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Review

Review of the Scientific Literature on Biology, Ecology, and Aspects Related to the Fishing Sector of the Striped Venus (*Chamelea gallina*) in Northern Adriatic Sea

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Abstract: Striped venus (*Chamelea gallina*) is one of the most important fish resources on the west coast of the Adriatic Sea. Recently, there has been a widespread die-off of *C. gallina* populations in Friuli-Venezia Giulia (northern Adriatic Sea, Italy), probably due to unfavorable climatic events. Overall, wild populations have become increasingly rare due to many factors affecting the ecological balance of the species. In this study, the available literature was reviewed to determine the current state of knowledge on the biology, ecology, fisheries, and status of *C. gallina* populations with reference to populations in Friuli-Venezia Giulia. However, few data are available in terms of peer-reviewed articles; much of it can be found in the gray literature (e.g., project reports, ministerial reports, institutional websites, etc.). However, a critical review of the sources reveals that the species is as endangered as the habitats it inhabits. As a result, conservation and restoration efforts have been undertaken to date as part of some larger project to protect the species. Therefore, considering the ecological and economic importance of this species, the results of the new studies will be useful for the scientific community and will be a key element in the conservation of this species.

Keywords: clams; fishing; hydraulic pumps; natural resource depletion; species conservation; stock sustainability

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1. Introduction

In recent years, given the increasing availability of primary products from aquaculture, the consumption of clams in Italy has increased to such an extent that Italy itself has become the first European producer and the second in the world after China [1–4]. As far as aquaculture resources are concerned, most of them are accounted for by some species belonging to the family Veneridae, commonly known as clams [1,3].

Clam farming in Italy has increased since the 1980s, also due to the introduction of the Japanese carpet clam, also known as the smallnecked or Manila clam (*Ruditapes philippinarum*). Although it is a subtropical to low-boreal species of the western Pacific, it has become permanently established in various parts of the world, including Italy. This is probably related to the overexploitation and irregular yields of the native (European) grooved carpet shell (*R. decussatus*) but also to the fact that *R. philippinarum*—which has considerable commercial value—is more resistant to disease and has a higher growth rate than the related *R. decussatus* [4–6].

In Italy nowadays, not all clam species are farmed; for example, the striped clam (*Chamelea gallina*) is obtained directly from natural stocks because of the peculiarities of its ecological niche and the influence of the seasons [7]. Thus, the recovery of the species in relation to its availability in the environment represents a clear element of "fragility" in the trade of *C. gallina*, but the economic interest in this species is remarkable. Therefore, it is critical to implement measures to restore and/or exploit natural populations that are prudent, scientifically sound, and allow for the conservation of the resource over time [8].

To understand as much as possible about the biology, ecology, and fisheries aspects (i.e., natural cycles and methods of exploitation, fishing stops, and potential range restoration) of this species, a review of the scientific literature is proposed. The aim is to define the current state of knowledge about the natural coasts of Friuli-Venezia Giulia (northern Adriatic Sea, Italy), identify knowledge gaps, and integrate official data from national surveys with data from different scientific documents.

2. Growth and Reproduction of *Chamelea gallina*

Chamelea gallina is a burrowing species and is characterized by a lenticular shell covered with numerous concentric rings, irregular, with a very variable colour (brown-whitish or grey with dark spots). The two thick valves are welded together by elastic bands and are characterized by a hinge mechanism with three teeth each [9].

The maximum known size is 5 cm (about 8 years old), while the average size ranges within 2.5–3.0 cm [10].

Chamelea gallina is a typical example of an infaunal, microphagous filter-feeder: water is inhaled from one of the two siphons formed by the fusion of mantle valves (inhalation siphon) and exhaled from the other (exhalation siphon) [11]. The animal filters the organic particles that make up its diet. In addition to the respiratory function, the gills also act as a filter for the food particles. These particles, coated in a mucilaginous substance secreted by the epithelium of the branchial organs, are transported on the ventral side by a system of cilia toward the cilia on the labial palps. The coarser particles are accumulated in the posterior region and expelled by contraction of the adductor muscles in the form of pseudofeces. This type of feeding makes them particularly sensitive to the water quality in their ecosystem and to the effects of suspended sediment. With respect to the latter, deleterious effects such as mechanical abrasion of the gills, stress and increased susceptibility to disease, and loss of growth due to changes in normal diet are foreseeable.

Chamelea gallina is a gonocoristic species (sex ratio ~ 1:1) [12] with external fertilization and an annual reproductive cycle characterized by a phase of gametogenesis in both males and females, followed by one or more gamete emissions [13]. The reproductive cycle of *C. gallina* exhibits high variability depending on environmental conditions, and the time period during which sexual products are emitted can vary greatly, even in relatively small areas [10].

The reproductive cycle has been studied in the Mediterranean [14–18] and the Black Sea [19]; the northern Adriatic Sea [20,21]; the Andalusian coast, especially the Gulf of Cadiz [22,23]; and the Algarve coast [24]. In the Mediterranean, gametogenesis may start in winter (i.e., November and December) and continue until March [25]. With the rise in temperature starting in April, the gonads reach maturity, and the first emissions of gametes may occur, peaking in June and July and in some cases in August and September [7]. On the coasts of Portugal (Algarve coast), this species has a release period between June and September, after gamete formation begins in November [26]. In the Adriatic Sea, the spawning period extends from March to September (with possible temporal extensions), while the reproductive pause is between October and December, with exceptions caused by temperature increases or anthropogenic stress [20].

The attainment of sexual maturity is determined by the size (approx. 1.6–1.8 cm [6]) and age of the individual, while fecundity is strongly influenced by environmental factors (especially temperature). Two larvae emerge successively from planktonic fertilization: the "trochophore", which is the simplest larva, and the "veliger", which is more complex. The larva is characterized by a very thin shell and a large circular velum. During the varying lengths of time (15–30 days) that the larva lives in suspension and is carried by the current, it begins to deposit calcium carbonate in the shell. When the weight of the shell no longer permits transport, the animal begins to sink into the substrate [27,28].

As for the populations in the Adriatic Sea, national research campaigns in 2017–2018 have deepened the knowledge of the reproductive, spawning, and resting phases of this species. In 2017, samples were collected in the Ancona-San Benedetto section (middle Adriatic Sea) from April to June, while in 2018, monthly analyses of the stock, oversize and undersize, were conducted from March to November [29–33]. These campaigns confirmed the reproductive peak between May and September and a period of maximum emission between June and July. From March to June, the sexes are perfectly identifiable for macroscopic and histological analyses to determine the maturity stage, while from July, after the spawning season, the highest number of undeterminable individuals is observed. The dormant period lasts until November, the month in which the gametogenic cycle resumes. The different environmental conditions between the two years were crucial for the different sizes of the first maturity found as the differences between the different studied areas, as reported in the available literature (Supplementary Materials Tables S1–S3). In 2017, an average surface temperature of 18.90 °C was measured in the Adriatic Sea (with a minimum of 13.20 °C in February and a maximum of 30.17 °C in August). The surface values of the Italian seas were well above the 1961–1990 climatological average [34]. In 2018, the surface temperature of the Adriatic Sea was slightly lower in March, reaching a minimum of 13.0 °C.

However, if we consider the average annual anomalies compared to the thirty reference years of climate from 1961–1990, 2018 ranks second in the entire series with an average anomaly of +1.08 °C [35]. The influence of environmental conditions on the biological cycle was also noted in the 2016 research campaigns, where mature specimens were also found in February; this phenomenon is due to energy requirements for reproduction. Energy reserves are important for reproduction, as the timing and rate of energy storage in clams depends mainly on temperature and food availability [25].

