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The long-term decline of the *Chamelea gallina* L. (Bivalvia: Veneridae) clam fishery in the Adriatic Sea: is a synthesis possible?

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Since the early 1970s a comparatively large clam fishery based on hydraulic dredgers has been developing, though later declining, along the Italian coast of the Adriatic Sea (Central Mediterranean). In the late 1970s the fishery yielded 80,000-100,000 metric tons per year (at least according to the best available estimates, based on confidential interviews with fishermen, fish retailers as well as examination of trade sheets) but later progressively decreased in most recent years to one sixth of the previous level.

In Italy it was the first fishery to be controlled through licences whose number had been set at the national level to keep the fleet and the fishing effort nearly unchanged, but the number of authorised vessels actually increased during the 1980s and technical improvements on the fishing gear allowed the boats to sweep greater ground areas per unit time. This explains why various measures were sought to reduce the fishing pressure on clam beds (such as withdrawal of vessels, imposition of closed seasons, larger open spaces in the sieves), and a limited reduction of the fleet was pursued in the late 1990s after large mortality events were recorded during late summer-early autumn of 1996.

At the same time the influence of unknown environmental factors was occasionally assumed for the fishery, and the greater abundance of clam beds as well as other fish and shellfish resources in the Adriatic in comparison with other Mediterranean areas was tied to the large freshwater inflow from the Po and other rivers.

Because of such discrepancies in the literature we reviewed all available papers (or nearly so) on the Adriatic clam fishery (including national laws, reports on the eutrophication of the coastal areas of NE Italy, and others) in order to understand the role of environmental factors (i.e. unrelated to the fishing effort) vs. fishing pressure for determining causes of the clam decline. Although the low qualitative level of many data makes it difficult to disentangle the decline's causes, indirect clues show that the progressive reduction of freshwater flow into the Adriatic Sea, as well as of its phosphate content, have been playing a relevant role in the matter.

Key words: *Chamelea gallina*, bivalves, Po, phytoplankton, productivity

INTRODUCTION

Along the Italian coast of the Adriatic Sea the *Chamelea gallina* L. (=*Venus gallina* L.=*Chione gallina* Deshayes) venerid dweller of coastal areas is mainly found in the fine well-sorted sand biocenosis described by PÉRÈS & PICARD (1964) and is targeted by a large fleet operating hydraulic blade dredges at 3-12 m depths.*

The target species is gonocorist, the sex ratio is 1:1 and the spawning season approximately spans between April and October with 1-2 peak(s) (FROGLIA, 1975a, b; CASALI, 1984; VALLI *et al.,* 1985; KELLER *et al.,* 2002). The earliest mature individuals are 13-15 mm (MARANO *et al.,* 1982; CORDISCO *et al.,* 2005), though full maturity is reached when clams are 20-25 mm and about two years old, while 25 mm is the minimum commercial size allowed. Adults and juveniles filter phytoplankton as well as other seston particles, and cease growing at water temperatures below 10°C (FROGLIA, 1975a).

In its first years the fishery that is the subject of this work recorded high fishing yields, but they soon started declining at a steady rate in spite of various measures adopted to limit the fishing effort (indeed this parameter seems not have much changed during the last two decades, see farther) and such a negative trend progressively reduced the commercial output to approximately one sixth of that from earliest times.

In order to obtain useful information for the fishery management surveys of the clam beds were carried out in the 1984-2001 period and studies on the reproduction of the targeted species in the 1970s, whereas investigations on the months of presence of eggs and larvae and the direct damage induced by the dredges on clam adults and juveniles were performed at different times. Nevertheless, causes of the decline in clam production remain obscure and negative impacts both by the high exploitation rate (FROGLIA, 1989; MORELLO *et al.,* 2005a) and unknown environmental factors (MINISTERO RISORSE AGRICOLE ALIMENTARI FORESTALI, 1994; FROGLIA, 2000) have been assumed. Moreover, the possible impact on *C. gallina* eggs and larvae by the large phytoplanktonic aggregates recorded in the Adriatic during the summer of 1989 was tentatively invoked to explain an exceptionally low level of landings in 1991 (STACHOWITZ *et al.,* 1990; DEL PIERO *et al.,* 1998; FROGLIA, 2000).

In spite of such uncertainties, national and local authorities pursued a fairly serious reduction of the fishing fleet and slight modifications of the dredge sorting grids were suggested by several authors to reduce the fraction of undersized clams in the catches (FROGLIA, 1989; MORELLO *et al.,* 2005a). However, the previously mentioned assumptions about the impact of environmental factors on clam beds strongly undermine the rationale of such measures, thus clearer notions are required on factors affecting the numbers of adult clams yearly recruited to the fishery. We therefore reviewed the literature available on the matter to understand the relevance of environmental factors vs. the fishing effort.

MATERIAL

Because of the extent of topics dealt with, the resulting information are herewith summarised in distinct subparagraphs.

Localization of beds-and harvesting operations at sea

The sturdy, round-shaped molluscan bivalve *C. gallina* is an infaunal dominant dweller of sandy coastal bottoms (3-12 m depths, in the western Adriatic clam beds which are mainly located 1,000-4,000 m from the coastline; CASALI, 1984) hosting the "biocoenosis of fine well-sorted sands" (SFBC) as described by PÉRÈS & PICARD (1964) for the Mediterranean, and previously recorded by VATOVA (1949) as *Chione gallina* zoocoenosis during his studies on the benthos of the northern Adriatic and in several areas of the North Sea (where the similar species *Venus striatula* = *Chamelea striatula* Da

* In this paper all unpublished technical reports are quoted as we received them from the authors as personal information, but they are not listed among the references as not easily traced in the Web. Copies of these reports are available from the corresponding author.

Costa lives, although the zoological status of the two sister forms is unclear; ANSELL, 1961; SPADA & MALDONADO-QUILES, 1974; BACKELIAU *et al.,* 1994; HAUTON *et al.,* 2003). Measurements of redox potential in sandy grounds in coastal areas off Venice (BARILLARI *et al.,* 1979) show that areas with clams are well oxygenated and contain little organic matter since the redox potential of the sediment was above 50 mV, thus implying that the oxidized stratum is relatively thick.

In the northern Adriatic Sea the phytoplankton productivity is greatly enhanced above the low levels of other areas of the Mediterranean Sea by large river inflows (on average 2,500 m^3 s^{-1}, after ARTEGIANI, 1984, during the 1923-1968 period; whilst the mean outflow of the Po river alone was close to 1,500 m^3 s^{-1} in 1917-2004; REGIONE EMILIA ROMAGNA, 1997; DEGOBBIS *et al*., 2000; MONTANARI & PINARDI, 2006; PUGNETTI *et al*., 2008) and large coastal sandy grounds are available. Thus *C. gallina* beds thrived and still do nowadays, although to a lesser extent, and this resource has been feeding the fishery examined herein.

The commercial dredges used to harvest *C. gallina* comprise a 0.6-0.9 t and 2.4-3.0 m wide iron cage which is lowered at sea from the bow and backward towed by the boat, in the past (until the late 1980s) thanks to a winch secured to a big anchor (usually set 200-300 m apart) and later thanks to the inverted propeller so that fishing speeds nearly doubled to the present 1-2 knots (FROGLIA & BOLOGNINI, 1987; MORELLO *et al*., 2005a). Two side sledge runners prevent the dredge from digging into the substratum more than 4-6 cm depth.

The cage is connected to a hose which serves to eject water under pressure (1.2-2.5 bar) from the nozzles to suspend sand ahead of and within the cage, easing the advancement of the gear. A first selection on benthic/infaunal animals is made through parallel bars, 11 mm apart, located on the lower cage wall, thus smaller organisms are soon returned to the sediment whereas those of greater size are further sorted once the dredge is retrieved and its output poured into a mechanical sieve mounted on the deck to separate clams equal to or above the 25 mm minimum landing size. Sieve discards are soon returned to the sea through an outboard chute (FROGLIA & BOLOGNINI, 1987; MORELLO *et al.,* 2005a).

As a rule, tows cover distances between 300 and 1000 metres (often longer tows aiming to explore new areas; MORELLO *et al.,* 2005a) and are carried out in daylight and fairly calm seas (up to a maximum of sea state 2 on the Douglas scale).

Short-term impact of the hydraulic dredges

Initially the actual and potential impacts of dredgers to the marine environment were minimised (FROGLIA & BOLOGNINI, 1987; SCIENTIFIC MARINE RESEARCH COMMITTEE, Statement quoted by FERRETTI, 1989) because few clam shells resulted in being damaged, the exploited grounds do not host submarine meadows or other relevant epibenthic communities, many discarded animals were still alive when returned to the sea and often belonged to widely spread species (or tentatively supposed so). Moreover, sampling by submerged pump on the benthic fauna of a few fished and un-fished sites in the maritime district of Manfredonia (southern Adriatic) showed in summer-autumn 1988 that the number of species in the former cluster returned to the pristine level (or rather so) 30-60 days after the dredger's impact (VACCARELLA *et al*., 1994). Ultimately, the swift fall of the suspended sediment at the original sites within several dozen seconds or a few minutes (MEDCOFF & CADDY, 1971; MEYER *et al*., 1981) probably also stimulated such over-optimistic thought.

Other trials by submerged pump performed by BRAMBATI & FONTOLAN (1990) to simulate the effect of dredgers on shallow sand grounds off Venice showed that 0.2% of the suspended material moved slightly away from the original location in the presence of a given current regime, and the just re-deposited sand had a considerably lower density than pre-resuspension sediment. Other authors also reported decreases of pelite content in sediments from dredged areas (MEYER *et al*., 1981; GIOVANARDI *et al*., 1994; HAUTON *et al.,* 2003). Moreover, stated that strong jets used to dislodge clams increase the water content of sand so that it appears partly "liquefied" though the sediment structure returned to the previous state within three months or less.

On average *C. gallina* makes up, by weight, 95% of the marketable catches (FROGLIA, 2000) yet discards are not negligible. According to surveys carried out in the fishing districts of Ancona and San Benedetto del Tronto (central Adriatic) rejects on average were 45% of the fished biomass. In grounds with purer sand undersized clams made up the bulk of rejects whereas the role of other species, notably other bivalves and polychaetes, increased at sites with more mixed sand-silt sediment (MORELLO *et al.*, 2005a). Concomitant sampling by non-commercial gears (a submerged pump as well as a hydraulic dredge whose cage had been slightly modified to retain smaller animals than usual) showed that the abundance of few invertebrates had increased, or conversely decreased, after distinct two-month and six-month closures of the fishery (MORELLO *et al.,* 2005b, 2006a). However, impacts due to hydraulic dredging could be demonstrated only for the gathered cluster of Gastropods and Bivalves but not for the entire macrobenthic community sampled on 1 mm sieves by the submerged suction pump as well as for the polychaetes, the crustaceans, the detritivore and suspensivore clusters, and such findings were tentatively attributed to the background high disturbance induced both by natural factors and previous fishing over the shallow grounds (FROGLIA, 2000; MORELLO *et al.,* 2005b).

