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Article

Innovative Vibrating Hydraulic Dredge for Striped *Venus* (*Chamelea gallina*) Fishing

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Abstract: This work proposes the experimentation of an innovative hydraulic dredge for clam fishing (*Chamelea gallina*) in the Adriatic Sea (Italy). This innovative gear aimed at increasing the selectivity of the typical hydraulic dredge used currently, while at the same reducing the impact on benthos through the conception, installation, and experimentation of innovative technological solutions, consisting mainly of a vibrating bottom panel on the dredge and a "warning device" on the dredge mouth. Comparative experiments of the traditional vs. the modified gear, employing two boats fishing in parallel on the northern coast of Abruzzi (Adriatic Sea) and contrasting the catch with both paired comparisons and through modelling, showed that the innovative hydraulic dredge retains fewer undersize clams while yielding similar amounts of commercial product, moreover of higher quality; at the same time, it takes on board less discard, and catches significantly less vagile fauna. In short, the innovative gear is gaining five times over a list of six parameters considered as positive and/or advantageous for the clam fishery. The results allow proposals of potential improvements to clam-fishing instruments to make the selection processes more effective while promoting a lower impacting fishery, which is essential for clam management.

Keywords: clam; selectivity; striped venus clam; innovative gear; Adriatic Sea

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1. Introduction

Clams are a high-value seafood product in the European Union, which is a net importer since production is relatively low in relation to consumption. Italy is the main producer (mainly from the Adriatic Sea) and Spain the main importer of the striped venus (*Chamelea gallina*), with this movement representing a significant flow of product [1]. Annual landings reached a peak value of about 100,000 tons in the early 1980s, and subsequently declined because the high fishing pressure was not sustainable [2]. The fishery experienced a drop in catches, and at present, annual landings are roughly of the order of 14,000 tons, with an approximate first-sale value of about €32 M (EU Member States for the 2015 DCF fishing fleet economic data call). Such reduction in catches spurred the Italian government to impose a number of management regulations on gear characteristics (technical measures), the number of fishing days per year (fishing effort or inputs) and individual catch quota per day (catches or outputs). After examining various scientific contributions, the bivalve mollusks belonging to the (super)genus *Venus* spp. have been considered by the Scientific, Technical and Economic Committee for Fisheries (STECF) as species with a high survival rate and therefore, in derogation from the provisions of Reg. (EC) n. 1967/2006 (2006) [3] and (EU) n. 1380/2013 (2013) [4], the minimum reference size for its conservation in Italy has been set at 22 mm in total length; the same minimum size was also confirmed later [5].

In Italy, over 90% of the clam catches come from the central northern Adriatic, with an annual quantity that currently approaches 50,000 tons. The gear types historically used in clam fishing were rakes and manual dredges, now almost completely replaced by hydraulic dredges. Over the years, the productivity of most clam stocks (and more generally, of any commercially exploited mollusk) has fluctuated widely, probably due to both intense exploitation and other anthropic and natural factors, as shallow coastal waters are particularly subject to pollution, freshwater inputs, variations in temperature, etc. [6].

With the advent of hydraulic dredges, a.k.a. "turbosoffianti" in Italian [7], clam fishing in the Adriatic has steadily intensified, becoming increasingly important in economic terms [8]. The management of the clam resources has been entrusted directly to the fishermen, through the Co.Ge.Vo.s [9,10], who autonomously plan the fishery closures based on the available resources, through the establishment of weekly operating calendars, daily working hours, suspension periods (usually at least two months between April and October) and allowed landings [6].

The term selectivity measures the selection process of a fishing gear, i.e., the process that leads to a capture, whose composition in individuals and species differs from that of the populations actually present where fishing is carried out. That is, the selectivity of a fishing gear represents the probability that different sizes and species get captured by that gear. Selectivity is thus the capacity to separate the organisms entering the fishing gear into a fraction caught and a fraction escaping through the mesh, as allowed by their size and shape [11,12].

For half a century now, gear selectivity has been one of the technological aspects indispensable for achieving a correct exploitation of fishery resources [13,14]. In fact, the control and improvement of selectivity, in synergy with a responsible management of the fishing effort, represent a necessary, but not sufficient, condition for sustainable resource management; one of the causes of the crisis facing some stocks lies precisely in not having intervened in the past on the two factors at the same time [6].