After hollowing, clams settled in a vertical position with siphons protruding from the sediment, starting the typical adult benthic life and filtration activity necessary to find organic matter and small planktonic organisms. The growth is relatively fast. In the Adriatic Sea, the clams have a diameter of 1.6–1.8 cm after about one year, and after about two years, the commercial size of 2.5 cm is reached [10]. As the clams grow, the shell increases in size and thickness and becomes more robust due to the deposition of calcium on the edge and inside of the valves, which can be seen in the concentric stripes and ribs. The thickness and strength of the shells are affected by solar radiation and water temperature at the surface. In a study conducted in the upper Adriatic Sea, Gizzi et al. [36] found smaller, macroporous, and less robust shells in organisms exposed to higher solar radiation. In other studies, the same phenomenon was found in organisms exposed to low surface temperatures [37,38].

These results suggest a relationship between temperature and its influence on calcium carbonate ($CaCO_3$) availability. Indeed, the availability of $CaCO_3$ varies with decreasing temperature, as does the energy cost of forming the shell itself [39]. However, comprehensive studies of these characteristics in relation to growth rate have not yet been conducted.

Clams' growth has been shown to be closely related to sea surface temperature, as low surface temperatures are associated with low growth and development rates [40,41]. The effects on the physiology of *C. gallina* were studied by Moschino and Marin [42] using samples exposed to different temperatures. The study considered the balance between the processes of energy acquisition (feeding and digestion) and energy expenditure (respiration and excretion), which allowed a direct measurement of energy status. It was found that *C. gallina* specimens exposed to high temperatures (28 °C) exhibited decreased energy acquisition and increased energy expenditure through respiration. This negative energy balance also has a negative effect on growth [42], as was found for the Spanish coasts when summer temperatures reach values above 27 °C [43].

Although there is no work that directly examines the correlation between growth, solar radiation, and sea surface temperature, the latter two factors have a direct influence on the biotic and abiotic components in the marine environment, such as the presence of phytoplankton both in terms of density and distribution [44]. The concentration of food supply is one of the factors that most influence the growth of filter-feeding bivalves [45]. In the Adriatic Sea, the distribution of phytoplankton is characterized by the influence of the Italian river courses, which flow in the northern area and have low density and high concentration of phytoplankton, while the Mediterranean waters in the southern area are characterized by high density but low concentration of phytoplankton, so that the phytoplankton content decreases from north to south [46].

Another factor affecting the growth of the species is anthropogenic pressure, both in terms of the impacts of fishing effort and the negative effects of water acidification and pollution, which contribute to the reduction in shell thickness [47].

Studies of *C. gallina* growth have been conducted over time using a variety of methods, so it is useful to consider and compare the results of the main methods. The age of clams can be estimated using a variety of methods: marking and recapture experiments, analysis of length-frequency distributions, counting of annual growth features (rings visible externally on the shell surface, internally in the microstructure of shell sections [24,48–50]), and analysis of the isotopic composition of oxygen along the direction of shell growth [50–52]. To ensure continuity, the same methods studied in the "National Management Plan for Fisheries Activities with the Hydraulic Dredging System and the Rake from the Vessel" were compared.

The following analyses are compared in the study mentioned above:

- The analysis of the modal components in the frequency distribution linking an age to the different pseudocohorts identified in the size distributions and whose evolution was observed over time. This method is widely used in older studies in the Mediterranean and Atlantic [12,43]; it is currently supported by other methods to allow comparisons and validations;
- Analysis of the outer growth rings of the shell. The formation of the outer rings occurs annually in winter, during a period of growth slowdown, and is considered by many authors to be rapidly applicable [14,26]. However, as mentioned above, this method could be flawed considering what Gizzi et al. [36] found regarding the influence of temperature on the development of the shell and consequently on its appearance;
- Microscopic analysis of the deposition lines inside the shell with counting of the annual cracks [48,53,54]. This approach overcomes the interpretation difficulties of the previous method. However, even in this case, the influence of solar radiation on macroporosity and fragility of the shell must be taken into account [36,50].

The results of the size frequency distribution analysis show that the sizes at 1 and 2 years of age correspond to 1.8 and 2.5 cm, respectively; however, at older age, the estimated sizes seem to be affected by a flattened curve [43]. When comparing the different methods, Mancuso et al. [50] found no significant differences between growth curves obtained using outer ring analysis and those obtained using inner rings. However, the numerous differences found in the various studies cited suggest a decreasing growth rate with age, with year-to-year variations due to many factors. Therefore, it was hypothesized that the attainment of the commercial size of 2.2 cm occurs between the second and fourth year of age, depending on the geographic area and survey method. For the Adriatic Sea, recent surveys conducted between August 2013 and April 2015 have shown that *C. gallina* reaches commercial size at about 1.5 years of age, with shell characteristics varying depending on latitude [50]. Greater porosity was observed in small shells, which decreased dramatically upon reaching the size associated with sexual maturity. These results suggest that *C. gallina* appears to prefer shell porosity during the first year of life in order to maintain a higher linear expansion rate and reach sexually mature size more rapidly [50]. Further studies conducted during the 2017–2018 national research campaigns for the northern and central Adriatic revealed negative allometric growth when the length-frequency curve was applied. This means that the weight of clams increases more slowly than their length [55–58].

3. Distribution and Habitat of *Chamelea gallina*

Chamelea gallina is distributed throughout the Mediterranean, reaching the coasts of the Algarve in Portugal, the Black Sea, and the Sea of Marmara [26]. The species is also found on the northern coasts of Morocco and until the mid-1990s was considered a conspecific of *C. striatula*, whose purely Atlantic range extends north to southern Norway. In the Mediterranean, *C. striatula* is an occasional species, occurring mainly on the Spanish coasts [59–61].

In Italy, the species occurs on all sandy coasts and is particularly abundant in the Adriatic Sea from Trieste to Molfetta and in some limited areas on the coast of Lazio and Campania. The clam prefers sandy or muddy-sandy soils of the infralittoral and circalittoral at depths from −1 to −18 m [62] with medium to high hydrodynamics. In the Adriatic, this means an area within 1 to 2 km from the coast, where it is abundant in the biocenoses described by Pérès and Picard "of well-sorted fine sand" [63]. Where it occurs, it often dominates in terms of both biomass and number of individuals forming distinct facies of the benthic community together with the tube-living bristle polychaete (*Owenia fusiformis*) [64]. The clam occupies a well-defined ecological niche in the Adriatic Sea, determined by precise chemical-physical conditions of both water and sediment (e.g., particle size, oxygen content, and redox potential). The optimal habitat is characterized by low variations in environmental parameters, chemical parameters with a redox potential greater than +50 mV [65], and sediment granulometry consisting of medium, fine, and very fine sands (<90%).

This range currently appears to be decreasing [66], and environmental factors may be affecting *C. gallina* populations [67]. The progressive increase in the granulometric component of muddy sediments, which are less suitable for the clam's development, seems to be responsible for the increasing rarity of the species, up to its complete disappearance in areas characterized by muddy sediments [66].

The phenomenon of rarity seems to be due to a variety of different factors, including:

- Reduction in the salinity of the estuarine water due to increased freshwater inflow, which may have altered the osmotic balance of molluscs;
- Discharge of toxins by industry and factories (e.g., mills);
- Leaching from agricultural lands and associated inputs of pesticides to water bodies;
- Severe storms;
- Oxygen deficiency (anoxia) or low oxygen concentration (hypoxia);
- Temperature fluctuations;
- Increased water turbidity due to elevated suspended sediment concentrations, a consequence of the presence of silt, a material of terrestrial origin whose transport to the sea via waterways increases significantly after abundant rainfall;
- Increased turbidity of the water due to the resuspension of sediments by wave action;
- Direction and intensity of ocean currents, which affect the transport and dispersal of species in the planktonic larval stage (i.e., veligers) [66].