Selectivity and fishing efficiency of the dredges

Tests by the mechanical sieves used on the vessel's deck to sort the clams into distinct size clusters showed (FROGLIA & GRAMITTO, 1981) that the 25% and 75% percentiles of the retained *C. gallina* were at 21.5 mm and 24.5 mm when the grid parallel bars were slightly less than 11 mm apart, and the same limits changed to 19.5 mm and 33.0 mm once the space between consecutive bars had been increased by one mm. As the sieving grids used for the tests were like those mounted on the dredgers' submerged cages, these data allowed for the first time to evaluate, to some extent, the selectivity of the gear at sea.

Later data showed that along a short track on sand a commercial dredge mainly caught 21-29 mm *C. gallina* clams (individuals being measured along their anatomical anterior-posterior axis) and within this size range nearly 90% of the specimens (initial average density: approx. 70 clams m^{-2}) were retained. Such findings differ from those of where 55%-65% of clams $\geq$ 23 mm were retained at four sites fished at somewhat higher speeds (as the fishing gear was towed using the inverted propeller) within the maritime district of Ancona (HAUTON *et al.*, 2002). Nevertheless, an average catching efficiency of 80%-100% was assumed for the local hydraulic dredges when they are trawled at low/moderate speeds. Similarly, numerical fishing efficiencies close to 90% for commercial-sized specimens were reported for hydraulic dredging on *Spisula solidissima* (Dillwyn), *Arctica islandica* (L.) and *Spisula solida* (L.) clams (MEDCOFF & CADDY, 1971; MEYER *et al.*, 1981; GASPAR *et al.,* 2003).

In silty sand grounds fairly high fractions of small clams are often retained because water jets cannot efficiently remove the sediment, and in scientific surveys carried out during the 1984-1997 period in the maritime district of Ravenna (where most *C. gallina* grounds contains silt coming from the nearby Po river outflow; CESCON & ROSSI, 1971), medians of 18-24 mm were mainly recorded for the sampled clams and an exceptional low value of 12.9 mm was obtained during the 1987 survey (PAOLINI *et al.,* 1998). It is worth noting, however, that in most commercial grounds the dredge selection curve at sea is probably very close to that calculated for mechanical sieves sorting the fished clams, as demonstrated by the observation that in 1992 Italian maritime authorities imposed 12 mm grids for the submerged iron cages but that rule was annulled one year later because of the fishermens' strong opposition (MINISTERO MARINA MERCANTILE, 1992, 1993). Anyway, the problem of stickier mixed sediments has been partly solved by adopting stronger water jets (and also heavier iron cages to adhere to the bottom; GIOVANARDI *et al.,* 1994; DA ROS *et al.,* 2003; MORELLO *et al.,* 2005a).

Shaking of clams in the dredges and mechanical sieves can damage their shells, but the fraction of specimens seriously affected does not exceed 5% (GIOVANARDI *et al.*, 1994) and the impact resulting in higher mortality is also presumptively low (MARRS *et al.*, 2002). MOSCHINO *et al.* (2003) report, however, that on average 18.5%-28.5% of the undersized *C. gallina* specimens caught at two sites were damaged, but almost all of them probably had been hit at a very low level as all samples of dredged clams were given mean "impact scores" (reckoned according to a visual scale developed by the authors) either close to the controls or such that they had one or both shell(s) slightly scratched. Indeed damage of such kind was supposed be almost harmless for the *C. striatula* specimens caught in low numbers by commercial dredges targeting razor clams in NW Britain (HAUTON *et al.*, 2003). In their paper MOSCHINO *et al.,* 2003 also state that clams smaller than 17 mm were less damaged, although data are therein pooled for all of the specimens.

Indirect mortality, physiological stress and other effects induced by commercial dredging on clams and the coexisting benthic macrofauna

Because of the decreasing *C. gallina* catches over the years (see farther) great attention has been paid to the potential role of the macrofaunal predation and how fishing operations could impact on such a phenomenon. Aquarium observations show that 50% of 20-25 mm rejected clams dig in the sand within approximately two hours, both at 10° and 20°C water temperatures, and the fraction of clams still exposed after 4 hours range between 17%-30% in distinct trials (MORELLO *et al.*, 2006b). Comparison with burial times of specimens from other nine Gastropods or Bivalves indicates that the second slowest species is the Arcid *Anadara inaequivalvis* (Bruguière), with half-times of nearly 20 minutes; thus *C. gallina* specimens probably react very slowly to dislodgement and exposure on the sediment surface.

Because of their slow reaction to exposure, the rejected or dislodged clams could be actively predated by the larger animals, and underwater visual inspections of dredged paths actually reveal that fishes and invertebrate predators start gathering within a few minutes (GIOVANARDI *et al.*, 1994; CHICHARO *et al.,* 2002), and crowding progressively increases (MEDCOFF & CADDY, 1971; GIOVANARDI *et al.*, 1994) although in most cases disappears within several hours or one day (MEYER *et al.,* 1981; JENKINS *et al.*, 2004).

On the contrary, MOSCHINO *et al.* (2003) state that they found low/moderate densities of predators after their fishing trials off Venice and maybe such a discrepancy is explained by the low level of clam banks in the area during that period, since MEYER *et al.* (1981) found that exceptionally high densities of fished *S. solidissima* specimens (on average 1,000 for each square metre) attracted concentrations of various decapod crustaceans and small teleosts up to 10-30 times the background level.

Naticid gastropods are known to actively prey on molluscan bivalves (GEORGE, 1965; MASSÉ, 1971c, d) and FROGLIA *(*2008) found that in the central Adriatic *Neverita josephinia* Risso adults mainly feed on 14-25 mm *C. gallina* specimens and, in samples collected with hydraulic dredges partly modified to catch more small bivalves, approximately 4,150 drilled shells were found together with 21,000 living clams. Thus the mortality induced by predators was high although not precisely assessed (it should be based on the proportion of drilled and intact dead shells, (GEORGE, 1965), as the number of shells found on the marine bottom depends on unknown rates at which they are therein laid and degraded, and both processes probably do not differ in the two mentioned shell pools). From the same samples it resulted that *Astropecten jonstoni* (Delle Chiaje) and *Astropecten irregularis* (Pennant) are not rare in the sandy shallow areas hosting clam beds (up to 11-12 individuals in samples gathered by the modified hydraulic dredged over 40 m^2, but usually densities were much lower) but both species feed on small prey (3-6-mm for clams) and the former sea stars prefer mainly benthic species typical of silty grounds.

It is reasonable to assume that the 18-24 mm *C. gallina* escape from most of the invertebrate predators because other Echinoderms such

Ophiura texturata Lamarck and *Echinocardium cordatum* (Pennant) catch bivalve postlarvae or juveniles not larger than 3-4 mm (CHRISTENSEN, 1962; MASSÉ, 1971b, d). With respect to decapod crustaceans, we learn from some experiments on *Carcinus maenas* (L.) predation on the sturdy *Tapes philippinarum* (Adams & Reeve) bivalve that the killing efficiency of 30-45 mm crabs is strictly correlated with the clam size (reported data show that single crabs which had been kept for two weeks, during the warm season, in fine-meshed bags each containing 15 clams of a given size range killed, on average, 10% and 30% of their 18-23 and 25-33 mm preys, respectively; GROSHOLZ *et al.,* 2003) and we may therefore assume that the small and medium-sized crustaceans living in the dredged grounds (see partial list in MORELLO *et al.*, 2005a) do not seriously harm the slightly undersized *C. gallina* (say 16-25 mm) routinely caught and discarded during fishing operations.

Only Naticids and Teleosts efficiently prey on *C. gallina* of size greater than 16 mm and other larger coastal bivalves (GEORGE, 1965; MASSÉ, 1971c; FROGLIA, 2008). CHICARO *et al.* (2002) found during their underwater observations that the sturdy 20-25 mm *Spisula solida* (L.) discarded by artisanal hand dredges in some areas of SE Portugal soon attracted sea stars and crustaceans, but they came to the conclusion that fish and cephalopods were the main zoological clusters preying on clams. Similarly, *N. josephinia* severely impacts commercial clam beds, as previously shown, and indeed the abundance of adults from this species was monitored in the maritime district of S. Benedetto del Tronto (central Adriatic) to explain the local scarcity of clam exploitable resources.

The small clams which are not retained by the hydraulic dredges (at least in sandy grounds because the fishing gear is much less selective in the presence of even low silt levels) are perhaps also impacted by the fishing operations because the strong water jets can help the predators to trace them. In spite of the absence of appropriate data, reports by MORELLO *et al.,* (2005a, 2006a) that the abundances of several invertebrates such *Diogenes pugilator* (Roux) as well as the sand stars *Astropecten spp*. increased at sites that had been left undisturbed for two months before being swept again, and conversely decreased at the same sites both during the fishing season and after a six-month fishery closure, may imply that their predation is not negligible for clams and other bivalves as well as that fishing operations curb, to some extent, the abundance of those predators.

Besides altering the burial behaviour of clams, dredging operations induce biochemical and physiological changes in response to the environmental stress, as the ATP and ADP content of foot tissues decreased compared to controls in nearly 26 mm fished clams, and the fall of phosphate compounds were sharper in specimens caught by high-pressure gears (DA ROS *et al.*, 2003). Moreover, DEL PIERO & FORNAROLI (1998) found anomalies in their samples with respect to the general rule that clams of a given size weigh less at greater depths and all of this was tentatively attributed to negative effects of dredging on the growth of the rejected specimens. Similarly, FROGLIA (1974) found that the shells of 2-3 mm *C. gallina* are very fragile and therefore assumed they would be damaged by the hydraulic dredgers and suggested the fishery needed to be closed in summer for at least one month.

Finally, MORELLO *et al.* (2005b) found that at a few sites sustaining an exceptionally high fishing pressure (being swept by dredgers up to 20 times a year; MORELLO *et al.,* 2005a) infaunal samples obtained by submerged pump and filtration on 1 mm sieve contained more polychaetes than bivalve biomass, in spite of the high sand content, and such an observation was attributed to the higher resilience of the short-lived worms in the disturbed environment.