The studies on this subject aim at finding technical solutions that allow fishing to target only sizes and species of commercial interest, allowing the escape of juveniles and limiting the bycatch, often comprised of species of ecological and environmental value [15–17]. To do this, fishery technology research is directed towards two main directions: making technical changes to the gear in use (different meshes, insertion of selection grids, etc.) and advancing alternative gear [12]. The available data show considerable annual fluctuations, but in any event a sensible decrease in the total density of the resource, accompanied by a rarefaction of sizes above 25 mm, then the minimum marketable size [18].

In an attempt to solve some of the production [19] and environmental [20] problems linked to hydraulic dredging, an experimental dredge was built already a couple of decades ago, with a vibrating bottom panel; that gear presented at least three points in its favor, although based only on preliminary assessments at that time: significant selectivity towards undersize clams; reduction of the bycatch and finally, an improvement in the quality of the commercial product [21].

Moreover, with the vibrating bottom panel, the riddling goes on continuously, allowing the immediate release of the sorted-out organisms, which are then repositioned in the area of origin, thus avoiding a "contagious" redistribution. In conclusion, these positive preliminary results suggested real benefits of the modified dredge, with wide margins for further improvement [22].

To pursue the reduction of the impact of fisheries through innovation [23], an improved vibrating hydraulic dredge has been designed, prototyped and experimented [24].

1. The envisaged outcomes of this newer gear are as follows:
2. increase the selectivity towards clam juveniles;
3. minimize the amount of discard taken on board;

4. reduce the bycatch of vagile fauna;
5. improve the clams' commercial quality;
6. monitor in real time the functioning and effectiveness of the adopted modifications.

The aim of this work is the description of this innovative dredge and the appraisal of the applicative results in comparison with the traditional hydraulic gear.

2. Materials and Methods

2.1. Experimental Design

The trials at sea started on 9 October 2019 and ended on 12 June 2020, with a suspension of about 4 months (from end of January to beginning of June 2020) due to the COVID-19 emergency.

The study was carried out in GFCM-FAO Geographical Sub-Area 17 (GSA 17: northern and central Adriatic). It involved an area of about 18.5 km^2 around the harbor of Giulianova (Figure 1), on depths ranging from 5 m to 10 m. The 40 + 40 hauls considered as valid for catch comparisons between traditional and vibrating gear summed to 19 linear km of dredging, equal to about 0.6 km^2. The ecosystem of the sampling area is typical of coasts degrading with a gentle slope, where the sandy bottoms become more and more mixed with mud as the depth increases.