4. Survival, Production Decline, Local Mass Mortality, and Fishery-Induced Mortality for Released Undersized Individuals

In the last 20 years, the shellfish fishing sector has undergone an extreme crisis caused by local phenomena of mortality, also massive in nature, both chronic and occasional, in the Italian fishing vessels involved in the exploitation of the resource. At that time, the owners of fishing companies using hydraulic dredges reported widespread shellfish mortality in the central and northern Adriatic Sea, stretching from Veneto to Abruzzo. However, more recently (2020), events affecting limited areas were observed (Supplementary Materials Table S4).

In 2008 alone, marinas recorded production declines ranging from −15% to −61% (Ravenna and Monfalcone, respectively) due to mortality, with an overall average of −49% of total production. In the shellfish consortia of Chioggia and Venice, the decrease was −55% compared to the overall average and even −71% compared to 2007 [68].

Recent events in the upper Adriatic Sea refer to 2018 and 2020. Overall, a decrease in biomass levels was observed between 2017 and 2018, in marine areas off Grado (Friuli-Venezia Giulia). In particular, in 2017, a biomass of marine clams ≥2.0 cm was observed (about 4 g/m^2)—this value seems to be close to zero (0.2 g/m^2) in the following year—confirming the condition of a significant production crisis in this area [69].

The short-term effects of dredge fishing on benthic communities have long been studied [70]. Studies have been conducted on the survival of clams returning to the sea after sieving, using laboratory simulations in experimental tanks to determine the ability of shellfish to re-bury [70]. In addition, experimental survival campaigns were conducted as part of a monitoring series prior to the implementation of various measures in the northern Adriatic Sea to assess the average survival time under controlled environmental conditions [69,71–73].

In the first study cited, Morello et al. [70] considered two factors:

- The stress to which the bivalves were subjected after capture, which in turn was divided into two categories (hydraulic bivalve dredges: specimens collected in the collection tank, marked "D"; hydraulic dredges plus sieve sorting: specimens collected before returning to the sea, marked "S");
- Temperature, checking survival at +12 °C and at +20 °C.

The authors collected 20 specimens for each category studied (i.e., D and S; total n = 40), which were kept in separate tanks with the same basic physical parameters (the experiment was repeated in triplicate). Subsequently, two tanks were kept at +12 °C for four hours and two others at +20 °C. The number of clams that did not die during these 4 h was checked. The study showed that there were no significant differences in the percentage of bivalves that died after 4 h (<35%), nor in the time it took 50% of the specimens to die again (about 3 h). This suggests that clams can burrow regardless of temperature and/or disturbance factor. These results are consistent with what several authors have said about the capabilities of organisms that live in high-energy environments and are constantly exposed to natural environmental stress and are less susceptible to disturbance by fisheries [74–76].

In addition, in 2013, in a study conducted by ISPRA [71,77] on clams caught with commercial dredges, overall, 40 bivalves were selected for each station and placed in plastic containers lined at the bottom with water-soaked absorbent paper. The containers were maintained in a thermostatic cell at a controlled temperature of 18 ± 0.5 °C (mean ± standard deviation). Each day, the number of dead individuals was recorded to calculate the lethal time LT_{50} (number of days in which 50% of the organisms die). Results ranged from 3.80 to 10.20 days, with an average of 6.20 days.

In 2018 and March 2019, AGRI. TE. CO. [69] conducted similar survey campaigns to ISPRA in 2013, using 30 individuals per station instead of 40. In both years, analyses of specimens from four stations near the entrance channel to the port of Lignano Sabbiadoro (northern Adriatic Sea) resulted in a 7-day LT_{50} with survival rates ranging from 36.7% to 50.0%. On the other hand, the campaigns carried out in July 2019 in the marine waters off Grado (northern Adriatic Sea) did not yield any results due to the absence of specimens (Municipality of Grado, 2019) [69].

In these cases, it should also be considered that the LT_{50} value is influenced by seasonality and other factors such as salinity and dissolved oxygen availability, as well as fishing activities. For instance, in a study on air exposure, Matozzo et al. [78] observed different survival times of 4, 5, and 7 days at different salinities (i.e., mean salinity, hypersalinity, and hyposalinity) at 28, 40, and 34 PSU, respectively (mean salinity of the Adriatic Sea).

Projects are currently underway to improve the selectivity of fisheries based on hydraulic dredging [29–33]. In these projects, experimental tanks are used—again, the bottom of the tanks is covered with sand—to mimic natural conditions in the laboratory at constant temperature, using a) a feeding system with microalgae and b) a metal cage fixed in the sea to prevent the clams from escaping and to evaluate their survival. In addition to survival under standard conditions, potential survival of individuals stressed and/or damaged by the dredge and/or screen will also be considered [29–33]. Additional surveys will be conducted with underwater cameras to monitor survival after passage of the hydraulic dredge and to assess the ability and time to burrow due to fishing operations.

5. Fishing Methods and Fisheries

The catch of *Chamelea gallina* is one of the most important fishing activities in the Adriatic Sea area. For the economy of this sector, the management of coastal stretches is fundamental, especially in response to natural disasters. The most severe in recent years was the summer of 2008, whose losses affected the production of the following years [79–88] (at least until 2011, according to the Socioeconomic Observatory of Fisheries and Aquaculture-Agriculture of Veneto).

The industrial clam fishery started in the 1930s and 1940s and was exclusively manual during a limited period of the year, between November and February. The turning point of this fishery was the introduction of the engine, which facilitated not only the locomotion but also the use of the windlass, which could no longer be operated manually. Since the 1970s, the use of the engine favored the development of a new fishing system: the hydraulic dredge. This device consists of an iron cage in the shape of a parallelepiped with an adjustable blade at the front to cut the sediment, and a system that directs pressurized water to the nozzles arranged in different rows. The first row of nozzles, located near the blade, has a blasting function to facilitate fishing, while the other three to four rows, located inside, provide initial cleaning of the fish trap, and remove much of the sediment present. The fish trap is supported by two sleds and generally has a width of about 2.70 m and a weight of 600 kg [12]. Fishing is conducted in the reverse direction after the dredge is lowered from the bow. At the end of the haul, the basket is lowered, and its contents are poured into a collection tank, which is followed by the washing and sieving phase [7]. The sieving phase is crucial for the selection of commercial size clams, and the parameters and limits set in the ministerial guidelines are crucial for defining the selectivity of the dredge. However, there is potential for the fishermen to influence the actual selectivity of both the dredge and the screen to ensure uniformity of removal between boats in the same compartment and to define the minimum diameters of usable holes.

The selectivity of the fishing gear used is one of the fundamental technological aspects considered indispensable in population dynamics to achieve a correct exploitation of fishery resources [89]. Selectivity is defined as the measure of the selection process of a fishing gear or the process that results in a catch whose composition is different from that of all organisms present in the area where the fishery is conducted [89]. This term refers to the ability of a fishing gear to catch mainly only certain sizes of a certain species, and the selection of the different species present in the sea. In order to have fishing gears that allow the escape of juveniles of a given species, meshes with appropriate opening and shape are usually used. Selectivity by species, on the other hand, depends on the armament used [89]. Thus, selectivity depends on both the technical and ethological characteristics of the target species.

In the case of the bivalve, a burrowing organism, selectivity depends on the distance between the dredge bars and the diameter of the holes in the sieve. Dredge selectivity studies have shown that fisheries do not catch small specimens that are not even brought on board for sieving. As mentioned above, the sieving stages are the most important selection processes, where national regulations and self-regulation of the consortia influence the selectivity, which does not allow the collection of individuals less than 2.1 cm in diameter. A study carried out in the Adriatic Sea showed that the selectivity of the vibrating screens currently used is optimal, since the retention of organisms less than 2.2 cm is negligible [90]. The drop is sufficient to allow reasonable seeding and restocking, and the percentage of clams smaller than 2.2 cm that return to the sea immediately after sieving is over 95%. The fishing system in Italy has been regulated since 1995 by Ministerial Decree No 44 of January [91], which allows the establishment of shellfish management consortia (Co.Ge.Mo.). Over time, the legislation has been updated and renewed in several steps [92–99].