Evolution of the fishing fleet and effort on clams during the last 35 years

The first Adriatic hydraulic dredges came into service in the early 1970s and within a few years outnumbered the traditional hand-manoeuvred gears (as pictured in GAUDENZI, 2008) because catches and economic yields were much

Table 1. Evolution and distribution of the Italian fleet of hydraulic dredgers along the Italian coast of the Adriatic Sea

	No. authorised or active hydraulic dredgers							
Maritime districts	[1974] [A]	[1979] [A]	[1985] [A]	[1987] [B]	[1993] [C]	[1997] [D]	[1998] [E]	[2002] [F]
Monfalcone	5	m.d.	38	38	m.d.	88	42	17+25*
Venice	12	m.d.	65	65	m.d.	88	96	70+25*
Chioggia	66	m.d.	91	91	m.d.	95	74	57+15*
Ravenna	2	m.d.	15	15 [I]	m.d.	18	18	18
Rimini					m.d.	36	36	36
Pesaro	96	m.d.	94	94	m.d.	65	65	65
Ancona	20	m.d.	22	22	m.d.	73	73	73+25**
San Benedetto of Tronto	58	m.d.	77	77	m.d.	83	83	58**
Pescara	75	m.d.	128	148 [L]	m.d.	139	102	98
Termoli					m.d.	11	10	10
Manfredonia	49	m.d.	64	65 [M]	m.d.	67	56	50
Molfetta	0	m.d.	13	15 [M]	m.d.	12	10	8
TOTAL ADRIATIC	383 §	560	607	630	778	775	665	585+65*

m.d. missing date
A After Froglia, 1989;
B After Froglia & Bolognini, 1987,
C After Irepa, 1995;
D After Ministero Politiche Agricole Forestali, 1997;
E After Ministero Politiche Agricole, 1998;
F After Ministero Politiche Agricole Forestali, 2000;
I After Piccinetti, 1988;
L After D'Amico, 1988;
M After Vaccarella *et al.*, 1988;
* No. boats authorised to catch only *Callista chione* (L.);
** 25 dredgers authorised to move from the maritime district of San Benedetto of Tronto to that of Ancona;
§ After Froglia, 1989, 240 boats used traditional small dredges equipped with water pumps and 143 boats the large fishing iron cages still in use nowadys;

higher. Initially, most fishermen simply added a water pump to slightly enlarged versions (1.6-2.0 m wide) of the traditional dredges but such an "intermediate solution" was soon abandoned for the larger gears still in use nowadays. In turn, this implied more powerful engines and larger boats (FROGLIA, 1975b, 1989).

In 1974 the hydraulic clam dredges numbered 383 (of which 240 were modified traditional dredges) along the entire Italian Adriatic coast and ten years later they had increased in number to 607 in the same area (Table 1). Dredgers peaked at 778 in 1993 and then the fleet started decreasing (especially after the unexplained massive mortality recorded in clam beds in late summer – early autumn of 1996 (ANONYMOUS, 1997; CESCHIA & GIORGETTI, 1998; DEL PIERO *et al.,* 1998). Within the EU-funded reduction plans, fishing capacity dropped to 665 in 1998 and 585 (plus 65 boats authorised to catch and sell *Callista chione* L. only) in 2002, to subsequently remain nearly unchanged (MINISTERO POLITICHE AGRICOLE, 1998; IREPA, 2006). It should be noted that the fleet reduction greatly affected the maritime districts of Monfalcone and Pescara where a severe scarcity of clams had been recorded for years (see farther). Thus many authorised boats of both areas actually operated at low activity levels, or even fished with hooks and fixed nets, as is known for the Manfredonia maritime district (MARANO *et al.,* 1987; IREPA 2003) though this was probably also true for the district of Monfalcone because the local fleet had disproportionately grown (Table 1).

In the late 1980s authorised vessels started towing the dredges by inverted propellers so that their operational speed approximately doubled as stated above (up to 2.0-2.2 knots; MORELLO *et al*., 2005a) although more severe limits to the amount of clams to be landed were progressively imposed, from 2.5 in 1979 down to 0.6 metric ton(s) per day and boat in 1992 (MINISTERO MARINA MERCANTILE, 1979, 1985, 1992). Moreover, the creation, since 1995, of consortia among shell fishermen (MINISTERO POLITICHE AGRICOLE FORESTALI, 1995) allowed governance of the fishery on a local scale, thus making law enforcement more effective. Indeed, data reported on the daily clam landings in the important maritime district of Chioggia between August 1998 and July 2000 confirm that on average boats did not surpass the 0.6 ton limit, and in winter their output was much lower (about 60%) because clams stay deeper in sand and are less easily caught (DEL PIERO, 1988; FROGLIA, 2000). Similarly, the good correlation between daily quotas and landings was confirmed by data reported for the district of Ancona and Rimini.

For Ancona area we have detailed information by MORELLO *et al.* (2005a) on the fishing pressure exerted from October 2000-July 2001 (a period that was then followed by fishery closure during August-September 2001, thus the report actually concerns an entire year) thanks to continuous monitoring of some dredgers at sea by electronic position recording units (connected with the vessel's navigation system). In this study the entire 2-12 km coastal strip (the total area of which is 314 km^2) was partitioned into 50x50 m surface units (or "pixels") to count how many times they were occupied during the sampled fishing days. On the whole 1,657 fishing days were monitored (i.e. about 20% of time spent at sea by the entire fleet during the 9-month study) and data showed that the boats mainly operated over a total area of 252 km^2, the "pixels" of which were on average fished 4.87 times. If these data are extended to the entire fleet we find that on average the dredgers approximately entered those pixels 25 times during the study to catch clams (approximately 35 times if the less frequently explored sub-areas are excluded and the analysis is restricted to 155 km^2), and a few of them up to 120-140 times.

The distribution of clams is fairly regular within each 50x50 m area unit (MARRS *et al*., 2002) and dredgers in most cases simply go straight through each "pixel" because of its comparatively small area (the vessels spend about 1 minute to go 50 m at the usual 2-knot towing speed), they therefore assigned a 150 m^2 (i.e. 3 x 50 m, since the hydraulic clam dredges are 3m wide) swept ground area to each "fishing track" passing through the pixels, we come to the conclusion that during the study the district's 75 authorised vessels had swept 380 km^2 on the whole and therefore the total area with clams at densities of commercial interest (densities $\geq$ 5 kg per 1000 m^2 of clams not smaller than 25 mm), estimated at 188 km^2 in a scientific survey carried out in September 2000 during the fishery's annual closed season, had been exploited approximately twice (MORELLO *et al*., 2005a) and 2.45 times the more relevant 155 km^2 sub-area. The grounds of a few "recruitment hotspots" resulted in being swept up to 20 times each year as mentioned before (MORELLO *et al*., 2005a).

All of those data demonstrate how the fishing pressure on clam resources is high for the Ancona area although comparison with estimates by FROGLIA (1989) shows that the situation was not so different in the mid-1980s, when the hydraulic dredges were towed by the anchor at lower speeds, since he calculated by a different approach (based on available information about the number of the authorised vessels, average days at sea and fishing hours per day) that the Adriatic areas with commercially exploitable clam beds (i.e. adults at densities beyond 12.5 kg per 1000 m^2 at that time) were swept twice each year. Regarding the district of Ancona it is also interesting to see that the report (MARRS *et al*., 2002) shows that many more days were spent at sea in winter while the fishing effort sharply decreased in spring and early summer 2001, probably because mass mortality events had often been recorded in the area during the warm months.

With respect to other maritime districts it is relevant to note that the imposition of local lower daily quotas and repeated records of low activity levels for the vessels authorised to catch clams in a given area implies a semi-permanent impairment between the local fishing capacity and *C. gallina* abundance. Thus the more precocious adoption of the 0.6 ton per day and boat limit in the maritime district of Pescara (two years earlier than elsewhere; MINISTERO MARINA MERCANTILE, 1987), long fishery closures in the same fishing district as well in that of S. Benedetto del Tronto (up to 18 months in 1994-1996) and the 0.25 ton per day and boat limit adopted in the Monfalcone area since late 2000 (MINISTERO POLITICHE AGRICOLE FORESTALI, 2000), as well as fairly strong reductions of local fleets (MINISTERO RISORSE AGRICOLE FORESTALI, 1996; MINISTERO POLITICHE AGRICOLE, 1998), probably mean that the fishing effort deployed in the three mentioned districts has changed little during the last 10-20 years and administrative measures counterbalanced the greater efficiency of the hydraulic dredges.

Although detailed information is still lacking on the matter, the adoption of EU Regulation No. 1967/2006 (COUNCIL EUROPEAN UNION, 2007) presumably further contributed to lessening to some extent the fishing pressure on the clam beds as shallow marine areas within 0.3 nautical miles of the coastline are now closed to the hydraulic dredges.

Evolution of the Adriatic *C. gallina* landings during the last decades

Since the late 1970s – early 1980s data on the Adriatic and national *C. gallina* landings have been intermittently collected by surveys based on different methods (mainly interviews with fishermen and fish dealers as well as declarations by local associations of dredgers, and in a few cases extensive harbour inspections); although the precision of such estimates often remain undetermined they are considered fairly accurate because are much larger than official fishing statistics based on declarations compulsorily filled by the fishermen each month.

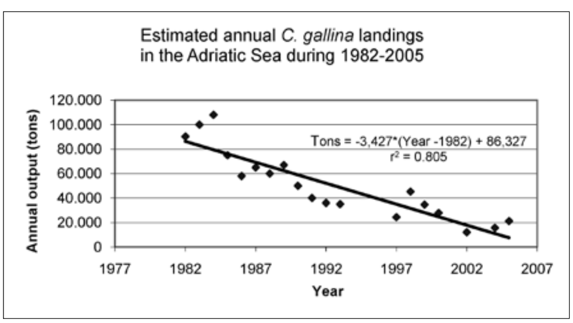
In 1974 the Adriatic clam landings were reckoned to be around 80,000 metric tons (FROGLIA, 1975b) on the basis of the number and capacity of the national shellfish canning plants, customs declarations issued for the fresh product exported abroad and estimates of the fraction of the catches sold locally. According to the minutes of a debate held in Ancona in late June 1975 among scientists and officials of the fishermen or canneries associations such annual clam output was 10 times higher than about 30 years earlier (ANONYMOUS, 1975).

In 1983 the Italian association of shellfish farmers estimated the national production of several bivalves, and the figure of 90,000 metric tons was put forth for *C. gallina* (i.e. "common clams") as the inter-annual mean during 1980-1981 (FEDERMOLLUSCHI, 1983). Specifically, nearly 95% of catches came from the northern and central Adriatic Sea. In 1982 an extensive survey aiming at assessing the total output of the Italian fisheries (CINGOLANI *et al.,* 1986) showed similar annual Adriatic clam landings.

Further estimates of the annual national clam landings in 1983-1993 are anonymously reported in the *C. gallina* sheet filled in a monograph summarising all data available on the catches and biology of marine shellfish and ground fish targeted by Italian fishermen (RELINI *et al*., 1999). Estimates were based on data gathered by the Italian Association of Canning and Tuna Industries (ANCIT; indeed, most clams were cooked and canned) and probably are not very accurate and include fairly small amounts of the Venerid *Paphia aurea* (Gmelin) as it is known that since the mid-1980s an undefined fraction of the authorised dredgers turned to that resource (FROGLIA, 1989). In any case the new resource was mainly exploited in the central Adriatic (FROGLIA *et al.,* 1998) and in our data set was relevant only in 1991 (Fig. 1. and attached data), with an annual estimate of about 6,000 tons (our estimate, after data by MINISTERO RISORSE AGRICOLE ALIMENTARI FORESTALI, 1994). Thus, the clam landings for that year have been accordingly modified. Similar cor-

Fig. 1. Evolution of the estimated amounts of C. gallina *landed yearly along the Italian coast of the Adriatic Sea during 1982-2005*

Year	Annual landing
1982	90.277
1983	100.000
1984	108.000
1985	75.000
1986	58.000
1987	65.000
1988	60.000
1989	67.000
1990	50.000
1991	40.000
1992	36.000
1993	35.000
1997	24.298
1998	45.239
1999	34.578
2000	27.777
2002	12.024
2004	15.670
2005	21.125



rections have also been adopted for 1988-1990 and 1992-1993 assuming, in the absence of more appropriate information on the matter, that the *Paphia*/*Chamelea* ratio was constant in the Adriatic clam landings. However, this procedure was not used from 1997 onwards because the *Paphia* adult biomass was low in scientific surveys performed in 1997-2001 and the activity of the hydraulic dredgers from the central Adriatic has been progressively decreasing since the mid-1990s (RELINI *et al*., 1999; FROGLIA, 2008).