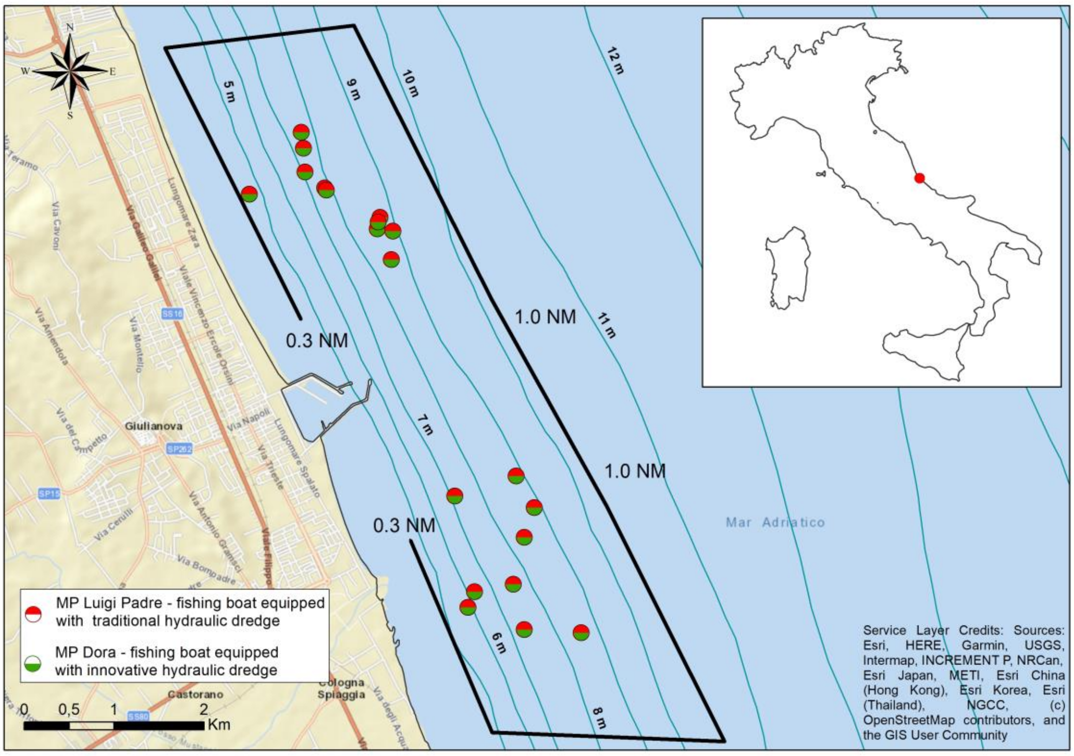

Figure 1. Geographical view of the Adriatic Sea in the Abruzzi coast with details of the sampling area for *Chamelea gallina*, sampling stations and bathymetry. Red and green half dots represent the sampling stations for MP Luigi Padre (traditional hydraulic dredge—half red) and MP Dora (innovative hydraulic dredge—half green).

Two fishing boats dedicated to the commercial fishing of striped clams, *Chamelea gallina* (L.), and equipped with hydraulic dredges were used for sampling:

- the MP Luigi Padre (registration 8PC 601, overall length 14.90 m, gross tonnage 14 GT, engine power 150 HP), mounting a traditional hydraulic dredge (mouth width, 3 m; total weight, 600 kg; fixed bottom panel, with horizontal rods; space between the rods, 12.5 mm; hydraulic power, 1.8 bar);

- the MP Dora (registration 7PC 366, overall length 15.95 m, gross tonnage 16 GT, engine power 150 HP), equipped with an innovative gear whose construction characteristics are shown below (mouth width, 3 m; vibrating part of the bottom panel, with horizontal rods; space between the rods, 12.5 mm; hydraulic power, 1.8 bar).

As usual with hydraulic dredging, the gear was lowered and put into action from the bow of the fishing vessel, which pulled it backwards, keeping the engine at about 1300 rpm, i.e., the necessary to proceed with a constant speed of 1.6 knots. Each haul, except for special needs, lasted 10 min, equal to a 500 m pull, or 1500 m^2 of explored surface. During the haul, each boat proceeded one next to the other. At the end of the haul, the gear was raised, and all its content unloaded on a "tray", from where a cochlea sent it to the on-board sorter. After measurements, each catch was released overboard.

2.2. The Innovative Hydraulic Dredge

The innovative hydraulic dredge has the same shape and size as the dredges traditionally used in Mediterranean for clam fishing but presented some innovative characteristics (Figure 2) compared to the traditional dredge.

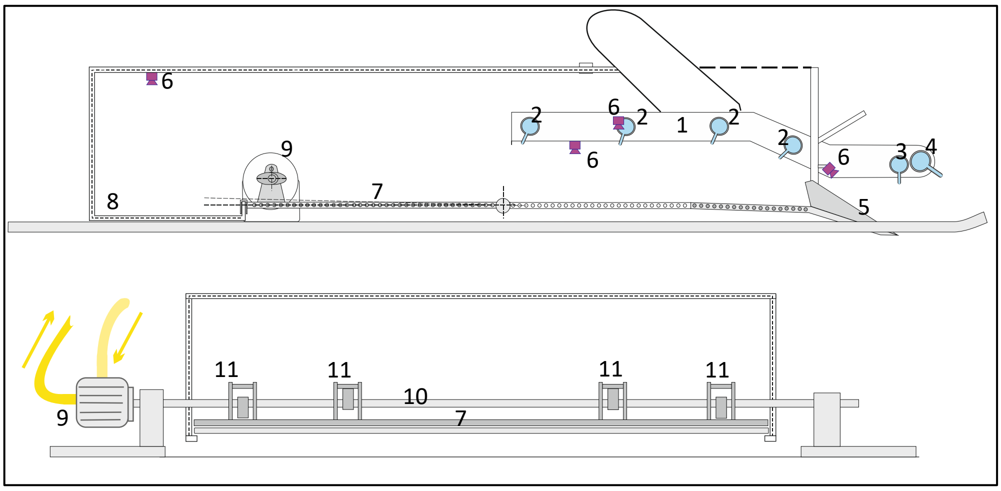

Figure 2. Schematic representation of the dredge prototype: side view (top) and rear view (bottom). (1) supply line of pressurized water; (2) transversal rows of nozzles, directing the water jets toward the cage bottom, favoring sand elimination; (3) transversal row of nozzles directing the water jets downward, favoring penetration of the front blade; (4) frontal row of nozzles providing forward, 45° inclined water jets, aimed at warning the vagile species; (5) front blade; (6) wireless underwater cameras; (7) oscillating section on the dredge bottom, hinged frontally to the fixed section; (8) clam storage basket on the rear end; (9) hydraulic motor; (10) camshaft; (11) pins integral to the oscillating section, for its lifting due to the cams action. Non-Scale representation due to the technical sketch without any picture scale.