However, if we consider only the maximum number of shellfish allowed, the legislation dates back to 1965 with Law No 963 and its implementing regulations of 1968. In those years, each fishing boat could catch up to 2500 kg of shellfish, and there was neither a fishing season nor restrictions on the fleet in terms of numbers or geographical distribution among the different areas. The introduction of these restrictions over time and the blocking of new licenses have led to changes not only in the fishing sector but also in related industries. This was followed by the reduction in the daily limit to 1200 kg and the introduction of the biological fishing ban. When the fleet finally stabilized, the limit was further reduced to 600 kg.

A brief review shows that it is not possible to use catch levels as an indicator of stock welfare. While annual catches in the 1970s were about 100,000 t live weight, today, they would not even reach 35,000 t per year (even if all authorized fishing vessels fished the maximum allowable amount on all fishing days).

In addition, the introduction of the Regulation (EC) No 1967/2006 [100] has contributed to a further reduction in fishing effort by reducing the total areas available for fishing by about 52%. Subsequently, the application of the Decree of 27 December 2016 [98] was also crucial. Weekly fishing days were reduced by 20% (from 5 days provided for in the Decree of 22 December 2000 [93] to 4 days), and maximum catches were reduced by 33% (from 600 to 400 kg per fishing vessel).

Thus, the implementation of this plan has resulted in a significant reduction in fishing effort. First, there has been a decrease in total fishing days, and second, there has been a reduction in the maximum marketable quantity. In addition, the quotas and the change in commercial size (Reg. (EC) No 1967/2006) [100] have allowed the planned quotas to be reached in a short time, further reducing the impact on dredging areas.

Currently, there are 17 administrative consortia in Italy (Supplementary Materials Table S5a,b), almost all of which are equipped with a remote sensing system. Remote sensing allows the verification of fishing effort also from a spatial point of view and the adoption of appropriate management measures based on the exploitation rate of the areas (rotation of fishing areas), as well as the possibility to calculate the actual catch per unit effort (CPUE) based on the actual fishing effort in terms of actual fishing hours.

Initially, the actual potential impact of dredges on the marine ecosystem was minimized [62] because few mollusks appeared to be harmed by the fishery and organisms discarded at sea were still alive. Furthermore, in a 1988 study in the southern Adriatic Sea, Vaccarella [101,102] showed that 30–60 days after the passage of dredges, natural conditions returned. Subsequent studies have brought to light the effects of dredging mainly on snails, bivalves, and crustaceans, while the effects on the rest of the macrobenthic community are generally attributed to natural factors and past fishing activities in shallow waters due to adaptation to environmental stress [101,102].

However, disturbance also affects the sediment component, for which some studies have shown a change in composition and pelitic fractions in areas where dredging has occurred [70]. On the other hand, medium- or long-term studies have shown that communities can recover in about six months if fishing effort is reduced [70].

Among the studies conducted on the impact of this fishing system, there is a 2018 study that shows that fishing pressure on *C. gallina* in the upper and middle Adriatic has not led to bottlenecks and, consequently, to an impoverishment of the genetic variability of the species [103].

The recent regulation of 5 July 2019 [104] confirms the catch limit of maximum 400 kg per day per fishing vessel for four days of weekly fishing according to the "National Plan Rigetti" [105–107] promoted by the then Italian Ministry of Agriculture, Food and

Forestry (MIPAAF). It also establishes the spatial limits of the various shipping companies in the water under their jurisdiction, an activity that is monitored thanks to the provisions of GPS. The minimum size is set at 2.2 cm, while undersized products are relocated by the consortia to restocking areas after being sighted on board or ashore, with all commercial-sized shellfish returned to the fishing vessels. Fish quantities are recorded daily in special registers. Between April and October, there is a minimum two-month fishing break in each compartment, plus additional blocks determined by the consortia themselves in case of mortality or marketing problems.

Remedial measures primarily include seeding, restocking, and rotation of fishing areas. These measures are now implemented by most consortia and supported by scientific advice from the research institutions they sponsor, which they also rely on for monitoring.

The above comments on fishing effort show that this indicator is not reliable enough to determine the presence or absence of *C. gallina*. The different laws and guidelines, as well as the "National Plan Rigetti" [104–110], have established the biomass per m^2 as a criterion for monitoring the good status of the resource. In order to facilitate the work of fishermen and to provide an immediate tool for determining the health status of a fishing area, the biomass of commercial-sized organisms is studied. By combining socio−economic and biological aspects, it is possible to determine average density values that represent both limits below which fishing activity is not allowed and the optimal values to achieve optimal fishing results.

Marine compartments are characterized by widely varying conditions: there are large areas ranging from 30% to 60% where fishing is not allowed because they are breeding areas within 0.3 miles offshore, depending on the health classification, or areas subject to restrictions. In each fishing area, there are areas of high density, even over 1000 small clams/m^2 (<1.0 cm); these areas are flanked by areas with a few dozen specimens with an average size of 1.8–2.0 cm.

The minimum density of clams to be commercially fished was set at a minimum of 1 individual per m^2 at commercial size in M.D. 24 July 2015 [97], which corresponds to a value of 5 g/m^2. Not only the mean values should be considered but also the values below the lower limit, slightly above and above the upper limit. In addition to the biomass, the study of the frequency distribution of the lengths allows one to determine the areas where the clams will exceed the commercial size in the following months in order to plan the catching and seeding actions in areas of low density. Table 1 shows the reference values for clams in the different compartments.

Table 1. Reference values of clam density (g/m^2) in the various FAO Geographical Sub Areas (GSAs) (Reg. (EC) n. 1967/2006) [100].

Survey Area	Site	Good Management	Critical Range	Prohibition of Fishing
			g/m²	
GSA17	Upper-Middle Adriatic	>10.00	5.00–7.50	<5.00
GSA18	Southern Adriatic	>8.00	4.00–6.00	<4.00
GSA9–10	Tyrrhenian	>8.00	4.00–6.00	<4.00

Each association sets limits for underutilized areas and daily quantities for its area to avoid oversupply of product to the market and provides continuous monitoring to plan fishing activities. Monitoring may reveal that the average density of commercial product is below the established limit, in which case, fishing activities must be suspended for 15 days. If the levels are in the critical range, the shipping authorities are informed, and monitoring is repeated within two months until the levels in the area or sub-area no longer exceed the reference level for closure.

Bottom trawling represents the most widespread fishing method in Italy (33%), followed by artisanal fishing (24%) and multi-purpose vessel fishing (14%). It is confirmed that the fishery is mainly concentrated in the Adriatic Sea, where 59% of the catch is taken, while the Tyrrhenian Sea accounts for 20% of the total [111,112].

This scenario includes the shellfish fishery, which accounts for 16.6% of catches and 13.7% of values, with clams accounting for 53% of the total. In the last twenty years, the production of clams has been subject to a fluctuating trend worldwide (Figures 1 and 2), especially in Italy. The Community policy of the early 2000s, which promoted the renewal of the fleet, led to an increase in production between 2006 and 2008, while the following years were affected by the great die-off of 2008 and the increase in fuel costs, with a recovery in 2012. The almost constant production in recent years is due to the new measures adopted at the community level in terms of commercial size and fishing areas (Figure 1).