Since 1997 Adriatic clam landings have been regularly estimated by extending the catches recorded from small groups of dredgers, and a decreasing pattern over time was found, down to 12,000 tons in 2002 (IREPA, 1998, 2000, 2001, 2002, 2003, 2006; LABANCHI, 2007). Moreover, the IREPA staff had previously recorded 62,300 tons *C. gallina* during a 12-month survey in 1986-1987.

In spite of the minimum legal limit of 25 mm, the mean size of the *C. gallina* specimens landed yearly probably decreased with time because the dredgers dealt with impoverished commercial resources and routinely caught undersized clams during operations at sea (MARRS *et al.,* 2002, however, reported a "fairly regular" size distribution above the legal 25 mm limit for some clam samples) and traces of such a deleterious pattern can be found in several scientific reports (D'AMICO, 1988). It should be noted, however, that the presence of fairly large fractions of slightly undersized specimens among marketed clams was observed even in the mid-1970s, when the fleet was not so large and fishing yields were high (FROGLIA, 1975b, 1989), because the product was mainly sold to canneries (RELINI *et al.,* 1999) and all clams had the same price (maybe smaller specimens were preferred because of the supposed higher flesh content, after FROGLIA 1975a). Thus, the 23-27 mm marketable range presumably decreased to a limited extent in sand areas where the size selection of clams is mainly performed in the submerged fishing cage but to much lower values, say 20-25 mm, in sites with more mixed sediment implying that the clam mean weights progressively decreased by 20%-40% in the Adriatic landings (FROGLIA, 1975; MARANO *et al*., 1982; ARNERI *et al*., 1995). In turn, such changes in the size structure of the *C. gallina* landings mean that comparisons are restricted to data collected simultaneously or only a few years apart.

Anyway, if all available data are summed up we see that during the last 25 years clam landings on average have been decreasing by 3,500 tons each year, down from the 110,000 t peak of 1984, although much stronger drops were recorded in 1985-1986 and 1990-1991 (Fig. 1

and attached data). In 1998 landings conversely increased greatly over the previous year's level (partly because of the long fishery closure imposed in 1997 after the 1996 massive mortality) but the output did not surpass 45,000 tons.

Broad comparisons among average landings of boats based in the northern, central and southern sub-areas of the Adriatic Sea are possible only for some years. Nevertheless, available data show that dredgers of the southernmost Manfredonia and Molfetta districts account for approximately 12% of the total Adriatic fleet but their annual output never surpassed 4.5% of the clam landings (indeed the vessels often operated with fishing gears other than the hydraulic dredges; MARANO *et al.*, 1987; IREPA, 2003) whereas boats of the central Adriatic had by far the best daily yields compared to the others during the 1980s although such prominence progressively decreased during the last 15 years (Tables 1, 2).

Finally, two issues deserve attention, the first one being the upward trend of clam prices (due to a progressive shift of clams towards direct consumption whereas sales to canneries have been declining, from 50% and 80% of the marketed biomass in 1974 and 1987, respectively to about zero in recent years; FROGLIA, 1975b; RELINI *et al.,* 1999; IREPA, 2003) which counterbalanced the long-term decrease of annual landings. Secondly, the adoption of re-seeding (mainly with 14-18 mm specimens) to counteract the negative trend of catches was employed but these measures seem have been adopted over small areas and only in recent times (DEL PIERO *et al*., 1998; PRIOLI *et al*., 1998) after the setting up of local consortia among shell fishermen (MINISTERO POLITICHE AGRICOLE FORESTALI, 1995, 2002).

Table 2. Synopsis of available data on the clam landings, fleet size and average days spent at sea in distinct years and Adriatic sub-basins

Year	Northern	Adriatic	Central	Adriatic	Southern	Adriatic
	Tons	Mean No. days/boat	Tons	Mean No. days/boat	Tons	Mean No. days/boat
1982 [1]	27,567	140*	56,435	145*	6,275	m.d.
1986-87 [2]	17,778	m.d.	41,710	m.d.	2,811	m.d.
1991 [3]	14,725	m.d.	22,218	m.d.	1,503	m.d.
1997 [4]	9,967	113	11,453	75	2,878	136
1998 [5]	8,618	85	32,480	88	4,141	114
1999 [6]	12,669	124	19,113	116	2,796	96
2000 [7]	7,277	108	19,262	118	1,238	117
2001 [8]	m.d.	m.d.	16,320	101	1,713	79
2002 [8]	5,326	130	5,941	77	757	148**
2003 [9]	9,850	m.d.	12,101	m.d.	272	78
2004 [9]	m.d.	131	m.d.	90	m.d.	51

* Estimate based on the frequencies of boats at sea recorded by CINGOLANI *et al.* (1986) on sampling days;
** After Irepa, 2003, an undetermined large group of local dredgers turned to fixed gears
[1] After CINGOLANI *et al.*, 1986;
[2] Irepa, 1989; m.d.: missing datum;
[3] After Ministero Risorse Agricole, Alimentari, Forestali, 1994;
[4] After Irepa, 1998;
[5] After Irepa, 2000;
[6] After Irepa, 2001;
[7] After Irepa, 2002;
[8] After Irepa, 2003;
[9] After Irepa, 2006;

Scientific surveys of the clam distribution and abundance along the western Adriatic coast during 1984-2001

Under pressure from fishermen worried about declining yields (D'AMICO, 1988; FROGLIA *et al.,* 1998), in 1984 Italian maritime authorities promoted for the first time a survey to monitor, by standardised dredging hauls, the distribution and abundance of *C. gallina* beds along the Adriatic coast (IRPEM *et al.*, 1986) and similar explorations were carried out, with several time and spatial gaps, up to 2001 (FROGLIA, 2000) or locally to 2002.

All 1984-2001 surveys were carried out during the fishery closed season (initially June, later May-June or June-July or even other months in some areas/years) by 50 m hauls run in parallel to the coastline, at depths progressively increasing by one metre, on 2-12 m grounds (or even deeper if enough clams were sampled in the outermost stations). Haul rows were either 4 or 8 km apart and 2.4 m wide hydraulic dredges were used (actually derived from those targeting *Ensis* spp.), inserting in their central sections special grids with 6 mm open spaces to collect clams down to 12-14 mm (at least in the sandy areas where these bivalves are more abundant) together with specimens of legal size (FROGLIA *et al.*, 1998; VACCARELLA *et al.*, 1998; FROGLIA, 2000).

Such sampling design was considered random stratified because the precise location of the hauls within each 1 m depth site was chosen by chance (RUSSELL, 1972; FROGLIA, 2000). Precautions were taken (such as avoiding work during the first two days following rough seas) to assure the gear efficiency be close to maximum. Commercial and juvenile biomasses at sea were estimated from the recorded average yields and the number of stations with clams.

If data from the scientific surveys and various sedimentological studies are summarised (IRPEM, 1986; PRIOLI *et al.,* 1998; VACCARELLA *et al.,* 1998; FROGLIA *et al.*, 1998; FROGLIA, 2000, D'AMICO, 1996a, b) we see that clam beds spread over 875 km of the Italian coast of the Adriatic Sea but the most exploitable ones are on shallow sandy grounds (PAREA, 1978; CESCON & ROSSI, 1971) whose locations have not much varied in time and face no more than 60% (probably less as shown for the best known districts; Table 3) of the mentioned coastline.

Annual estimates of the clam "standing crop" were summarised by FROGLIA (2000) as histograms, and our Table 4 has been derived from those data. We see that total areas covered by the clam banks in distinct maritime districts ranged by approximately 50% over time and the median value of the mean densities of the commercial clams (i.e. size $\geq$ 25 mm) recorded during surveys of 1991-1997 were either very low or much less than those during the 1984-1990 period. If such data are coupled with the numbers of dredgers authorised in each district in 1993 (when Adriatic vessels peaked at 778) the decline of adult clam densities results as being independent from the size of the local fleet.

In spite of the lack of appropriate statistical testing, data in columns D and F seem to point out that fishing districts where dredgers on average had taken advantage of larger commercial standing crops during the 1984-1990 period later experienced sharper reductions of the exploitable resource. As the districts are listed from north to south, data confirm that clam shoals decreased more moving southward.

Somatic growth, age structure and mortality rate of the *C. gallina* beds and inter-annual variations of the abundance of pre-recruits as assessed through the surveys of 1984-2001

From several studies on the somatic growth of *C. gallina* specimens from exploited beds of distinct areas of the Adriatic Sea we learn that clams on average reach 15-20 mm at the end of their first year, about 25 mm a year later and 32-34 mm when are three-year olds (POGGIANI *et al.,* 1973; FROGLIA, 1975a; MARANO *et al.,* 1982; ARNERI *et al.,* 1995; FIORI *et al., 2008*). Analysis either of sample modes over time or the shell outer margin show that clams cease growing at water temperatures below 10°C (POGGIANI *et al.,* 1973; FROGLIA, 1975a).

However, in the Gulf of Trieste (NE Adriatic) a sophisticate ageing technique based on

Table 3. Coastal length of the Italian maritime district facing the Adriatic Sea and sub-sectors exploited for catching common clams

	No. authorised or active hydraulic dredgers					
	Years				Total	Max. useful
Maritime districts	[1987] [1]	[1997] [1]	[1998] [1]	[2002] [F]	coastline (km)	coastline (km)
Monfalcone	38	88	42	17+25*	50	45
Venice	65	88	96	70+25*	80 [4]	80
Chioggia	91	95	74	57+15*	65 [7]	30
Ravenna	15 [I]	18	18	18	83 [7]	#83
Rimini		36	36	36	40 [7]	#40
Pesaro	94	65	65	65	44 [7]	32 [12]
Ancona	22	73	73	73+25**	70 [7]	26 [2]
San Benedetto of Tronto	77	83	83	58**	48 [7]	15 [2]
Pescara	148 [L]	139	102	98	128 [7]	#82 [11]
Termoli		11	10	10	32 [7]	#32
Manfredonia	65 [M]	67	56	50	190 [7]	70 [6]
Molfetta	15 [M]	12	10	8	45 [7]	10 [10]
TOTAL ADRIATIC	630	775	665	585+65*	875	530

[1] Numbers of authorised vessels from various sources, as on Table 1;
[2] After Froglia & Bolognini, 1987;
[4] The entire coastline supposed expoitable for clam dredging (after Del Piero *et al.*, 1998);
[6] After Fig. 1 in Marano *et al.*, 1998;
[7] Coastal length estimated on geographic map (scale 1 to 450,000; Mercatore, projection);
[10] Only coastline from the Oftanto's outflow to the SE limit of the town of Barletta (after Fig. 1 in Vaccarella *et al.*, 1998);
[11] The coast between Vasto and Cape Ferruccio supposed unexploitable as it is mainly rock;
[12] The coast north of Pesaro unexploitable as mainly rocky;
Imprecise estimates due to lack of detailed information;

the amounts of distinct oxygen isotopes laid in the clam shell showed (KELLER *et al*., 2002) that, in the small sample of examined (9 clams) specimens, they had on average grown to 11 mm when 1 year old and reached the minimum 25 mm legal size at the age of 2.5 years. In this study the presence within the 0 age group of two semi-cohorts of juveniles respectively settled in the sediment in spring and early autumn was also demonstrated, in agreement with previous reports on the *C. gallina* breeding season in the Adriatic Sea and the existence of two main reproductive peaks during this time (POGGIANI *et al*., 1973; FROGLIA, 1975b, 2008; MARANO *et al.,* 1982; VALLI *et al*., 1985). Moreover, data by KELLER *et al.* (2002) showed that some clams had experienced poor growth rates in summer, as also stated for the commercial beds of the central Adriatic.