Part of the bottom panel of the innovative dredge was modified to obtain an oscillating section, with the aim of favoring the escape of undersize individuals, and thus reducing the capture stress (in the traditional dredge, the bottom panel is fixed). Such a section, visible in Figure 2, is frontally hinged to the rear fixed section of the dredge bottom, while its rear border can vertically oscillate due to the rotation of a camshaft which is operated by a hydraulic motor supplied with hydraulic fluid by an on-board pump. The camshaft has two pairs of cams, out of phase with each other by 180°. In the rear edge of the oscillating section, there are four integrated frames. The top of each frame supports a pin which is the element receiving an upward push by the cams. Each push is exerted by one pair of cams, generating two oscillations per rotation. In the interval of two contacts between cams and pins, the section rests on the front border of the clam storing basket. The frequency of oscillation can be varied by setting the rotation speed of the hydraulic motor. The oscillating system is represented in detail in Figure 3.

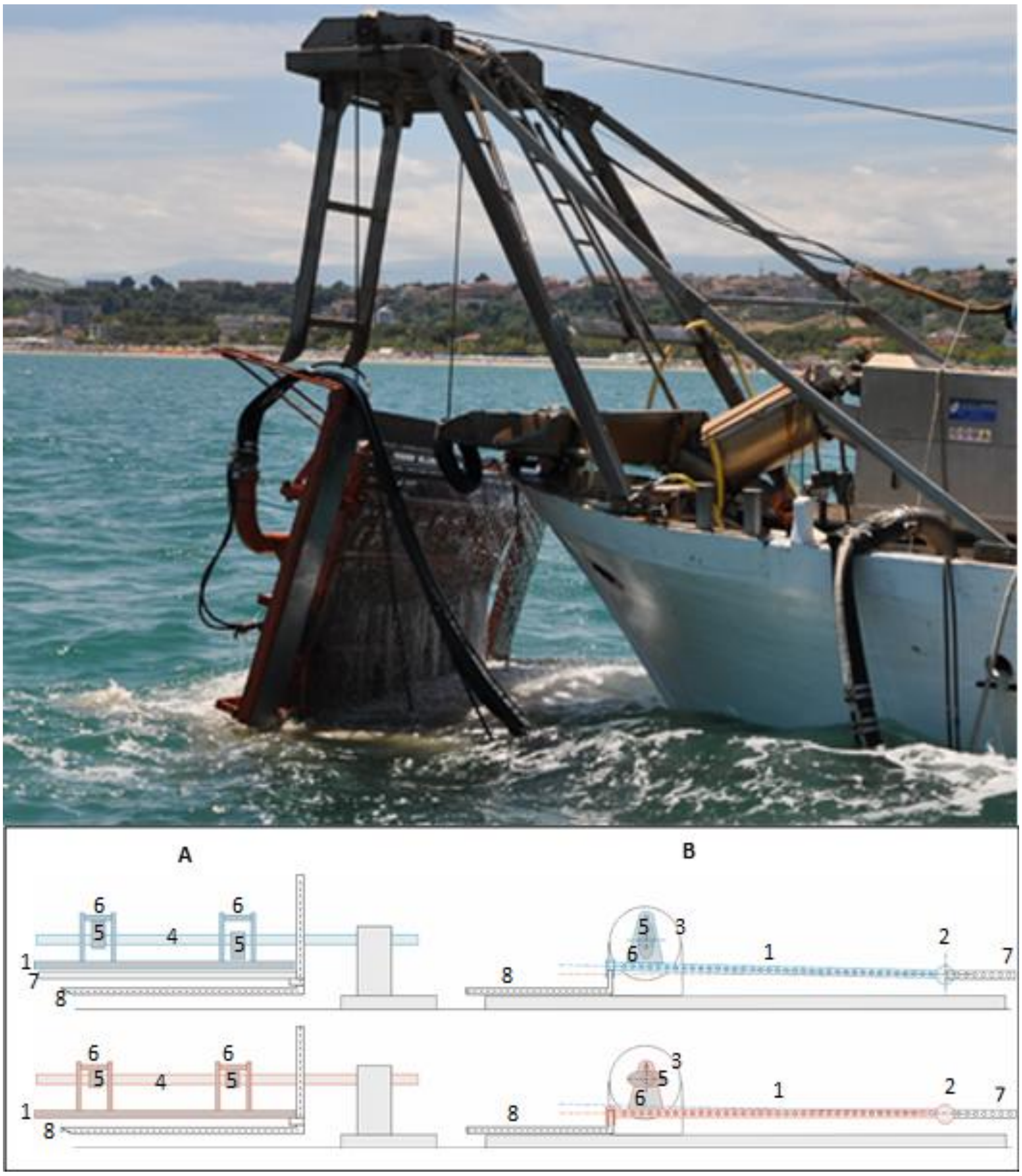

Figure 3. In the upper side a picture of the vibrating hydraulic dredge on the ship. Below a detail of the oscillating system of the prototype: rear view (**A**) and side view (**B**). (1) oscillating section of the dredge; (2) hinge (center of rotation) of the oscillating section; (3) hydraulic motor; (4) camshaft operated by the hydraulic motor; (5) cam; (6) frame with a pin, integrated in the oscillating section, for the lifting during cams rotation; (7) fixed section or the dredge bottom; (8) clam storage basket on the rear end. (**Top**): oscillating section lifted in its highest position by the push of cams on the pins—(**Bottom**): the cams do not touch the pins and the rear border of the oscillating section rests on the front wall of the basket.

Given the continuous stress of the catching process, even after the sifting action has been completed, and considering the impacts against the back wall that risk damaging the product (Anjos et al., 2018), the final part of the bottom panel has been left fixed, so as to form a collection basket, i.e., a much quieter and “cleaner” area than the ordinary.

Apart from the traditional sets of nozzles used to facilitate blade penetration and sand removal (90° vertically oriented), another row of nozzles has been installed up front, obliquely oriented at 45° (see feature #3 in Figure 2), producing a jet of water that hits frontally up to 1.5 m from the dredge mouth, hence preceding the actual arrival of the cage, and allowing in this way the vagile species to escape and avoid capture, and the clams to close earlier in time and thus reducing the amount of inter valvar sand.

