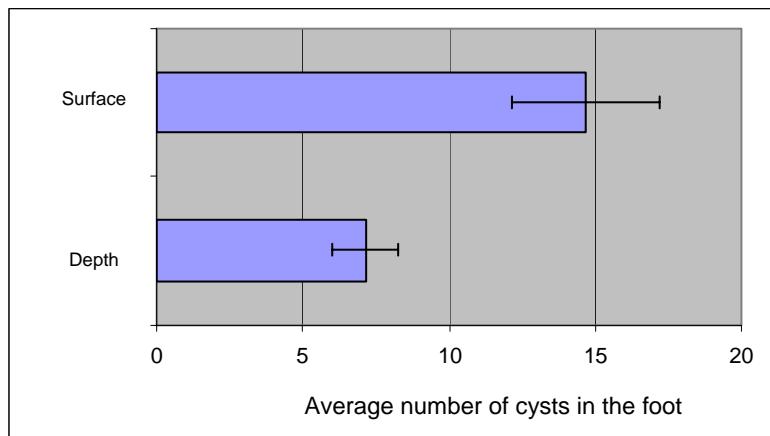
Fig. 26: Average number of cysts in the foot ± standard error (cockle found on the sediment n=35, found in the sediment (n=40), size: around 3cm. U.C.O, June 2003, not published)

Parasitism is not the only factor that can explain the rise of cockles on the sediment surface. The lack of oxygen is the most implicated factor.

We note a lower resistance to thermal stress (heatwave for example) when cockles are infested by *Himasthla spp.* (Lauckner, 1983). Indeed they die more quickly that uninfested ones.

Parasites represent a serious cause of direct mortality (especially the first year), and thus a factor of regulation of populations. It seems as well to make them more sensitive to environmental disturbances (climate, pollution...) or decrease the growth rate (Lauckner, 1983; Jonsson & André, 1992; Wegeberg & Jensen, 2003; Thielges, 2006). Thus, the impact of pollutions could be amplified by an important parasitism.

A second question facing us: Can the parasitic infestation and the induced mortality be considered as a consequence of a weakening of animals caused by ecosytem dysfunctions (pollutions, or disturbance of balances)? Weakened cockles, with immunity deficiency, will be more easily attacked by parasites. Further studies are necessary to attempt to provide some answers to these questions.

Finally, no studies have shown that these parasites could be transmitted to humans and cause disease. Even in the absence of cooking, they are destroyed by the acidity of the stomac and by digestive enzymes.

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