Studies from coastal areas of Italy (and nearby zones) where clams are not commercially exploited show wandering growth rates at different sites, as individuals sampled by hand dredges at regular time intervals in shallow waters of Gulf of Naples were on average 7-9 mm at the age of 1.5 years, 13-18 mm at 2.5 years and 25 mm at 3.5 years (NOJIMA & RUSSO, 1989), and MASSÉ (1971a, 1971c) reported that at two oligotrophic sites near Marseille clams were less than 10 mm after their first year and did not live further. On the contrary, at nearby sites with higher levels of seston in the water two-year *C. gallina* individuals were around 25 mm or even slightly more (MASSÉ, 1971b, d; BODOY, 1983). Similarly, in sandy areas close to the Tiber river's outflow clams resulted in growing to 25 mm within two years (COSTA *et al*., 1987), and actually were the by-catch of a small fishery aimed at razor clams.

Estimates of natural mortality based either on the analysis of the age structure of clam samples or the Hoenig's longevity-mortality correlation curve (HOENIG, 1983) greatly vary among distinct papers, with M= 0.6-2 (CASALI, 1984; FROGLIA, 2000). Moreover, such estimates are focused on 1+clams because they can be sampled by hydraulic dredges and the Hoenig's function presumptively allows the estimation of fairly constant mortality rates as the juxtaposition with longevity implies scattered deaths, thus it concerns adults and advanced juveniles.

Data reported by JUKIĆ *et al.* (1998) on the size structure of *C. gallina* samples caught by standard hydraulic dredges in a short series of fishing trials performed during August 1995 on sand grounds of the eastern Adriatic, close to the Neretva river outflow, that had previously been exploited only in June-July 1991 show that the natural mortality suffered by clams of the age cohorts 0+ and older was presumptively high because less than 10% of the clams were beyond 27 mm.

It is not well known whether slower growth is related with higher natural mortality rates per unit time as scarce estimates exist for the smaller clams experiencing the lowest survival rates, but data reported by MASSÉ (1971c) for the clams at a station in the Gulf of Fos (southern France) show that they decreased in his samples from 600 to 100 ind m^{-2} as the mean length moved from to 3 to 5 mm (i.e. probably within 3 months), whilst samples obtained in the middle Adriatic between spring and late autumn of 1998 and 2000-2001 (HAUTON *et al.,* 2002) indicated that clams decreased by 15%-30% each month as they grew by 1.5-3.0 mm/month within the 7-18 mm range, thus some support exists for the hypothesis that slowly growing *C. gallina* juveniles on average die earlier.

On some occasions the Adriatic clam beds underwent mass mortality events (CESCHIA & GIORGETTI, 1998; FROGLIA, 2000) but information on such phenomena are scarce. In some papers the negative impact of freshwater floods (in Italy usually taking place either in late autumn or winter) is reported (FROGLIA & FIORENTINI, 1989; DEL PIERO, 1998; PAOLINI *et al*., 1998; PRIOLI *et al.,* 1998) but are local phenomena, although their effect can extend over time because distinct clam age classes are involved. To our knowledge, the mortality of 1996 along the coast of the northern and central Adriatic in late summer – early autumn of 1996 (DEL PIERO, 1998; FROGLIA *et al*., 1998) was a unique and largest-scale event of its kind ever recorded, and happened after many weeks of calm seas during which events of bottom hypoxia had been recorded at some sites (REGIONE EMILIA ROMAGNA, 1997).

The cause(s) of such large mortality during summer 1996, targeting both adults and pre-recruits (DEL PIERO, 1998) remain(s) unexplained, but ties with protozoan infections was hypothesized (BERRILLI *et al.,* 2000). Other events of mass mortality had been intermittently observed in the area of Ancona in the late 1990s and were tentatively attributed to the strong metabolic effort due to the production of gametes (about 50% of the body weight during the entire spawning season in 25 mm clams; BODOY, 1983).

In the scientific surveys of the 1984-2001 period great relevance was given to the abundance of clams of 1+ age class, as this item of information could be useful for planning, to some extent, the fishery during the following year. Surveys showed that the abundance of pre-recruits largely changed on local scales (FROGLIA, 2000), thus no clear patterns were defined. As an example, during the survey of summer 1994 the level of pre-recruits was fairly good (at least, better than in previous years) in the maritime district of Monfalcone and low in that of Venice (DEL PIERO & FORNAROLI, 1998; DEL PIERO *et al*., 1998), and the same conflicting pattern was true for the neighbouring districts of Ancona and San Benedetto del Tronto (FROGLIA *et al.,* 1998). Pre-recruits, however, seem have been fairly abundant during summer 1985 in all maritime districts south of the Pesaro district (MARANO *et al.,* 1987; FROGLIA & FIORENTINI, 1989; VACCARELLA *et al.,* 1998).

The surveys carried out in the maritime districts of Venice, Chioggia, Ancona and San

Benedetto del Tronto in 1998-2000 or 1998-2001 showed that pre-recruits of modal size close to 14 mm were very abundant along the coast of the two latter areas during summer of 1998, perhaps because of the long fishery closures locally imposed during the previous year (PELLIZZATO & VENDRAMINI, 2002; HAUTON *et al*., 2002).

Several environmental factors potentially influencing the abundance of the exploited *C. gallina* beds

Studies on the ecology and physiology of *C. gallina* are scarce, but some information on environmental factors influencing its abundance may be gained from several studies carried out since the mid-1970s in the northern Adriatic in response to phenomena such as "red tides", fish killing due to anoxia/hypoxia in bottom waters, as well as "marine snow" which could negatively impact both human health and tourism. However, most studies were carried out intermittently and concerned the other Adriatic sub-basins only to a limited extent.

Further useful information may be gained from studies on the hydrography and circulation of the Adriatic Sea and its correlations with local climate as well as from those directly measuring either the phytoplankton biomass or the primary productivity of coastal waters.

As previously noted the possible negative impact of "marine snow" (i.e. gelatinous floating masses originating from phytoplankton blooms through various processes; STACHOWITSCH *et al.,* 1990; GIANI *et al*., 2006) on clam abundance was assumed (DEL PIERO, 1998; FROGLIA, 2000) because the gelatinous "clouds" are known to passively include zooplankton (RINALDI, 1992) thus bivalve eggs and larvae could be killed and the adult clams be choked if aggregates are pushed ashore by coastal currents and winds. Conspicuous mucilaginous events were seen in the Adriatic Sea during mid-spring – late summer of 1988 and 1989, whereas the phenomenon decreased in the same months of 1990 and 1991 and then was again fairly significant in 1997, 2000, 2004 (GIANI *et al*., 2006). In those years the mucilaginous "clouds" were mainly 10-15 km offshore (RINALDI, 1992; GIANI *et al*., 2006) and covering the sea surface for dozens of square kilometres.

Data in Fig. 1 show that the Adriatic clam landings were close to the regression curve both in 1988 and 1989, thus a strong additive mortality on adult clams may be excluded according to the best available data. Also, one-year and two-year delayed impacts by the "marine snow" do not seem probable, because the commercial output slightly decreased in 1992 over that of the previous year and grew in 1998 as well as in 2005. The "fairly regular" catches of 1988-1989 also disagree to some extent with the idea that adult clams were severely impacted by the "marine snow", whilst that of an increased mortality of the clam stages in plankton and early juveniles is at odds with the observations that mucilaginous aggregates were for most of the time far offshore from the coastal areas where adult clams live and spawn (CORDISCO *et al.,* 2003). Moreover, reductions of annual outputs during 1990-1991 were not so severe as to agree with the assumed recruitment failures (DEL PIERO, 1998; FROGLIA, 2000).

In the autumn of 1975 a wide "red tide" determined by planktonic dinoflagellates was seen for the first time along straights of the NE Italian coast fairly close to the Po outflow and the same happened in the following years (REGIONE EMILIA ROMAGNA, 1984). Although blooms comprised of non-toxic dinoflagellates (BONI *et al*., 1986) laws were enforced to ensure regular monitoring on a national scale for the presence of toxic algae (such as *Dinophysis* spp.) in coastal waters as well as DSP and PSP (Diarrhetic and Paralytic Shellfish Poisons, respectively) in commercial bivalves. However, for clams, rules were and still are less severe because they filter relatively small water volumes per unit time and flesh weight (GAUTHIER, 1974) thus they are both safe for human consumption and not seriously damaged by dinoflagellate toxic blooms, not least because the latter are rare (although their frequency is increasing slightly over time; see HONSELL, 1999b).

Since the late 1970s – early 1980s the Indo-Pacific Arcid *Anadara inaequivalvis* (Bruguière) (sometimes erroneously named *Scapharca inaequivalvis* = *Scapharca cornea*) have been more or less abundant at some sites and sub-areas of the western Adriatic (RINALDI, 1972; CASALI & COLAFRANCESCHI, 1986; MISTRI *et al*., 1988; RELLINI *et al.,* 1999) and the spreading of that exotic species was attributed to its higher resistance to anoxia (and the same reasoning holds for the similar *Anadara demiri*, Piani, whose presence was reported for the first time some years ago; MORELLO & SOLUSTRI, 2001) due to the presence of a haemoglobin in haemocytes (MISTRI *et al*., 1988; DE ZWAAN *et al.,* 2001). In spite of the hypothesis that *A. inaequivalvis*, if locally abundant, might compete with *C. gallina* for space and food, data from various areas of the Adriatic Sea show that the former bivalves mainly live at 10-16 m depths (FROGLIA *et al.,* 1998b; RELINI *et al*., 1999) whilst the commercial clam beds usually lie not beyond 10-12 m depth (CASALI, 1984; RELINI *et al*., 1999), and therefore such different localization reduces the inter-specific competition. FROGLIA *et al*. (1998b) also came to the same conclusion after examining the evolution of an abundant *A. inaequivalvis* cohort during 1991 which exceptionally settled at good densities at 4-8 depths together with clams.

