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Asari clam (*Ruditapes philippinarum*) in France: history of an exotic species 1972 – 2015

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Abstract: In 1972, France underwent an oyster (*Crassostrea angulata*) crisis and urgently needed to diversify its aquaculture. Thus, Asari clam (*Ruditapes philippinarum*) was introduced at that time for aquaculture purpose, concomitantly with the introduction of Pacific oyster (*Crassostrea gigas*). All Asari clam adults and spat originated from the same area (Puget Sound, WA, USA). After a promising start and the implementation of a national Research & Development program, Asari clam culture rapidly faced a series of concomitant handicaps: firstly, in spite the fact that cultural practices were optimized and locking points addressed, leasing ground availability was limited during the 1980s' due to certain reluctance from oyster farmers to share their leases and/or diversify their activity; secondly, mortality events in the parks probably due to the spat quality, diseases and/or zootechnical errors and/or predation by triggerfish; and thirdly economical competition with Italian production rapidly increased, exacerbated by the occurrence of neonaturalized Asari clam populations and the resulting professional fishing. Meanwhile, European vs national regulations, concerning minimum legal shell length of clams devoted to the market, were unfavourable to France due to contrasted rules between the Mediterranean Sea and the Atlantic Ocean; eventually, several diseases impacted drastically clam populations. At the end of the 80's in Northern part of Brittany (France), mass mortality occurred due to brown ring disease, later related to a prokaryote (*Vibrio tapetis*). Presently, the French production remains limited to 2 – 3000 metric tons, mainly based upon professional fishing on neonaturalized populations located in two sites (Arcachon bay and Morbihan Gulf). In Arcachon bay, a comprehensive population dynamics study demonstrated the concomitant effects of fishing activity and environmental characteristics on the population dynamics. A management model was developed to assess various scenarios mainly based on conservation measures (*i.e.* fishing area, and/or fishing licences number, and/or fishing period). Implementation of those recommendations has provided some encouraging results. However, Asari clam fitness remains poor: a genetic impoverishment due to population isolation was argued by fishermen, but transplant experiments demonstrated that these bivalves kept their plasticity, at least in terms of growth and condition index. Thus, several environmental factors were investigated as possible key parameters explaining low clam performances. Again, pathologies were pointed out and particularly the high pressure exerted by the protist *Perkinsus* sp. (perkinsosis). Moreover, a new pathology was discovered in 2005 in Arcachon bay, the brown ring disease. Although the etiological factor has not been confirmed, viral origin is suspected. A meta-analysis comparing Asari clam characteristics in Arcachon Bay with the international literature pointed out that their reduced condition index in this bay was likely resulting from combined unfavorable factors (e.g., diseases, trace elements). However, 30% of the condition index variability among sites at the worldwide level was explained by food availability (chlorophyll *a* concentration). A comparative morphometric studies on four populations of the French Atlantic coasts, using conventional shape analysis, also revealed significant relationships between morphometric ratios

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and environmental parameters (chlorophyll *a* concentrations and seawater temperature). Eventually, marine ecologists and state managers as well, must deal with conflictual goals: on one hand Asari clam is an important exploited bivalve in France, on the other hand, the species remains an exotic species which needs careful attention (e.g., European regulations on invasive species).

Key words: *Ruditapes philippinarum,* France, aquaculture, Professional fishing, diseases, environmental stressors

The context of the Asari clam introduction

The decision to introduce Asari (Manila) clam *Ruditapes philippinarum* in France in the 1970's was taken in a particular national context. Firstly, France had a long expertise in shellfish aquaculture since the beginning of the oyster farming in the 1860's. The French shellfish production has been mainly focused on oysters, the native European flat oyster *Ostrea edulis* (1860–1910), the Portuguese oyster *Crassostrea angulata* (1910–1970) and since then the Pacific oyster *C. gigas* (Goulletquer and Héral, 1997). In 1967, oyster farming represented 66% of shell production in France (55,450 t) (FAO, 2014). Thus, State organization (e.g., leasing ground system), infrastructures (e.g., grow out facilities) and technologies (*e.g.* hatcheries) provided favorable conditions to new bivalve species development (Flassch and Leborgne, 1992). Secondly, historical background of French shellfish production, mainly based upon a monoculture approach, therefore showing a weakness when facing disease outbreak, has prompted the State managers to facilitate shellfish diversification. This target was reinforced by severe oyster mortality outbreaks leading to the Portuguese cupped oyster collapse at the beginning of the 1970's (Comps and Bonami, 1977). Moreover, the emergence of Asari clam production in North America since its introduction in 1936 comforted the idea that this bivalve could be a suitable target species considering the wide range of environmental/climatic conditions observed in France.