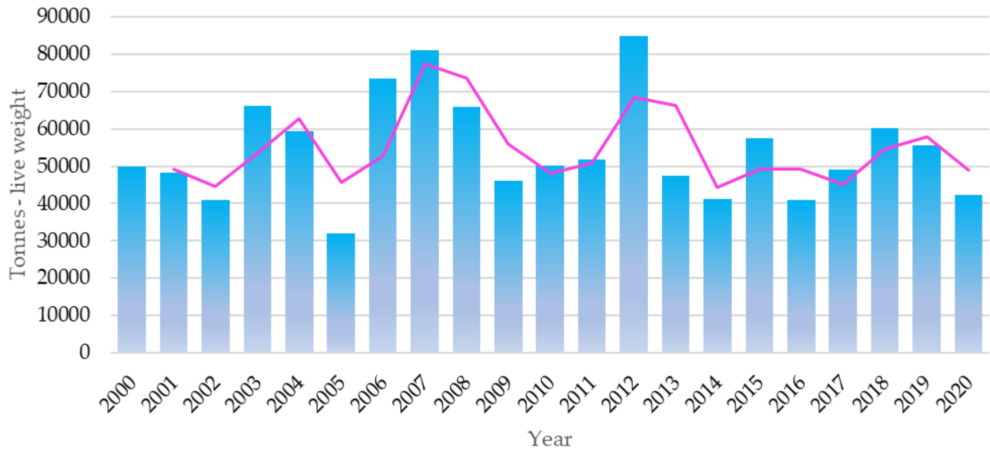

Figure 1. Global capture production of striped venus (*Chamelea gallina*) from 2000 to 2020. The purple line indicates the moving average value ([4,5] FishStatJ v. 4.02.06).

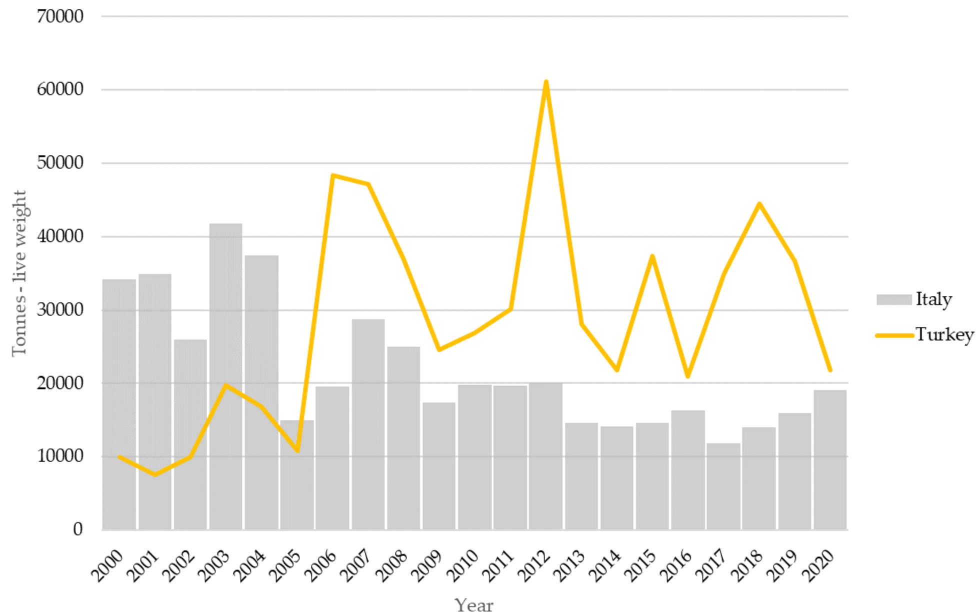

Figure 2. Comparison between Italian (grey) and Turkish (yellow) production of striped venus (*Chamelea gallina*) from 2000 to 2020 ([4,5]; Bivalve Molluscs Activities of official control 2018 (FishStatJ v. 4.02.06)).

In terms of total production, Italy is second only to Turkey; however, this trend is influenced by EU policies because, since 2006, when the Regulation (EC) No 1967/2006 [100] was issued, imposing numerous restrictions on shellfish fisheries in EU countries, Italian production is no longer dominant compared to Turkish production but plays a minor role that is gradually decreasing until today (Figure 2).

The surveys carried out included income economic data in addition to production values, and it was highlighted that the retail price for the Adriatic compartment is also subject to a seasonal decline, which on an annual basis led to a decrease in 2017–2018 (0.50%).

As mentioned above, the clam fishery in Italy is managed by GSA17–18, as well as GSA9–10, for which production is defined by minimum quantities and fishing days and areas. The fishery is mainly concentrated in the Adriatic Sea with a total of 588 vessels out of 706. In economic terms, hydraulic dredges as a segment contribute about 5.70% to the gross production value of the entire Italian fishing sector. The total production in 2017 and 2018 represented 10.36% of the total fish production of the Italian fleet.

In order to protect this resource, the different maritime departments monitor the resource based on the reference points indicated in M.D. 24 July 2015 [97], in accordance with the "National Rigetti Plan" (Annex 2 of M.D. 17 June 2019) [99].

However, the survey campaigns carried out do not include data for the Friuli-Venezia Giulia sector. The sources used were different: until 2011, the IREPA data could be used [79–88]; for the other years, documents of the Friuli-Venezia Giulia Region, of the administrative consortia, and of the relevant scientific institutions were used.

6. Status of the *Chamelea gallina* Stocks in North Adriatic

In the Friuli Region, the Monfalcone Fisheries Management Consortium (Co.Ge.Mo. Monfalcone) is entrusted with the management of *Chamelea gallina* stocks, but also, in general, with the management of all stocks fished by fishing boats with dredges, including the razor clam (*Ensis minor*) and the peanut worm (*Sipunculus nudus*) used as bait for recreational fishing.

The collection areas are mostly classified as "Class A" (16 areas), but there are also many "Class B" areas (22 areas); only one area belongs to "Class C" [113,114]. The sector audits carried out by the Friuli-Venezia Giulia Region and the Ministry have shown that the official control system for the live bivalve mollusk sector is functioning in accordance with the provisions of the Regulations. Moreover, in Friuli-Venezia Giulia, it was found that the activity planning process is adequate, the installations are consistently classified according to the risk, and the monitoring activity is regularly carried out by the service manager [115] (Official control mussel activities, 2018).

In the last 20 years, the policy applied to the sector, in addition to massive mortalities, has led to a radical decline in both the number of pieces and tonnage of production of this species. However, since 2010, the number of vessels affiliated to the consortium has remained unchanged, only the type of fishing that the vessels operate has changed (Supplementary Materials Table S6). In 2011, the 42 hydraulic dredges were divided as follows: 20 to collect clams offshore and 22 to collect cockles (*Cerastoderma* spp.) in the open Adriatic Sea. After an initial redesign in 2015, the vessels were reduced to 18, only to be reduced to 12 in July 2017 [116].

Most of the data are from surveys conducted by IREPA [79–88] on behalf of MIPAAF [105–107]. However, the data for 2000 refer to the Friulian and Venetian compartments with a total of 223 fishing vessels, so it is not possible to determine the number of fishing boats with hydraulic dredges. Due to the interruption of the IREPA survey activity from 2011, the knowledge gap could be filled only in 2014. This year, the censuses, and the organized collection of data on the specific economic sector resumed, thanks to the participation of the Socio-economic Observatory of Fisheries and Aquaculture, promoted by "*Veneto Agricoltura*" and Adrifish. The almost unchanged evolution of the number of boats is reflected in the tonnages and revenues of the sector, which seems to have increasingly higher costs.

Again, the change in data source leads to different interpretations. In fact, in the IREPA data, clams caught with dredges are treated individually, so that until 2011 only the production of *C. gallina* (Table 2) can be attributed to this system and is not associated with other species.

Table 2. Trend of the average quantities of clams caught in the Friuli-Venezia Giulia maritime compartment and related revenues in millions of euros (IREPA Onlus) [79–88].