Wireless underwater cameras (Spydro®, Cesarea, Springfield, IL, USA) have been positioned on both the traditional and the innovative dredge to monitor the deterrent functions on the vagile fauna and to control the action of vibrating mechanism. Installed in various places on the cage, these cameras transmit the images to a remote station, in order to monitor the effectiveness of the modifications and eventually modify their arrangement during the experiment.

2.3. Data Collection

A total of 21 sea tacks were carried out, divided into 10 days (morning and/or afternoon), chosen on the basis of weather conditions and/or obligations related to the pandemic emergency; altogether, 120 hauls were made, 60 per each boat, 8 + 8 of which were just preliminary tuning essays, and, thereafter, discarded from paired comparisons. More in detail, among the 52 + 52 hauls used for experimental, 40 + 40 were considered for catch comparisons; 4 + 4 intended for testing the innovative dredge with blocked vibrating panel; 1 + 1 hauls were used for the trial with colored clams; 7 + 7 hauls were completely unusable, due to technical malfunctioning of one of the boats. The hauls valid for determining amount of discard and evaluating the associated vagile fauna were 40 + 40; samples for biometry were collected in 13 + 13.

Data were recorded for haul code, date, name, position and time; haul duration and length; total take, weight of commercial catch and undersize capture; amount of discard; presence of vagile fauna, i.e., highly motile animals (such as shrimp, cephalopods, cyclostomes, selachians and bony fish, but excluding crabs). The unit of measurement for commercial catch and undersize capture, obtained after sorting, is the commercial “10 kg bag”, the total take resulting from their sum.

Discard comprises of all the material that comes on board together with the clams—including more or less compact sand, dead mollusks shells, plant material, sometimes anthropogenic waste, etc. and has been categorized into “low, medium, high”; the capture of vagile fauna has been recorded as presence/absence.

The hauls used for catch comparison were 44 (of which 4 intended for testing the innovative dredge with blocked vibrating panel); 1 haul was used for the trial with colored clams; the hauls valid for determining amount of discard and evaluating the associated vagile fauna were 40; samples for biometry were collected in 20 hauls; and 8 hauls were completely unusable, due to technical malfunctioning.

To verify that the two hydraulic dredges had a similar behavior during fishing, apart from the innovative modifications, 8 hauls were carried out without setting into operation the vibrating bottom panel of MP Dora (but the warning nozzles, which could not be switched off, remained active).

The ability of the two dredges to retain commercial clams while releasing undersize specimens has been verified during the fishing phase by releasing previously colored (with food grade dyes) clams in the dredges mouth.