Observations by MOSCHINO & MARIN (2006) that 20-25 mm *C. gallina* specimens seasonally caught off Venice greatly increased their respiration rate at a water temperature of 28°C so that the metabolic balance between the energy adsorbed by the ingested food and that spent through respiration was strongly negative (as measured by the "Scope for Growth" methodology; e.g. WIDDOWS & STAFF, 2006) suggest wild clams may be very stressed at such high temperature, and many of them die at last (FROGLIA, 2000), local mass mortality happened in the fishing district of Venice during the summer of 1998). However, data from various commercial bivalves such as oysters and mussels (e. g. TREMBLAY *et al.,* 1998) demonstrate that anomalous increases of respiration rates take place at very high (and therefore stressing) water temperatures not commonly reached (such as the 28°C value recorded by MOSCHINO & MARIN, 2006, at -5 m).

Moreover, the mass mortality of 1996 fell in a rainy and somewhat cold summer (REGIONE EMILIA ROMAGNA, 1997), whereas in 1998 clam landings were comparatively high (but the precautionary extended fishery closure adopted during most of 1997 contributed to such positive output), in spite of the high bottom water temperatures recorded that summer (FROGLIA, 2000). Thus the notion of the higher temperatures of the Adriatic coastal waters during the last decades playing a key role (GIANI *et al.,* 2006) in reducing the *C. gallina* annual outputs is not supported by these observations (Fig. 1).

In the past some authors (CECCHERELLI, 1985; FROGLIA, 1989) tied the existence of the Adriatic mechanised clam fishery to the higher primary production presumptively induced in that area by the large local freshwater inflow (ARTEGIANI, 1984; DEGOBBIS *et al*., 2000). It is therefore of great relevance to understand whether the qualitative and quantitative composition of coastal phytoplankton has changed during the last 20-30 years to the point of reducing the density and/or the total surface of the commercial clam beds.

On the whole data on the Adriatic phytoplankton are scarce until the late 1970s and mainly concerned the northern-eastern and central sectors (INNAMORATI *et al*., 1995; ZOPPINI *et al*., 1995) although since then the NW coastal waters of Emilia Romagna have been regularly monitored (and data contained in annual reports dating back to 1982) in order to outline the physical and chemical factors determining undesirable phenomena such the previously mentioned "red tides" (i.e. blooms by dinoflagellates), bottom hypoxia/anoxia and later "marine snow" (REGIONE EMILIA ROMAGNA, 1984; GIANI *et al.,* 2006; MONTANARI & PINARDI, 2006). Monitoring was concentrated in that fairly small area because it was and still is greatly affected by the Po river outflow and eutrophic phenomena are consequently more frequent and severe.

All of those studies show that phytoplankton are abundant only in a strip bordering the Italian coastline, as well as in more offshore areas of the northern Adriatic where freshwater coming from Po intermittently spreads (FONDA UMANI *et al.,* 1992; HOPKINS, 2002), due to the rivers large amounts of phosphate and nitrogen-derived salts that are delivered to marine coastal waters. Data obtained spanning nearly 30 years at the coastal sampling stations of Emilia Romagna (500 m from the shore all year round, with additional seaward stations in spring-summer) show that the northern Adriatic (i. e. the Adriatic sub-area to the north of the Ancona maritime district) may be thought of as a large estuary because the phytoplankton abundance is strictly tied to the Po outflow as this is by far the largest local river although other relevant rivers (e.g. Adige and Tagliamento) also flow nearby into the same sub-basin (REGIONE EMILIA ROMAGNA, 1984, 1987; DEGOBBIS *et al.,* 2000) and the concentrations of dissolved nutrients decrease at greater distances from the Po's delta.

Because of the large nutrient inflow coming from land sources through Po and other nearby rivers the weight ratio between the dissolved nitrogen and phosphorus salts is far from the optimal 7:1 value (corresponding to 16:1 as numbers of nitrogen and phosphorus moles, or "Redfield Ratio") after which the phytoplankton cells always take those chemical elements, at any given concentration of each of them in the surrounding marine water. Indeed recorded weight ratios usually ranged from 20-120 (mean being 30 in the most recent years; RINALDI *et al.,* 2002) in the northern and central Adriatic and has been increasing over time. Such high N:P ratios imply that most nitrogen-derived salts cannot be used by the phytoplankton cells for lack of phosphorus to be taken together (i.e. phosphate is the factor limiting phytoplankton growth; REGIONE EMILIA ROMAGNA, 1984; VOLLENWEIDER, 1992; GIOVANARDI *et al.*, 2008).

As amounts of phosphorus-derived salts to be managed were much smaller than those of nitrogen-derived compounds, appropriate measures have been adopted during the last three decades (mainly by changing the chemical composition of soap powder and by treating urban and farm organic discards; REPUBBLICA ITALIANA, 1986, 1989; MARCHETTI *et al.,* 1989) to reduce the phosphorus load delivered to the Adriatic Sea, thus the coastal phytoplankton have been influenced (although MARCHETTI *et al.,* 1989, found that in late 1980s the phosphorus load annually delivered by Po was still unchanged in spite of the adoption of the mentioned national laws) and "red tides" are now far less common (HONSELL, 1999b; TOTTI *et al*., 2002). Preliminary surveys carried out in the 1998-2000 period to assess the ecological level of Italian marine coastal waters after EC No. 60/2000 (PARLAMENTO EUROPEO, 2000) showed that along the Adriatic coastline eutrophy was restricted to some areas close to the Po river outflow (RINALDI *et al,* 2002; GIANI *et al*., 2006). Moreover, the total phosphorus (i.e. water dissolved or bound to the mineral particles in suspension) delivered by the river decreased over time to the present low level of 5,200 metric tons per year (GIOVANARDI *et al*., 2008).

However, experiments carried out by ZOPPINI *et al.* (1995) during the 1990-1992 period in three stations 3, 12 and 30 km off the coast between Fano and Senigallia (Ancona maritime district), show that on average 63 to 273 gC m^{-2} were produced each year and such estimates (obtained by "old" experimental methods, excluding nanoplankton, to obtain data comparable with those from previous papers) were close to those recorded for highly productive sites such as the lagoons of NW Italy and marine sites close to the Po delta; authors consequently came to the conclusion that the primary productivity was locally much higher than expected.

A direct influence of the phytoplankton abundance on clam banks seems to be outlined by the observation that an exceptionally "dry" 1985 and 1990, during which either winter or autumn were very cold (REGIONE EMILIA ROMAGNA, 1986, 1991), were followed by sharp decreases of clam landings in the same and the immediately following years (Fig. 1). A somewhat different pattern, however, was seen for the very low Po outflow in 2005 (whose mean that year was close to 800 m^3 s^{-1}, about 50% of the long-term annual mean; PUGNETTI *et al.,* 2008) as clam landings did not change much over those of 2004 (Fig. 1) although were at low levels.

In the northern Adriatic fishing districts the reduction of the annual *C. gallina* landings were also tentatively tied to changes in the sediment texture (this in turn implying changes in the local hydrology and coexisting macrofauna, as well as in the abundance and composition of the sediment-seeded bacteria), with progressive increases of silt on coastal grounds (PRIOLI *et al*., 1998; PELLIZZATO & VENDRAMINI, 2002), but no precise information are available on the areas where this happened. However, FRASCARI (2006) stated that the sediment discharge from the Po had been severely decreasing during the previous 25 years because of heavy excavation in the river bed to obtain sand and gravel for building material, thus her statement agrees with the previous ones. Moreover, ALBERTELLI *et al.* (1998) stated that comparison between their grab samples obtained at six stations along the coast between Chioggia and Ravenna and those collected by VATOVA (1949) nearly 50 years earlier demonstrated that over large areas at 10-20 m depths the original *Chamelea* zoocenosis had been replaced by one whose dominant species were *Corbula gibba* (Olivi) and *P. aurea* and the sediment was muddy sand.

DISCUSSION

Since the mid-1980s the large clam fishery of the Italian coast of the Adriatic has been steadily declining in spite of various administrative measures (reduction of landings allowed for each fishing day, partial fleet reduction, creation of local consortia among fishermen) taken to counteract such a negative pattern, and in recent years annual landings have decreased by weight down to approximately one sixth of those recorded about 25 years ago.

Understanding the causes of such a strong reduction of the fishery's output is inherently difficult because of the multiple factors potentially involved (either tied to the fishing effort or independent of it) as well as the scarcity of appropriate data on them. Indeed studies on the fishery aimed more at evaluating the biomass of adult clams available each year to rule the fishing effort than at disentangling factors impacting on the decrease of the commercial landings. It is therefore necessary to use the available data in a "qualitative manner" to define the pattern of distinct factors over time and space, giving up with the idea of more rigorous analyses based on standard statistical testing. Any conclusion will be therefore based on the conceptual coherence of evidence derived from the distinct factors examined as well as periodical reassessment of the matter as new data are made available.

The main change that occurred in the fishery targeting *C. gallina* was the use of inverted propellers to tow the dredges' submerged iron cage because this new fishing technique appreciably increased the sweeping speed of the gear (from about 0.5-1.0 to 1.0-2.2 knots) thus larger areas could be explored within each time unit and lower clam biomasses were needed for commercial exploitation (the minimum density approximately decreased from 12.5 – 20.0 to 5.0-10.0 g m^{-2}, the exact value depending on the sale price of clams; FROGLIA, 1989). Such innovation took place in the late 1980s when several administrative measures had been previously adopted to freeze the fishing effort on clam beds (reduction of the quotas from 2.5 to 0.6 ton(s) per day and boat and a 20% cut in the maximum number of days each authorised vessel could spend at sea; MINISTERO MARINA MERCANTILE, 1985, 1989), and therefore the impact on clam beds was partly reduced. Indeed comparison of the data and estimates reported by FROGLIA (1989) and MARRS *et al.* (2002) on the fishing effort exerted either on the entire Italian Adriatic coast or in the maritime district of Ancona alone, we see that the total ground area swept annually by the authorised dredgers presumably had increased to a limited extent between the late 1980s and about ten years later because the ground surface hosting commercially exploitable clam densities was on average swept 2.0 and 2.45 times each year, respectively.

In spite of the absence of appropriate data on the sensitive issue of the "true" size composition of the *C. gallina* landings (indeed the diffusion of data taken quarterly in Italy on fish and shellfish commercial samples after EU Regulations No. 1631/2001, 1581/2004 is still restricted; COMMISSION OF EUROPEAN COMMUNITIES, 2001, 2004), the mean weight of clams has been decreasing and therefore more individuals make up a given amount of commercial product. In turn, this implies that clams started suffering higher fishing mortality rates and FROGLIA (2000, 2008) actually reported that in the 1984-2001 annual surveys the mean size of the “legal clams” (i.e. with size ≥ 25 mm) progressively decreased from 29.5-31.5 to 26.0-28.5 mm, thus implying that older individuals (3 years or older) were disappearing. Such a finding agrees with fishermens’ statements reported by ANONYMOUS (1975) that in the early 1970s the 25mm clams were thought only suitable for canneries, although some differences existed among distinct geographic areas, as well as with limited evidence from old photographs that the marketed clams were somewhat larger in the past (ERCOLANI, 2008; GAUDENZI, 2008). On the contrary, MARS *et al.* (2002) thought that the clam landings of the Ancona district were basically comprised of 1-year old individuals, but only one fourth of clams they sampled during their study of 2000-2001 in market places were slightly below the 25 mm size limit.