Asari clam introduction in 1972–1974

Asari clam was introduced between 1972 and 1974 in accordance with 1972 ICES code of practice for the introduction of Non Indigeneous Species (NIS). One consequence was the very little amount of officially imported individuals (all coming from Puget Sound, WA, USA): 500,000 spats, and 1,000 adults (Flassch and Leborgne, 1992) which roughly represented a total biomass of 70 kg. Flassch and Leborgne (1992) suggested that this initial input originated the totality of the European production in 1989 (20,000 t). Today, this strategy provides argument to fishermen that claim that one of the reasons of the actual poor fitness of Asari clam in some parts of France is related to genetic impoverishment. However, two observations mitigate this empiric statement. Firstly, the high level of heterozygoty in French hatcheries (Moraga, 1986; Jeffroy, 2011) and the moderate loss of genetic diversity measured in many European ecosystems (Chiesa *et al.,* 2011; 2014) suggest that unofficial introductions were also carried out in Atlantic and Mediterranean waters. Secondly, transplant experiment between areas showing different environmental characteristics has demonstrated the high growth plasticity of Asari clam: individuals living in adverse situation with poor fitness were able to recover high growth and condition index when transplanted in suitable sites (Dang *et al.,* 2013).

Addressing the technical feasibility and providing advice to shellfish farmers: 1975–1986

The three first years after introduction were mainly devoted to (1) growth performance comparisons with the native species *R. decussatus*, and (2) development and implementation of suitable techniques so as to optimize clam yield. It was clearly demonstrated that the exotic species showed improved performance compared to the European species, therefore prompting the managers to develop a comprehensive Research & Development program focusing on the Asari clam. The first attempts were successfully achieved in Tudy Island, leading to the first production figures: 125 kg and 1500 kg, in 1977 and 1978 respectively (I.F.R.E.MER,, 1988). Several national R & D scientific programs followed those preliminary field trials in Asari clam production, lasting from 1981 to 1986. Even though positive results were recorded concerning growth performances and spat production in hatcheries, they were mitigated by high spatial variability and high mortality rates in some growing sites, especially when performed in tidal flats (compared to ponds) where temperature variation is high and where hypoxia may occur at low tide (Goulletquer, 1989). High mortality rates were also reported in early spring due to reduced food availability and high turbidity rates over the winter time leading to reduced physiological condition. Asari clam production were first reported in 1982 in the aquaculture national statistics to rapidly reach ca. 500 metric t/y after 1985.

The first serious problems arise (1986–1992)

From 1986, Asari clam aquaculture production reached a plateau at a relatively low level, *i.e.* 500 mt/y. Actually, we can almost state that the story of Asari clam in France was compromised during this period of time due to four main reasons.

Firstly, suitable leasing grounds were already occupied by oyster farmers that were not ready to cease them: in the mid 1980's, out of the 212 km^2 of flats devoted to culture, only 0.03 km^2 concerned Asari clam (I.F.R.E.MER, 1988). Meanwhile, this period of time was marked by oyster overstocking, maximum cupped oyster production and a drastically changing market leading to a precocious shellfish industry. Contrasted performances of Asari clams in France did not motivate oyster farmers to diversify their activity with this new product and placed them in a "wait-and-see" strategy (Robert and Deltreil, 1990).

Secondly, Asari clam populations were severely and rapidly impacted by diseases outbreaks. It started in 1986 with the VTP (vibrio of *Tapes philippinarum*) in hatcheries but this disease was rapidly stamped out. The most emblematic pathology emerged in 1987: the brown ring disease (BRD), being likely partly responsible for the clam aquaculture collapse in Northern Brittany, France (Paillard and Maes, 1990, 1994; Paillard, 2004). BRD was characterized by the occurrence of obvious abnormal conchiolin deposit adhering to the inner shell, obstructing valve closure, and leading to overall clam weakening. The aetiological agent was described 3 years later (*Vibrio tapetis*). Rapidly, BRD was also described in Italy (1993), Spain (1993), Ireland (1998), United Kingdom (1998), Norway (2008) likely due to shellfish transfers among European countries. Then, BRD progressively reached other parts of the world in Asia (Park *et al.,* 2006; Paillard *et al.*, 2008; Matsuyama *et al.*, 2010). A herpes-like virus has also been detected in the context of larval mortality in a French hatchery in 1997 (Renault *et al.* 2001). Subsequent molecular works showed that this virus was the same as OsHV-1 infecting *Crassostrea gigas* (Arzul *et al.,* 2001).