The largest shell dimension was measured on board, using a caliper, on 30 clams per tack, from a random sample taken before sorting; 780 biometries from 26 hauls were suited for comparisons between traditional dredge and innovative gear.

2.4. Data Processing

The statistical significance of the results was assessed with paired comparisons (i.e., parametric and/or non-parametric tests, depending on the type and distribution of the data) [25]. The χ^2 test was used on data with elements divided into different bins; the

Friedman test, a non-parametric test for equality of medians in several repeated measures of univariate groups [26], was calculated to compare medians of non-normal heteroskedastic data under the null hypothesis of comparable medians; and the Wilcoxon test, a non-parametric rank test, has been employed to compare medians of non-normally distributed paired samples.

In addition, a Generalized Linear Mixed Models (GLMM) approach was applied to the biometric data, to also account for the random variability among hauls in addition to within each haul (i.e., between gears). Following Holst and Revill [27], Equation (1) describes the polynomial of order k for clams of length l in haul h:

$$p_k^{(h)}(l,\ \beta) = \log \frac{q_t^{(h)}}{q_c^{(h)}} + \beta_0 + \beta_1 \cdot l + \cdots + \beta_k \cdot l^k + b_h \tag{1}$$

where q_t and q_c are the sub-sampling ratios (i.e., individuals sampled per individuals caught in haul h) for the test (i.e., innovative) and control (i.e., conventional) dredges, respectively, and b_h corresponds to the random variability of haul h.

Binomial GLMMs of three polynomial orders (i.e., linear, quadratic and cubic) and with random intercepts were fitted to the data, following a Markov Chain Monte Carlo (MCMC) Bayesian approach. The resulting models were compared pairwise, by applying the Leave-One-Out Information Criterion (LOOIC) for Bayesian models [28,29]. An alternative Bayesian R^2 [30] was calculated to assess the performance of the model which was selected based on the results of the LOO comparison.

3. Results

3.1. Catches

3.1.1. Validation of the Innovative System

In order to exclude that the differences in performance could be attributed to different operational characteristics of the two boats, control hauls were carried out without making operative the vibration of the bottom panel on MP Dora.

No significant differences (Wilcoxon test for paired samples, $p < 0.1$) were observed between the total takes of MP Luigi Padre (172 ± 85 kg) and those of MP Dora without vibrating panel (202 ± 128 kg).

With regard to the amount of discard taken on board, significant differences were observed to the detriment of the innovative dredge with inactivated vibrating panel compared to the traditional one (χ^2 test $p < 0.05$).

Finally, due to the small number of data, significant differences in the capture of vagile fauna could not be defined in favor of the innovative dredge without vibrating action (three occurrences) compared to the traditional gear (five occurrences).

3.1.2. Entire Take, Undersize Capture and Commercial Catch

Table 1 reports the mean weights resulting from the dredging operations.

Table 1. Entire take, undersize capture, commercial catch with traditional vs. innovative dredge.

Fishing Vessel	Bottom Panel	# of Hauls	Mean Weight (kg)					
			Entire Take	StD	Undersize	StD	Commercial	StD
Luigi Padre	Fixed	40	128	±63	52	±35	75	±33
Dora	vibrating	40	110	±67	17	±24	93	±60

On average, in the 40 hauls considered, the innovative dredge caught a total of 86% of what was taken by the traditional gear: a difference in total takes that is weakly significant (Wilcoxon test for paired samples, $p < 0.05$).

The innovative dredge, on the other hand, caught only one third of undersize clams compared to the traditional gear: a highly significant difference (Wilcoxon test for paired samples, $p < 0.0001$). Carrying out an "internal" comparison, the undersize clams represented only 15% of the entire take of MP Dora, while in MP Luigi Padre the percentage rises to 41%.

As a corollary result, the innovative dredge caught 129% of commercial size clams caught by the traditional gear: a significant difference (Wilcoxon test for paired samples, $p < 0.05$).

Figure 4 shows the comparison, in the same location, between the unsorted entire capture collected with the traditional vs. the innovative gear. It is possible to clearly observe the difference in terms of presence of muddy substrate and discard much higher using the traditional hydraulic dredge.

Figure 4. Comparison of the unsorted catch between traditional (**A**) and innovative (**B**) gear.

3.1.3. Biometric Analyses

In addition to their use for population dynamics studies and for resources assessment, biometric measures (Table 2) have a direct importance for the commercial product and for the fishermen [31] (in fact, above average sizes get higher prices, and the uniformity of size simplifies on board operations.