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Tons	998	-	-	903	1447	1245	1340	1019	632	529
Revenue (M EUR)	4.88	-	-	3.90	6.40	4.75	4.67	4.51	2.93	2.41

The decrease in tons caught (it is recalled that in 2000 the data for the Friuli and Veneto sectors alone reached 5185 tons with a turnover of 10.86 million euros) and a not always favorable evolution of demand led to a decrease in the progressive growth of the revenues of the specific economic sector, with a decrease of more than 2 million euros between 2002 and 2011.

For the years 2012–2019, there are not many reliable sources, so it was preferred to provide certain data directly from the Administrative Community of Monfalcone. In this case, the data include the landed quantities for the razor clam resource, but there is no information on the revenues generated in the market (Table 3).

Table 3. Production (tons) of striped Venus (*Chamelea gallina*) and razor clam (*Ensis minor*) in the Maritime Compartment of Monfalcone (2013–2018) [116].

	2013	2014	2015	2016	2017	2018
Chamelea gallina	201.7	205.3	130.1	62.6	2.5	14.6
Ensis minor	115.8	62.4	18.0	19.9	23.9	4.0

Peanut worm (*Sipunculus* spp.) production in anticipation of clam recovery totaled 84 tons between 2015 and 2018, with an annual average of 21.10 tons [117], although a multi-species breakdown is not regular. Looking at the trend of annual landings from 2002 to 2018, a downward trend can be observed, but as mentioned above, these data alone are not sufficient to assess the good status of the resource and it is necessary to continue with studies aimed at determining the biomass of commercial specimens per m^2.

Between 2016 and 2019, cognitive surveys of the presence of *C. gallina* were carried out on the coasts of the Monfalcone marine compartment, where the Marano Lagunare and Grado areas are located between the mouth of the Isonzo River and the mouth of the Tagliamento River, in order to reactivate the resource for both complementary dredging activities and beach replenishment. The survey area is shown in Figure 3.

The analysis of the macrobenthic community associated with the natural banks of *C. gallina* along the canal of Lignano, at an average depth of -2 m, shows the presence of bivalves with percentages ranging from 37.8 to 33.7%, of which the species studied represent 24.3 and 28.7%. Gastropods are the largest group, with percentages ranging from 49.3% to 56.4%, while crustaceans complete the picture with an average of 9.9% to 12.8%.

At a lower bathymetry (-1 m), the macrofauna census led to the identification and cataloging of nearly 800 specimens, both in an initial survey phase in 2018 and later in 2019, with different results in the two years. In the first year of the survey, prior to feeding activity, gastropods represented the largest group (46%), followed by bivalves (45.9%). On this occasion, bivalves represented 35.50% of the total specimens recorded, while crustaceans represented 8.1%. In the second year of the study, i.e., after at least one dietary intervention, the results showed a dominance of *C. gallina* (53.7%), followed by gastropods (38.5%), other bivalves (6.3%), and, finally, crustaceans (1.5%) [74,116,117].

Figure 3. Coastal strip area of Friuli-Venezia Giulia (northeast Italy) investigated for the presence of *Chamelea gallina*. Each symbol represents a sampling site (modified from https://www.emodnet-bathymetry.eu/, accessed on 23 August 2022).

The same studies were also carried out in the same years at the mouth of the Tagliamento River, where it was found that the macrobenthos associated with *C. gallina* consisted of 35.7–46.4% crustaceans, 40.4–44.8% bivalves, and 8.80–23.90% snails.

An analysis of 140 specimens of macrobenthic fauna carried out in the Pineta di Lignano area showed that the community associated with the natural shores of *C. gallina* was mainly composed of gastropods (57.9%), followed by bivalves with a 25% share (16.4% bivalves and 8.6% other bivalves) and crustaceans (17.1%) [74,116,117].

In addition, analyses of abundance distribution of size and abundance were performed in different areas each year. For clarity, the areas studied per year and the available data are listed in Table 4 (data for each area are grouped below).

Table 4. Investigated coastal strip of Friuli-Venezia Giulia (northeast Italy) by year for *Chamelea gallina*. The data are contained in the scientific reports AGRI.TE.CO. produced for the Friuli-Venezia Giulia Region and the Co.Ge.Mo. of Monfalcone [73,116].

Survey Area	Population Structure	Biomass Pre-Restocking	Biomass Post-Restocking	Biomass	Surviving Tests
Punta Sdobba	2016	2016–2018	2016–2018	-	-
Banco Mula di Muggia	2016	2016–2018	2016–2018	-	-
Banco d'Orio-Bocca d'Anfora	2016	2016–2018	2016–2018	-	-
Isola di Sant'Andrea	2016	2016–2018	2016–2018	-	-
Lignano Sabbiadoro	2016	2016–2018	2016–2018	2018–2019	2018–2019
Tagliamento river mouth	2018–2019	-	-	2018–2019	2018–2019

Looking from the northeast to the northwest, the size distribution studied in 2016 was different. In the Punta Sdobba area, there is a higher concentration in the 1.5–2.5 cm size range, with no recruitment (specimens < 1.0 cm), probably due to the lack of larval settlement in summer. For Banco di Mula di Muggia, several individuals (n = 500) were examined to determine the structure of the population, which shows two distribution peaks: the first around 1.1 cm and the second around 1.9–2.0 cm, identifying the cohort that settled in summer 2015 and the fraction in the second year of life, respectively. In the Banco d'Orio-Bocca d'Anfora area, the biometric analyses concerned only 25 specimens: most of the few remaining belong to the second-year cohort (class 1+), and only four specimens belong to class 0+ (first year).

On the coast off the Isola di Sant'Andrea, the population shows a bimodal trend with peaks at 0.7–0.8 cm and 1.9–2.2 cm. Numerically, the cohort class 1+ (second year of life) is the most consolidated, showing the lowest recruitment and representing 25% of the total population. For Lignano Sabbiadoro, the 2016 surveys revealed a population with a clear distribution peak around 2.1–2.2 cm, confirming the stronger presence of the 2.0–2.4 cm class (about 60%) and the newly emerged fraction (0.1–1.5 cm), which represents 14.10% of the total [116]. In 2018, the number of sampled individuals along the Lignano canal (n = 36) revealed a population with an average length of 1.97 cm. These few tens of clams can be divided into three different size groups: > 2.1 cm the most numerous (about 64%), 1.4–1.7 cm, and 0.8–1.1 cm the other two with a representativeness of 15–20% each [74].

In the shoreline-only section (approx. −1 m depth), a population structure of *C. gallina* with a bimodal trend and distribution peaks at 0.7–0.8 cm (most evident) and 2.3–2.5 cm was observed in the same year.

The 272 clam specimens with an average size of 1.38 cm show a distribution in size classes, with 61% of specimens between 0.1 and 1.5 mm, 32.4% at 2.0 cm, and 6.6% between 1.6 and 1.9 cm [74]. For 2019, the same areas of the channel and the coast indicate different values. In the channel, the average length was 1.5 cm, which affected the size distribution, for which four size classes were identified: 51.7% with a size of 0.1–1.5 cm; 20.7% with a length between 1.6 and 1.9 cm; 6.9% with a size below the commercial class (2.0–2.1 cm); and the remaining 20.7% with a size of 2.2 cm. On the other hand, in the coastal region, the average length is 1.81 cm. In this case, the trend is also bimodal, but the peaks of the distribution are 1.2–1.8 cm. The distribution in size classes shows that 39.8% of the specimens fall in the 0.1–1.5 cm class, 14.5% in the 1.6–1.9 cm class, and 45.7% are larger than 2.0 cm [117].