Thirdly, shell farmers had to cope with mortality events (in spring and autumn 1992) that affected 2/3 of the parks. Those mortalities were probably due to the spat quality and/or zootechnical errors and/or predation by triggerfish (Auby, 1993).

Finally, French clam aquaculture rapidly underwent severe economic competition with the naturally production, in France (Gulf of Morbihan and Arcachon) but also especially with the Italian products. Rapidly, neonaturalized populations occurred in Italy (Venice lagoon, Sacca di Goro) leading to large professional fishing and an economic competition between aquaculture and commercial fishing. Moreover, European regulation implemented a different capture length for Atlantic and Mediterranean sectors, 35 mm (40 mm from 1998 to 2008) and 25 mm shell length, respectively. This prompted to economic discrepancies with Italy and more generally Mediterranean products because France had to homogenize this parameter for its whole territory and had to select the most restrictive value (35-mm minimum shell length). Eventually, neonaturalized Asari clam populations also occurred in France (e.g. in 1988 in Arcachon Bay) and national commercial fishing production (1,500 t) was already three times the national aquaculture production in 1990. In this context, the clam exchange value dropped from the equivalent of

8.4 €/kg (1120 ¥/kg) to the equivalent of 6.1 €/kg (820 ¥/kg) in 1988 and 1989 respectively – presently the exchange value is ca. 2.5 €/kg (330 ¥/kg).

As a result, from the 12 hatcheries producing clam in 1987, there is still only the SATMAR (Société ATlantique de MARiculture) in France in 2015.

Relative stagnation of the production (1992–2015)

Unfortunately reliable long-term statistics of Asari production are unavailable at the national level (Caill-Milly, 2012), due at least to three main reasons: 1) the precise identification (*R. philippinarum vs. R. decussatus*) is not compulsory for landings; 2) the difficulty in discriminating between aquaculture and harvesting production from different professional status (fishermen, shellfish farmers who may present a fishing activity); as well as 3) the reform of the French system in charge of commercial catch statistic that occurred in 2008. However, over the last years, we can consider that 50% of the production is provided by aquaculture and the remaining 50% by commercial fishing to reach an overall yearly production of ca. 2,500–3,500 t (Agreste, 2015). Most of the aquaculture production is economically sustainable by private companies having a full control over the clam life cycle – from hatchery production to marketable size. In France, this production is rather disseminated into a limited number of production units, e.g. Chausey Islands (Northern Brittany) is a leading French rearing area with 120–210 t/y (Toupoint *et al.*, 2008; Ifremer 2015). With regard to commercial fishing, 80% of the production is carried out from two areas, Arcachon bay (ca. 500 t) (Southwest Atlantic coastline) and Morbihan Gulf (ca. 300 t) (Southern Brittany)– Those both production areas benefite from regular stock assessments (started in 2000 for Arcachon (Sanchez *et al.*, 2014), in 2001 for Morbihan Gulf (D'Hardivillé *et al.*, 2014)).

Besides the necessity to monitor an exploited site, stock assessment is a relevant tool to reinforce a management strategy for a sustainable development. Based on stock biomass and shell length distribution, but also on population dynamics parameters like growth performance and natural mortality rates (Dang *et al.*, 2010b), a management model for Asari clam was proposed and developed in the case of Arcachon bay (Bald *et al.*, 2009). The model allows observing the trajectory of Asari clam biomass along years according to various conservation measures parameters (i.e., number of fishing licences, no-take zone superficies, fishing days) and environmental conditions (i.e., sea temperature, trophic resources). An host-pathogen-environment numerical model has been also developed for BRD; simulations using 1℃ and 2℃ increases in temperature showed that climate warming might favor the spread of BRD in France but also in south Atlantic and Mediterranean countries (Paillard *et al.*, 2014).