On the whole, available data seem to point out that the amounts of clams landed for a given swept area or time spent at sea have been decreasing as shown, to some extent, by the previously quoted reduction of the minimum exploitable densities of ≥ 25mm clams, from ≥ 20 g m^{-2} in the late 1980s to 5-10 g m^{-2} ten years later (FROGLIA, 1989, 1998; PRIOLI *et al.*, 1998). We may therefore conclude that a progressive decrease in average densities has occurred since the mid-1980s, together with partial shifts in the distribution of the clam beds as well reductions of their total area in some districts (PRIOLI *et al.*, 1998; PELLIZZATO & VENDRAMINI, 2002). However, data gathered during the scientific surveys of the 1984-2001 period (herewith not detailed) show that mean densities and total areas were uncorrelated and the latter did not change much if data of various years are pooled (Table 4). In

Table 4. Synopsis of available information on the C. gallina *adult biomass found along the Italian Adriatic coast in the scientific surveys of 1984-1997*

	A	B	C	D	E	F
Maritime districts	Range of estimated areas with commercial clam beds (km^2)	Central estimate of areas with commercial beds (km^2)	Initial “standing crop”** (ton./km^2)	Final “standing crop”# (ton./km^2)	Estimated surface/boat ratio (km^2) (1993)	Initial “standing crop”/boat ratio (ton.)
Monfalcone	27-44	35.5	27.6	5.6	0.40 (0.80§)	11.0
Venice	80-110	95.0	m.d.	12.6	0.99	-
Chioggia	71-106	88.5	9.6	6.6	0.93	8.9
Ravenna	64-108	86.0	2.3	2.4	4.78	11.0
Rimini	52-127	89.5	5.6	12.3	2.48	13.9
Pesaro	70-122	96.0	11.5	11.5	1.48	17.0
Ancona	194-300	247.0	18.2	8.1	3.38	61.5
San Benedetto Tronto	89-216	152.5	30.2	11.8	1.51	45.6
Pescara	150-389	204.0*	18.4	§§	1.69	31.1
Termoli	28-46	37.0	17.6	5.4§§§	3.36	59.1
Manfredonia	85-158	135.0	5.5	3.7	2.01	11.1
Molfetta	5-16	10.5	47.6	0	0.70	33.3

* estimate derived from the minimum recorded surface with commercial clams multiplying this value by the median of the maximum/minimum surfaces ratios in the other 11 Adriatic maritime districts (data after FROGLIA, 2000, see also text);

** median of the mean clam densities recorded in the 1984-1990 surveys (data from 4-7 years, only 2 years for the Chioggia district;

\# median of the mean clam densities recorded in the 1991-1997 surveys (data from 3-7 years);

§ surface/boat ratio estimated assuming that only 50% of the authorised dredgers actually targeted *C. gallina*;

§§ value non estimated because for this district only very oscillating data from three years are available;

§§§ data from only three annual surveys;

recent times several studies focused on the indirect mortality (i.e. independent of the amounts of clams landed) induced by the hydraulic dredgers on the *C. gallina* aggregates since it was supposed that further increases of the number of times a given area is swept each year could severely impact the clam because they are mechanically/physiologically stressed (DA ROS *et al.,* 2003; MOSCHINO *et al.,* 2003; MORELLO *et al.,* 2006b) and exposed to preying macrofauna (MORELLO *et al.,* 2006a; FROGLIA, 2008). However, the fishing effort presumably did not change so much during the last 20 years (FROGLIA, 1989; MARRS *et al.,* 2002). Indeed the selectivity and high efficiency of the hydraulic dredgers (55%-65% of the clams ≥ 25 mm caught at 2 knots towing speeds but the same fraction can be close to 100% if the dredges move slowly; PICCINETTI, 1988; HAUTON *et al., 2002*) probably set limits to how frequently the clam aggregates can be exploited. Indeed, in the past, annual commercial catches were roughly estimated assuming that grounds were on average swept twice a year (D'AMICO, 1988; PICCINETTI, 1988; FIORI *et al., 2008*) actually found in their quarterly samplings near Rimini (northern Adriatic) during late 2006 – late 2007 two semi-cohorts of clams reaching the 25 mm legal size.

The predation by large invertebrates mainly concerns the smallest clams and perhaps it is not negligible as shown by the findings by MORELLO *et al.* (2005a, 2006b) that mean biomasses for each square metre of *D. pugilator*, *A. irregularis* and *A. jonstoni* changed with intensity of the fishing effort, although if it was too intense their biomasses decreased, probably because the predators are partly killed by the hydraulic dredgers. However, data reported (FROGLIA, 2008) for the maritime district of San Benedetto del Tronto (central Adriatic) show that Naticidae spp. are the unique invertebrates efficiently preying on *C. gallina*, in agreement with reports from other Mediterranean areas (GEORGE, 1965; MASSÉ, 1971a), and indeed the local low densities of clams in several years was tentatively tied to the greater abundance of those predators. Also Teleosts are probably predators of some relevance for clams, especially for the larger ones, as seen during underwater observation on the sturdy bivalve *S. solida* (CHICARO *et al.,* 2002). However, fish usually leave the shallow *C. gallina* grounds in winter for deeper waters and in summer the fishery undergoes two-month or longer closed seasons and these factors presumably curb to some extent the Teleosts' impact on the clam beds. At last it should be stressed that findings by MORELLO *et al.* (2005a, b) on the existence of several "recruitment hotspots" (i.e. sites where young clams crowd) swept up to 20 times a year imply that the indirect mortality induced by the hydraulic dredgers is not so severe.

Ties between the comparatively high productivity of the Adriatic Sea and the abundance of *C. gallina* beds as well as other fish resources and the good performance of the local mussel aquaculture were assumed in the past (BOMBACE, 1985; CECCHERELLI, 1985; FROGLIA, 1989, 2000; SARÀ *et al*., 1998). Indeed it is widely known that most reared bivalves exclusively feed on natural seston thus the aquaculture plants are located in areas with high primary production, such as coastal lagoons or those close to the outflows of rivers (SARÀ, 1998; NEWELL, 2004) and in the past the same occurred near waste-water pipes (GAUTHIER, 1974) and at various times the use of bivalve plants had been planned to control eutrophication (BOMBACE, 1989; NEWELL, 2004).

Studies on juveniles and adults of various filtering bivalves showed that specimens can adapt to natural oligo-trophic waters or analogous experimental conditions by increasing their net food intake (i.e. the amount of organic matter absorbed per time and weight units) through various physiological processes (increase of the filtered water volumes and enhanced ingestion rate and absorption efficiency) within a few days (BAYNE *et al.,* 1993; HAWKINS *et al.,* 1998) and mussel and oyster cultures might actually be useful to "build up" commercial biomass in those areas (SARÀ & MAZZOLA, 1997; SARÀ *et al.,* 1998). Things, however, might be different for small juveniles as demonstrated by the sparse distribution of *Mytilus galloprovincialis* (Lamarck) in the nutrient-poor Mediterranean Sea, in spite of the favourable local temperatures and salinities (MANGANARO *et al.,* 1998). Moreover, the smallest (i.e. youngest) individuals of various bivalves result in requiring more energy per body unit (WIDDOWS & STAFF, 2006).

Although the clam growth rate is greatly influenced by the water temperature, and comparisons among data gathered in distinct areas are consequently difficult, several papers show that *C. gallina* sampled at nearby sites in the Gulf of Marseille and along the Italian coast of the central Tyrrhenian Sea exhibited diverging growth curves at different seston levels (either measured or derived from the literature) but a fairly constant 20-25 mm shell size at first maturity (MASSÉ, 1971c,d; BODOY, 1983; COSTA *et al.,* 1987; NOJIMA & RUSSO, 1989). Thus, slow growth probably implies low daily food rations for clams in the areas with less phytoplankton. The further observation by MASSÉ (1971c) that clams from an oligo-trophic site did not grow beyond 10 mm presumptively implies that specimens had been lethally starved since the predation rate on them should have been decreasing as they grow and the total biomass of the preying macrofauna be in equilibrium with clams. In turn, Massé's observation agrees with the hypothesis later put forth by OLAFSSON *et al.,* (1994) that events in the juvenile stage are those mainly shaping the abundance of the new adult cohorts in marine bivalves.

Regarding the relevant role of the mean somatic growth of clams for the fishery it is worth noting that strong reductions of this parameter need to be counterbalanced by increased densities of specimens of the same species (due to lower mortality and/or enhanced juvenile recruitment) in order to catch yearly appreciable amounts of clams, whereas all available information points to the opposite (the strong fishing effort negatively affects both the fished and undersized clams, and in Venerids and other Bivalves very young spawners usually produce fewer eggs per body weight; YAP, 1977).

If the tenet of a strong influence of the phytoplankton biomass both on the growth rate of *C. gallina* individuals and their size at death is true, this would explain why the commercial clam landings have been decreasing during the last two decades. Indeed, in the 1980s various measures were progressively adopted to reduce phosphorus quantities delivered to the Italian lakes and seas, and actually the total phosphorus load delivered yearly through the Po to the Adriatic Sea decreased from the median value of 12,800 metric tons from 1974-1978 to 5,200 tons in recent times (PROVINI & PACCHETTI, 1982; GIOVANARDI *et al.*, 2008). Although the fraction of total phosphorus in its dissolved form (the one algae actually take in) decreases both at very low and high levels of the Po river's outflow and also changes seasonally (BARBANTI *et al.,* 1992), estimates reported by PROVINI & PACCHETTI (1982) show that fraction was 30%-44% during the examined years. Moreover, the same report shows that most dissolved phosphorus was brought to the Adriatic Sea at an outflow level > 1,500 m^3 s^{-1}.

As phosphorus is thought to be the main nutrient limiting primary productivity in the Adriatic Sea (REGIONE EMILIA ROMAGNA, 1984; VOLLENWEIDER, 1992), the lower loads of orthophosphates (the main phosphorus dissolved form) delivered to the northern Adriatic due both to the decreasing Po annual mean outflow (GIOVANARDI *et al.,* 2008) and lower phosphorus concentrations presumptively influenced the phytoplankton abundance and concurrently with that of the *C. gallina* banks. Indeed preliminary surveys carried out along the entire Italian coastline in 1998-2000 to evaluate, by the purposely developed synthetic Trix index (RINALDI *et al.,* 2002), the biological quality of marine waters in agreement with EC No. 60/2000 (EUROPEAN PARLIAMENT, 2000) showed that eutrophy was recorded only in fairly limited areas close to the outflows of the Po and Tiber rivers (in the northern Adriatic and central Tyrrhenian seas, respectively).