In 2018, the number of sampled clams in the Tagliamento River estuary, was quite low (n = 80), of which 97.5% had a size of 0.1–1.5 cm and an estimated average total length of 0.64 cm. East of the Tagliamento estuary, a population of *C. gallina* was assessed with an average length of 1.19 cm and a trimodal distribution with a maximum peak at 0.8 cm and two other peaks with lower amplitudes at 1.7–1.9 cm and 2.3–2.4 cm [74]. In 2019, no clams were found at the mouth of the Tagliamento River, while in the eastern area, the average length was 1.0 cm, with a maximum of 1.9 cm [74]. On this basis, 87% represent the 0.1–1.5 cm class and the remaining 13% the slightly larger class (1.6–1.9 cm), with a frequency distribution of irregular size [117].

The surveys carried out between 2016 and 2019 show that the biomasses were very low compared to the reference values reported by M.D., which was also noted by the University of Trieste in 2012. The study found a significant lack of clams at depths greater than −5 m. The low abundance of clams is also reflected in the abundance of clams, which reached the density of 3 clams/m^2 in only three areas.

Tables 5 and 6 list the *C. gallina* biomass values in chronological and spatial order; data are grouped by area and survey year and further subdivided by size category [73,116]. Oversized organisms (greater than or equal to 2.5 cm according to Regulation (EC) 1967/2006) [100] those between 2.0 and 2.4 cm, assumed to reach this size within the three months following monitoring; and, finally, those less than 2.0 cm are considered.

Table 5. Biomass (mean value; g/m^2) of *Chamelea gallina* (divided by size as shell total length; cm) recorded in February 2016 before the reactivation activities in 2017, again to register the resource to proceed with a reactivation, and in September 2018 for the monitoring of the resource following the sowing that occurred in previous years [73,116].

Survey Area	February 2016			2017			September 2018		
	≥2.5 cm	2.4–2.0 cm	≤2.0 cm	≥2.5 cm	2.4–2.0 cm	≤2.0 cm	≥2.5 cm	2.4–2.0 cm	≤2.0 cm
Punta Sdobba	0.54	0.32	0.86	n.d.	n.d.	n.d.	0.00	0.00	0.00
Banco Mula di Muggia	0.10	4.42	4.51	n.d.	n.d.	n.d.	0.00	0.10	0.10
Banco d'Orio-Bocca d'Anfora	0.26	0.95	1.21	n.d.	n.d.	n.d.	0.10	0.10	0.20
Isola di Sant'Andrea	1.53	7.52	9.05	n.d.	n.d.	n.d.	1.50	2.00	3.50
Lignano Sabbiadoro	2.58	2.28	4.86	1.20	2.90	0.10	1.10	1.20	2.30

n.d. = data not available or not determinable.

Table 6. Biomass (mean value; g/m^2) of *Chamelea gallina* (divided by size as shell total length; cm) recorded during surveys carried out in the years 2018 and 2019 [73,116].

Survey Area	2018			2019		
	≥2.5 cm	2.4–2.0 cm	≤2.0 cm	≥2.5 cm	2.4–2.0 cm	≤2.0 cm
Punta Sdobba	1.05	0.30	1.35	0.65	0.15	0.85
Banco Mula di Muggia	5.65	2.40	8.05	9.40	4.30	13.70
Banco d'Orio-Bocca d'Anfora	0.00	0.00	0.00	0.00	0.00	0.00
Isola di Sant'Andrea	0.90	1.95	5.85	0.00	0.00	0.00

From Table 5, a framework emerges in which the biomass of *C. gallina* found is very modest, with average values of catchable product (2.5 cm) below 5 g/m^2 or close to zero (2018) [117]. Average abundance of 2.0 cm clams is quite low, approaching 10 g/m^2 at only a few sampling stations. In 2016, the subcommercial component (2.0–2.4 cm) was less than 1 g/m^2 in two areas (Punta Sdobba and Banco d'Orio-Bocca d'Anfora), between 1 and 4 g/m^2 in two others (Banco Mula di Muggia and Lignano Sabbiadoro), and the average value was 7.52 g/m^2 in the Isola Sant'Andrea area. Specimens smaller than 2.0 cm reach values close to 5 g/m^2 only in two areas (Banco Mula di Muggia and Lignano Sabbiadoro); also in this case, the coast off Isola Sant'Andrea presents the highest biomass values (9.05 g/m^2) [116]. These low biomass values worsen compared to what was reported for September 2018, the year in which monitoring was certainly affected by the mortalities that occurred (Implementation Plan D.M. 17 June 2019) [99], leading to results that were almost always close to zero.

However, it can be observed that the higher density areas maintained higher values even after these circumstances in 2016; on Isola di Sant'Andrea, the commercial size class even maintained a constant biomass.

The survey campaigns carried out show a negative trend for the Tagliamento estuary, where only small specimens have a biomass higher than 5 g/m^2 in the first year of the survey and tending towards 0 g/m^2 in all areas in the following year. The Lignano channel almost always shows values of 1 g/m^2, decreasing in 2019, while the area near the beach shows positive values of almost 10 g/m^2 at a depth of about one meter.

Considering only the Lignano Sabbiadoro area, for which continuous data are available, it is possible to draw a diagram that better illustrates the evolution of biomass in these four years of study (Figure 4). Mass mortality depends not only on the year and month of sampling, but the resource is also influenced by the absence of organisms of reproductive age (<1.8 cm) and the resulting recruits for the following year. In this case, areas with higher densities are also preferred.

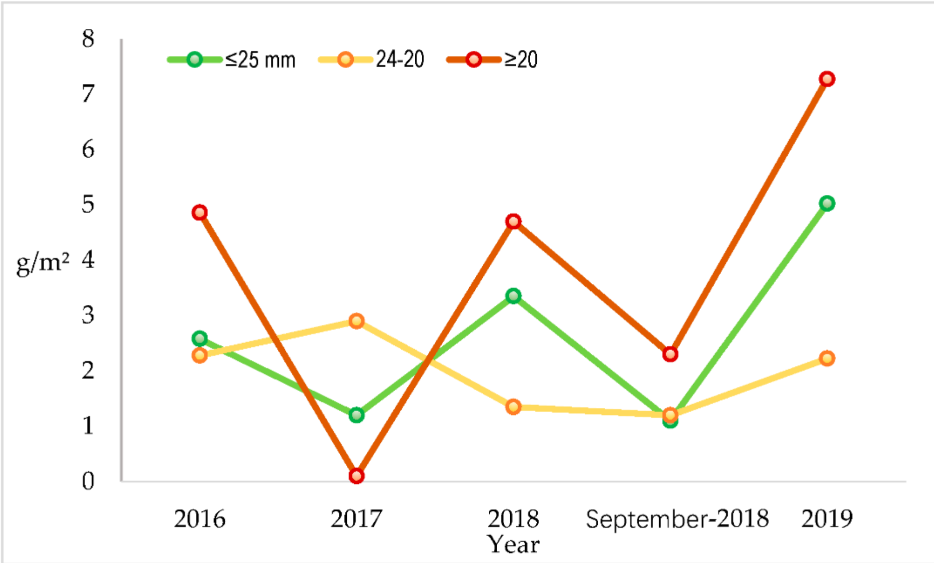

Figure 4. Trend of *Chamelea gallina* (divided by size as shell total length; mm) for the Lignano Sabbiadoro area in the years 2016–2019 [73,116].

It should be noted that the trend seems to be the same for each size class considered, except for 2018. In 2019, a recovery of the stocks is observed, probably also due to the reactivation actions carried out, although the values for the densities required for the capture areas are not yet available (Table 1).

In 2016 and 2017, recovery actions were carried out on products caught along the Veneto coastal strip. In 2016, a total of 51 tons of clams of the species *C. gallina* were processed, corresponding to about 23 million specimens with an estimated average length of 1.59 cm.