The Friedman test ($p < 0.01$, N = 780) shows a highly significant difference between the biometric measurements in favor of clams caught with the innovative dredge. The χ^2 test ($p < 0.01$) shows again a high difference in the number of undersize clams, significantly higher with the traditional gear: of 390 clams each, in the traditional dredge 136 are below the 22 mm size, while only 54 are kept by the innovative gear.

Table 2. Clam biometry with traditional vs. innovative dredge.

Fishing Vessel	Bottom Panel	# of Hauls	Size (mm)				
			≤21	22	23	24	≥25
Luigi Padre	fixed	13	103	33	28	35	191
Dora	vibrating	13	25	29	31	62	243
Fishing Vessel	**Bottom Panel**	**# Biometries**	**Mean (mm)**	**StD**	**Mode (mm)**	**Median (mm)**	**Min-Max (mm)**
Luigi Padre	fixed	390	24.1	3.52	20	24	10–35
Dora	vibrating	390	25.6	2.89	24	25	18–37

The GLMM approach confirms these results. Based on the results of the LOO comparison (Table 3), the quadratic polynomial qualified for further analysis, combining simplicity and performance. The mean of the posterior predictions (100 randomly drawn ratios per clam length for a hypothetical, randomly generated haul containing all possible lengths within the range), alongside the coefficients for both fixed and random effects with 90% credible intervals, are presented in Figure 5. All fixed effect coefficients (i.e., intercept and slopes of the linear—length—and quadratic—length2—parameters) deviated from 0 (i.e., outside the intervals). Among the 13 hauls sampled, hauls C, F and M contributed the most to the random effect variability, the first two with a negative random intercept and the third with a positive one (Figure 5b).

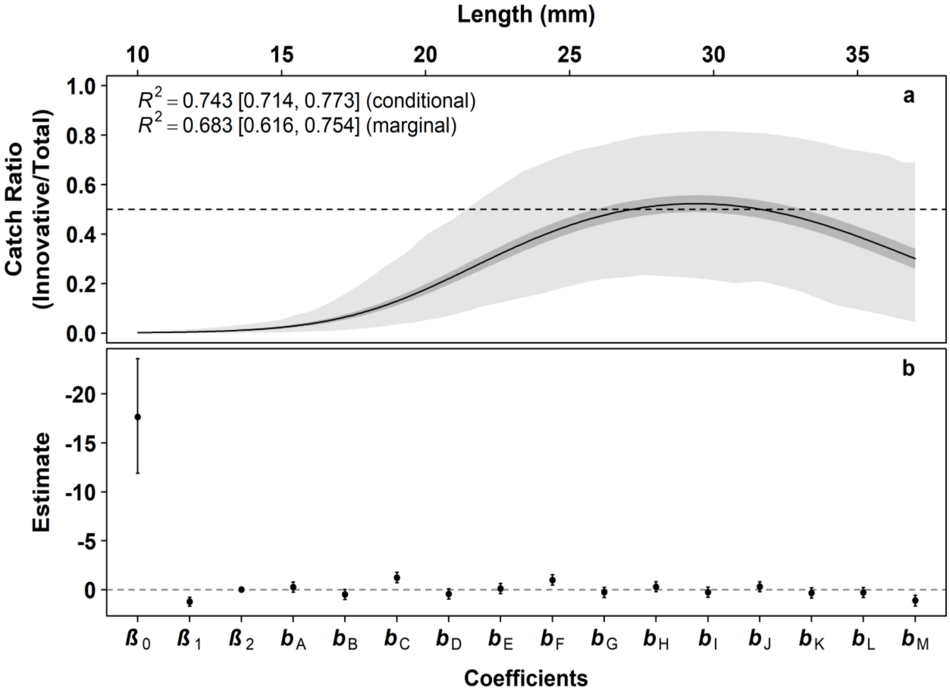

Figure 5. Visualization of model posterior predictions of catch ratio for a new, randomly generated haul (continuous for the range of clam lengths present in the samples) and coefficients. (**a**) The solid black line corresponds to the mean of the 100 posterior draws, while the dark gray shade indicates the area of mean ± 2 SE. The light gray shade indicates the 90% credible intervals for the posterior values. The dashed line corresponds to the 0.5 catch ratio (i.e., equal probability of catch between gears). Finally, the Bayesian R^2 values are reported with 90% credible intervals, with "conditional"

referring to the variance of the complete model and "marginal" only to the fixed part, excluding the random effects (i.e., hauls). (**b**) Model coefficients with 90% credible intervals (please note the inverted Y axis). The dashed line marks 0. Greek β_0 to β_2 labels correspond to the fixed effects, while b_A to b_M to the random intercept effect of each haul, respectively.