In France, part of the production stagnation is thought to be related to the limited Asari clams' fitness in several sites, possible making this species more sensitive to infectious diseases. Besides the BRD previously cited, several studies demonstrated that Asari clams have been severely impacted by perkinsosis, a pathology related to high infection by the protozoan *Perkinsus olseni* (Lassalle *et al.*, 2007; Dang *et al.*, 2010a). Recently, *P. chesapeaki* was also recorded in French clam populations (Arzul *et al.*, 2012). *Perkinsus olseni* effects on Asari clams remain poorly documented (Soudant *et al.*, 2013). At sublethal level ($<10^5$ cells/g dry weight of gill), parasite abundance can explain up to 26% of the variability in Asari clam growth in the case of Arcachon Bay population (Dang *et al.*, 2013). Moreover, Asari clams collected at the sediment surface (abnormal position) in this same bay exhibited a 3-fold higher *P. olseni* abundance than individuals buried in the sediment (i.e. normal position) and 27% lower condition index (Binias *et al.*, 2014). Finally, Arcachon bay is also impacted by another endemic disease, the Brown Muscle Disease, first reported in 2005 (Dang *et al.*, 2008; Dang and de Montaudouin, 2009; Dang *et al.*, 2009a; Dang *et al.*, 2009b). This disease affects the posterior adductor muscle to eventually drive the clam to the sediment surface where it rapidly dies. On-going research suggests a viral aetiology (Dang *et al.*, 2009b; Binias, 2013).

A meta-analysis to understand poor Asari clam fitness

Arcachon Bay is the leading area for Asari clam production based upon commercial fishing although it provides clams of poor condition. In 2014, a meta-analysis based on 41 publications originating from 10 countries, compared Asari clam parameters and environmental characteristics worldwide (de Montaudouin *et al.,* 2016). This large-scale study confirmed that Asari clam condition index (CI=flesh dry weight/shell weight) in Arcachon bay was significantly lower (/2) than in all other rearing areas. Chl *a* concentration in the seawater contributed to 30% of the CI variability, Arcachon bay appearing as an oligo/mesotrophic bay. Considering that morphological characters can be used as proxy of nutritional condition (Watanabe and Katayama, 2010), such role of environmental conditions was also highlighted by Caill-Milly *et al.* (2014). A comparative morphometric studies on four populations of the French Atlantic coasts revealed significant relationships between morphometric ratios (integrating weight density indicators) and environmental parameters (chlorophyll *a* concentrations, seawater temperature). Besides, Arcachon bay displayed higher values for *Perkinsus* abundance and prevalence, and chromium and arsenic flesh concentrations in the flesh. Finally, this is the only ecosystem where Asari clams undergo brown muscle disease.

Conclusion: Asari clam is also an exotic species

Although a distribution overlay with the native clam *R. decussatus* may occur, no study in France claims that Asari clam could be a plague as a direct competitor for other species (Laruelle, 1999) (although there is a suspicion that the parasite *Perkinsus olseni* could have been brought with it). In contrast, Asari clam populations have been a resource for seabird wintering in the English Channel – sustaining bird survival rate (Caldow *et al.,* 2007). Few studies have pointed out that the clam aquaculture may indirectly alter environment through intensive harvesting practices (Toupoint *et al.,* 2008). Since the Asari clam was introduced during the 1970s, there is no specific requirements in response to the 2007 European regulation on using exotics in aquaculture. Therefore, Asari clam is listed in the Annex IV of the Council Regulation (Non-native Species in Aquaculture Risk Assessment Scheme). Meanwhile, risk assessment strategy is considered as a suitable tool to deal with exotic/invasive species management, and prevent side effects from exotics' introduction. A preliminary study has used the Asari clam as a case study at the European level to test the risk assessment Excel-based application AS-ISK[i] (Invertebrate Invasiveness Screening Kit) (Copp *et al.,* 2014a) and assess the Annex IV suitability. With the Asari clam, the overall risk is medium with a mark of 2.1 out of 4. When focusing on four assessment topics which are 1) risk of introduction in unintended locations, 2) risk of establishment, 3) risk of dispersal, and 4) risk of environmental and socio-economic impact (Copp *et al.,* 2014b), marks are 3.0, 1.9, 2.0 and 1.4, respectively. This represents a first estimate of risk – not neutral in spite of the Annex IV – associated to the species transfer to additional countries.

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