All of this would also explain why the reduction of clam landings was stronger in going southward along the Adriatic coast and also estimates of the adult "standing crops" recorded during scientific surveys between 1984-1997 showed a similar geographic pattern (Table 4; data after FROGLIA, 2000), whereas the concentration of hydraulic dredges in the maritime districts presumptively had little effect (Tables

3, 4). Indeed the annual freshwater outflows are much higher in the northern Adriatic (on average 1/3 of the entire Mediterranean freshwater discharge during most of the 20th century; ARTEGIANI, 1984) and the central Adriatic receives less freshwater than the northern Adriatic because large rivers are locally lacking and the Italian southernmost regions on average experience a dryer climate. It may therefore be assumed that the nutrient enrichment of the marine coastal waters decreases from north to south along the entire Italian coast of the Adriatic Sea. All of this is confirmed, to some extent, by the INNAMORATI *et al.* (1995) report that, by reviewing all available information on the phyto- and zooplankton in the Italian seas during the 1970-1984 period, mesotrophic or eutrophic levels (i.e. mean chlorophyll a concentrations ≥ 5 mg m^{-3}) were mainly found in small areas of the northern Adriatic as well as at some sites of the Ligurian Sea. Although these data are biased by the much greater research effort exerted in the two mentioned geographic areas, the greater local abundance of phytoplankton is real.

It is worth noting, however, that in the late 1970s – early 1980s that the highest commercial yields were registered in the central Adriatic, thus it was assumed that in the northernmost maritime districts clams were negatively affected by an excessive primary production (CECCHERELLI, 1985). Such a geographic shift of the most productive areas might be explained, in our opinion, by assuming the lower yields recorded in the past for the northern Adriatic, mainly by the negative effects of the high mineral loads from the freshwater discharge, and afterwards they decreased together with the reduction of the mean outflow as well as the sediment load by the Po and other rivers flowing into the area (FRASCARI, 2006). In our opinion it is likely that the progressive reduction of the Po annual outflow experienced during the last 20 years (DEGOBBIS *et al.,* 2000; MONTANARI & PINARDI, 2006) disproportionately reduced the nutrient load of the marine coastal waters of the middle Adriatic, as nutrients originating from that river may arrive just north of Ancona when the Po outflow is as high as 2,000-3,000 m^3 s^{-1} (REGIONE EMILIA ROMAGNA, 1986), while local rivers bring nutrient loads that influence the coastal marine waters only within a few kilometres from their mouths (REGIONE EMILIA ROMAGNA, 1984). Anyway, the strong decreases recorded for the Adriatic clam landings during the 1985-1986 and 1990-1991 periods (Fig. 1) support the idea of a direct influence of the very low Po outflow during 1985 and 1990 (REGIONE EMILIA ROMAGNA, 1986, 1991) on the phytoplankton living in the 6 km coastal strip (or further offshore when particular oceanographic conditions prevail, HOPKINS 2002) of large portions of the NW and central western Adriatic (REGIONE EMILIA ROMAGNA, 1984). Commercial landings of the target species were also low in 2005 (the last year for which data are available on the matter) when the Po outflow reached an annual minimum of 800 m^3 s^{-1} (PUGNETTI *et al.,* 2008), although somewhat above the levels of the previous years and such a discrepancy could be due to the sparse levels of the entire period.

The decrease of the Adriatic clam landings since the early 1980s seems to be roughly correlated with reductions of the Po outflow because, from Figs. 6-10 of a paper by DEGOBBIS *et al.* (2000) where the oscillations of the annual and quarterly (or even bi-month) outflows during the period 1917-1992 were examined, we may roughly estimate that in the 1970-1974 period the average annual Po outflows were around 1,450 m^3 s^{-1}, while in the seven years from 1975-1982 the same parameter was 1,500-1,600 m^3 s^{-1} and 1,200-1,400 m^3 s^{-1} during the 1983-1992 period.

If we consider that in the Adriatic there usually exist(s) one or two main phytoplankton peak(s) each year, in late winter – early spring and in late autumn respectively (MILANI *et al*., 1990; FONDA UMANI *et al.,* 1992; DEGOBBIS *et al*., 2000; TOTTI *et al*., 2002) as well as *C. gallina* adults similarly having one or two spawning peak(s) in early summer and in early autumn whose importance varies in specific years (CASALI, 1984; KELLER *et al.,* 2002; CORDISCO *et al.,* 2003) and finally histological studies show the maturation process requiring several weeks at mild temperatures (FROGLIA, 1975b; MARANO *et al.,* 1982; VALLI & ZECCHINI-PINESICH, 1982; MATHIEU

& LUBET, 1993), we may come to the conclusion that the primary production of spring and late summer plays a relevant role in influencing the metabolism of clams, as adults will be able to produce gametes and the juveniles to grow faster. If comparisons to the Po mean outflow are consequently restricted to those months, we see that in the 1970-1974 period mean freshwater discharge was around 1,900 m^3 s^{-1} in late winter-spring whereas afterwards the value progressively decreased to around 1,450 m^3 s^{-1}; in late summer and in autumn 1,300 m^3 s^{-1} were introduced into the Adriatic Sea during the 1970-1974 and 1983-1992 periods, whereas the same parameter was around 2,000 m^3 s^{-1} in the "wet" 1975-1982 period (DEGOBBIS *et al.,* 2000). Those data, although roughly approximated, therefore confirm that the Po outflow remarkably changed on a seasonal scale after 1982.

Contrary to our hypothesis of a progressive reduction of the primary production in most of the western Adriatic Sea stand the findings by ZOPPINI *et al.* (1995) that in three coastal stations of the central Adriatic estimates of the phytoplankton generated on an annual basis were exceptionally high, although in our opinion those values might be biased because they are based on measurements of the net intake of radioactive carbon into the "in situ" phytoplankton for a limited numbers of distinct days (13 during the two-year experiment), thus extrapolation to an entire year might have been inappropriate. Indeed, authors themselves could not explain why their estimates were as high as the primary production at sites such as lagoons and marine areas near river outlets.

Our hypothesis that the nutrient content of western Adriatic coastal waters is of great relevance for the output of the clam fishery also agrees with the observation the large "marine snow" events (STACHOWITSCH *et al.,* 1990; GIANI *et al.,* 2006) have been frequently recorded over large portions of the northern and central Adriatic basins since 1997 because the phenomenon is tied to precocious warming of waters in spring, weak winds, reduced mixing, strong stratification of freshwaters (DE LAZZARI *et al*., 2008), thus such atmospheric conditions probably also affected, at least to some extent, the coastal strip where the *C. gallina* beds live, easing the formation of stronger thermal differences along the water column and decreasing local currents.

On the basis of the examined literature we come at last to the conclusion that a progressive decrease of the primary production (as well as changes in the composition of the phyto- and zooplankton communities, since nutrients influence it; PUGNETTI *et al.,* 2008) along the Italian coast of the Adriatic Sea strongly influenced the local clam banks and their net rate of biomass production. Other environmental factors, such as the curtailing of the sand loads delivered to the sea by the Po and smaller rivers (a reduction largely due to the use of sand for buildings) also has an impact since it can reduce the extension and quality of the coastal areas suitable for *C. gallina* as well as a decrease over the years of vertical mixing in coastal waters (HOPKINS, 2002; GIANI *et al*., 2006). The high fishing pressure that was always exerted on the clam banks also played a great role in causing the reduction of the dredgers' landings, but the primary production probably was one of the key factors on the matter. Our finding agrees with the recent statement by COLL *et al.* (2007, 2009) that various fish, shellfish and selachian population(s) of the western side of the northern and central Adriatic have suffered a progressive decrease of their biomass during the last three decades and for some of them this was probably due to a decline of the primary productivity.

It is therefore advisable that in the future the effect of phytoplankton on clams at various densities will be closely monitored by means of various condition factors proposed by LUCAS & BENINGER (1985) for bivalve rearing plants. In this view more extended seedling trials of the *C. gallina* juveniles (PRIOLI *et al.,* 1998) at selected sites could be useful for both scientific and practical purposes, although less stressing methods could be necessary (e.g. short fishing tracks and weaker water jets in the dredging cages) to avoid that the growth of the resettled clams is negatively affected as supposed by DEL PIERO & FORNAROLI (1998) for the clams routinely returned to the sea by the commercial fleet.

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Dugoročno opadanje zastupljenosti vrste *Chamelea gallina* L. (Bivalvia: Veneridae) u ribarskim lovinama u Jadranu: da li je moguće objediniti uzroke?

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SAŽETAK

Od ranih 70-ih relativno veliki dio ulova školjkaša bio je zansnovan na uporabi hidrauličnih dredža i bio je u porastu, naspram kasnijem padu ulova, duž talijanske obale Jadranskog mora (središnji Mediteran). U kasnim 70-im godinama zabilježen je ulov od 80.000-100.000 metričkih tona godišnje (i to prema najboljoj procjeni zasnovanoj na povjerljivim intervjuima ribara, prodavača morskih plodova i uvidom u ribarstvena trgovinska izvješća), no kasnije je progresivno ulov opadao i to na jednu šestinu prethodno navedenog iznosa.

U Italiji je to bio prvi dio ribarstva koji je bio kontroliran putem licenci i čiji je broj bio ustanovljen na nacionalom nivou kako bi se flota i ribarstveni napor održavali nepromijenjenim, ali broj ovlaštenih brodova se povećao tijekom 80-ih i tehnička dostignuća su omogućila da se jednim potegom može više površine izloviti po jedinici vremena. To objašnjava činjenicu zbog čega su primjenjene razne mjere kako bi se smanjio izlov naselja školjkaša (kao npr. povlačenje brodova, uspostava lovostaja, veći otvori na rešetkama), a ograničeno smanjenje flote je obavljeno u kasnim 90-im nakon veće smrtnosti koja je bila zabilježena u kasnom ljetu – ranoj jeseni 1996. godine.

Istovremeno utjecaj nepoznatih čimbenika u okolišu je povremeno bio prisutan i u ribarstvu, a veća gutoća naselja školjkaša kao i drugih riba i ostalih izvora školjkaša u Jadranu u usporedbi s drugim područjima u Mediteranu je bila povezana uz veliki unos slatke vode rijeke Po i drugih rijeka.

Zbog neusklađenosti u literaturi, pregledali smo sve dostupne radove (ili približno sve) koji se odnose na ulov školjkaša u Jadranskom moru (uključujući nacionalne zakone, izvješća o eutrofikaciji obalnih područja u sjeverno-istočnoj Italiji, i ostalo) s ciljem boljeg razumijevanja uloge čimbenika okoliša (tj. koji se ne odnose na ribarstveni napor) naspram utjecaja ribarstvenog napora kao mogućeg uzroka opadanja količine školjkaša. Niska kvaliteta mnoštva podataka otežava određivanje uzroka opadanja količine školjkaša, dok indirektni pokazatelji ukazuju na progresivno smanjenje dotoka svježe vode u Jadransko more i sadržaj fosfata kao čimbenike koji imaju važnu ulogu u cijelom procesu.

Ključne riječi: *Chamelea gallina*, rijeka Po, fitoplankton, produktivnost