Laboratory analysis indicated that the average length of the clam population affected by productive reactivation was 1.58 cm, representing a total of approximately 23 million specimens, distributed among size classes as follows:

- Class 0.1–1.5 cm (0+ specimens in I° year): 40.4%;
- Class 1.6–1.9 cm (1+ specimens in II° year): 26.2%;
- Class 2.0–2.4 cm (1+ specimens in II° year and subcategory of trade): 30.8%;
- Class 2.5 cm (2+ specimens in III° year and tradeable): 2.6%.

These were redistributed in four of the five areas studied, since in the Banca d'Orio-Bocca d'Anfora area the initial population included only 25 specimens, for which it was not possible to obtain solid baseline data that could have served as a basis for subsequent monitoring, as indicated in Supplementary Materials Table S7.

In the initial phase, the baseline biomass for each of the five areas was determined and then monitored at regular intervals according to M.D. 24 July 2015 [97] to verify the outcome and the evolution of the population. This program was also repeated for the year 2017, for which, however, only the data for the municipality of Lignano Sabbiadoro are available, while the monitoring continued in 2018 (Supplementary Materials Table S8).

In 2017, an area of 800 m^2 was identified along the coast of Lignano Sabbiadoro, where 26.30 tons of clams with an estimated average length of 1.29 cm were introduced. The calculations carried out estimate the number of *C. gallina* imported to be about 17.70 million and the amount of clams longer than 2.0 cm to be 14.6 tons [117]. Below are the tables by area that include the biomass data before and after reactivation for 2016; for the coast of Lignano Sabbiadoro, the data for 2017 are also given (Supplementary Materials Tables S9–S14).

In the post-recolonization period, the controls in the Punta Sdobba area showed a negative trend, probably due to the conspicuous presence of murexes of the species *Bolinus brandaris*, which are direct predators of the clams, because, except for the first sampling after one month, when the trend of seeding continues, the resource disappears until it reaches a biomass of 0 g/m^2 after six months [116].

Surveys were also conducted in the east and west of the seeding area to check for a possible spillover effect, but throughout the area, the biomass remained at values close to 0 g/m^2.

In the Banco di Muggia area, mortality was declining but not particularly high, indicating a good anchorage of the species in the new distribution area: 13 g/m^2, compared to the 4.8 g/m^2 originally estimated [116]. In contrast, the western seafloor did not show a positive trend. A similar trend could be due to the currents affecting the area within 10 m depth and running in the west-east direction, favoring the shift in planktonic larvae to the eastern sector with respect to the seeding area. A similar result during the monitoring allowed re-examining the abundance distribution of the sizes. In October 2016, the clam bank in Area 2—Banco Mula di Muggia had an average size of 1.59 cm and a proportion of juveniles around 1.1 cm, indicating summer settlement. In percentage terms, the size class 0.1–1.5 cm represents 49.2%, while the class $\geq$2.0 cm represents 37.3% of the total [116]. This result is consistent with the size distribution of the products sown in April, but with a positive trend due to summer colonization.

The results of the monitoring of the area off Isola di Sant 'Andrea are undoubtedly positive, even if they are not reported for the month of May (period of squid fishing with traps). Note the constant trend of biomass values for specimens of subordinate size (2.0–2.4 cm) and an increase in commercial size, indicating good settlement in the reactivation phase and constant growth. Biomass values for specimens smaller than 2.0 cm are also increasing, indicating good establishment of recruits.

Positive signs were also observed in the areas east and west of the site. In the east, the highest biomass (31.6 g/m^2) was recorded in July, with a subsequent gradual decline to about 5 g/m^2 in November 2016. In the west, the biomass of clams $\leq$2.0 cm showed signs of recovery compared to February 2016, with a final value of 19 g/m^2 in October 2016, consisting of 12.9 g/m^2 ready-to-catch clams and 6.3 g/m^2 2.0–2.4 cm specimens. The decrease observed between July 2016 and October 2016 is likely due to the resumption of commercial fishing activity [116].

Also in this case, the analyses of abundance distribution were repeated and showed the presence of all size classes, indicating a good settlement of the introduced bank, thus guaranteeing its development in the coming years if there are no disturbances due to external events. The analysis of the samples shows that more than half of the population falls in the size class 0.1–1.5 cm and that about 30% has a size greater than 2.0 cm [116].

The result of the intervention on the coast of Lignano Sabbiadoro was again positive both in the camp and in the eastern areas (22.7 g/m^2 of clams with size $\geq$ 2.0 cm), while in the western areas, there was a progressive depletion of the resource, probably due to the measures taken to stabilize the beach, with densities decreasing to zero since the controls in July 2016. Decreasing densities were observed in November, probably due to the resumption of commercial fishing [116].

The structure of the population of *C. gallina* detected in the last control in October 2016 shows that there was a significant recruitment during the summer, representing more than 80% of the total population, with a center of distribution at 0.6–0.8 cm. Compared to 12% of specimens $\geq$2.0 cm, it is interesting to highlight that 8.70% of them have commercial dimensions [116]. In the following year, 2017, a second productive reactivation activity was carried out with products from Veneto, for which only the data for Lignano Sabbiadoro are available (Supplementary Materials Table S12). Also in this case, the resource seems to stabilize after an initial decrease.

At the end of the activities and considering the final biomass values obtained during the four years of the study, it can be concluded that the reactivation activities had controversial results. Even if the reactivation was positive in some areas, the values quickly fell back below the values required by the regulation of 24 July 2015 [97], at least in the first year. Table S14 of the Supplementary Materials uses a color scale to show the potential for fishing effort in the study years, based on ministerial guidance for GSA17.

Possible explanations for the state of the resource can be given by studying the meteorological conditions that prevailed in the Friulian coasts in the last years. Indeed, the northern Adriatic regions have been affected by severe storms, often resulting in heavy rains and floods that caused damage both in Veneto and Friuli-Venezia Giulia. In the fall of 2018 alone, many hectares of forest were destroyed, and millions of cubic meters of wood were thrown to the ground [74]. On the coasts, these events have led to strong storms with subsequent erosion and deposition of material, which, although the burrowing organisms of the coast are accustomed to the disturbance of their habitat, has had a negative impact. The heavy inland rains have caused severe flooding in an area with numerous estuaries and carried large amounts of fluvial sediments and solid and liquid anthropogenic and natural debris (logs, mud, silt) into the sea.

The events may therefore have led to direct disturbance of benthic communities, especially if they are particularly sensitive to fluctuations, such as the striped Venus (*C. gallina*), leading to regression of areas, die-off, and consequent decline in biomass.

7. Conclusions

The data collection carried out allows for the evaluation of the population of *Chamelea gallina* in its entirety and the description of the evolution of the biomass and the evolution of the fishery in the last years for the in Friuli-Venezia Giulia compartment (northern Adriatic Sea, Italy). In contrast to the coasts of the Veneto, Emilia, and Marche regions (Italy), for which historical data series from the 1970s onwards are available, there is a lack of scientific literature for the study area considered here. However, thanks to the studies carried out by the relevant scientific institutions, it was also possible to draw a clear picture of the distribution of the species' occurrence in the study area.

In general, the policies followed in the sector in the last 20 years have led to a radical decrease in both the number of pieces and the tonnage of production of this species, in addition to massive mortalities. The information on the occurrence of *C. gallina* on the Friulian coasts is very patchy. Moreover, there are incomplete specific studies from recent times. However, the Monfalcone Management Consortium, in collaboration with the Scientific Reference Panel, is carrying out extensive work that, if made available, can fill the remaining gaps on this subject. For example, it is possible to include the number of fishing boats that fished with hydraulic dredges in 2000, 2001, 2012 and 2013, or some data on the landed tonnages of clams that are currently not available in any bibliographic source, or the data on the reactivation and subsequent monitoring activities carried out in May 2017 in the four areas of the Friulian coast.

Finally, there is little scientific literature on the resource in terms of mortality, while general information on market trends and impacts on the fisheries sector can be found in local online newspapers or ministerial documents.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse10091328/s1.

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