Table 3. Model comparison through the Leave-One-Out Information Criterion (LOOIC) for Bayesian models, based on the Expected Log Predicted Density (ELPD). Lower (absolute) ELPD and LOOIC values mean better fit. The middle columns correspond to the pairwise difference of ELPD against the model deemed initially better, which is displayed in the first row and therefore has a difference value of 0.

Model	ELPD	ELPD SE	ELPD Diff	ELPD Diff SE	LOOIC	LOOIC SE
Cubic	−229.645	10.946	0.000	0.000	459.289	21.892
Quadratic	−235.182	11.205	−5.537	3.755	470.364	22.410
Linear	−242.174	11.805	−12.529	5.733	484.347	23.610

Within the Bayesian framework, 90% credible intervals were preferred to classic 95% intervals due to computational stability reasons and the relationship of the latter with Type-S error [30,32]. Table 4 presents a complete report of the quadratic GLMM coefficients, including the random intercepts for each haul. The distribution of the model residuals, analyzed through histogram and Quantile–Quantile plots (not shown), approximated normality.

Table 4. Complete report of the quadratic GLMM coefficients. The estimate for each coefficient is provided along with measures of uncertainty (standard error of the mean, 90% credible intervals and the Monte Carlo standard error—estimation of the randomness associated with each MCMC run).

Coefficient	Estimate	Standard Error (SE)	05% CI	95% CI	MCSE
β_0	−17.664	3.594	−23.601	−11.889	0.06559
β_1	1.219	0.285	0.767	1.685	0.00511
β_2	−0.021	0.006	−0.030	−0.012	0.00010
b_A	−0.267	0.304	−0.793	0.248	0.00741
b_B	0.484	0.307	−0.011	1.006	0.00745
b_C	−1.242	0.329	−1.792	−0.714	0.00715
b_D	0.430	0.312	−0.101	0.958	0.00749
b_E	−0.121	0.307	−0.643	0.397	0.00718
b_F	−0.991	0.315	−1.525	−0.454	0.00725
b_G	0.258	0.313	−0.231	0.797	0.00734
b_H	−0.297	0.300	−0.804	0.209	0.00721
b_I	0.256	0.306	−0.258	0.784	0.00715
b_J	−0.310	0.306	−0.816	0.196	0.00713
b_K	0.329	0.320	−0.190	0.849	0.00737
b_L	0.288	0.307	−0.207	0.794	0.00723
b_M	1.094	0.322	0.575	1.671	0.00746

Moreover, a qualitative essay was carried out by introducing in the mouth of both dredges, during the pull, a few dozen of clams of two size classes (<22 mm and =23 mm), marked with non-toxic dyes; the two dredges recaptured similar quantities of (small) commercial clams (81% vs. 64%), while the innovative dredge retained fewer undersize clams than the traditional gear (28% vs. 60%).

3.2. Discard

Discard is here intended as all the material that is brought on board by the dredge together with the clams, including semi compact sand, shells of dead mollusks, plant material, sometimes anthropogenic waste, etc.

Significant differences appear between the two fishing gears (χ^2 test $p < 0.05$), in favor of the innovative dredge which collected less discard than the traditional one: in fact, on 40 occasions, 12 hauls, compared to only three, presented medium high amounts of discard.

3.3. Vagile Fauna

In order to assess the effectiveness of the warning system, the presence or absence of vagile fauna (excluding crabs) in the catch was recorded for each haul (Table 5).

Table 5. Highly mobile vagile species caught with traditional vs. innovative dredge (40 hauls each).

Group	**Common Name**	**Species**	**Occurrences**	
			Fixed	**Vibrating**
n.a.	—-	undetermined	6	5
cephalopods	cuttlefish	*Sepia officinalis*	4	
Selachians	skate	*Raja* sp.	2	
bony fishes	Dover sole	*Solea vulgaris*	13	5
bony fishes	tub gurnard	*Chelidonichthys lucerna*	2	
bony fishes	greater weever	*Trachinus draco*	(1)	
bony fishes	spotted flounder	*Citharus linguatula*		1
bony fishes	generic bony fish	?	(2)	1
TOTAL			**27**	**12**

The innovative dredge caught significantly fewer vagile organisms than the conventional one (χ^2 test $p < 0.001$); in fact, as occurrences, 30% of the time against 68%.

3.4. Videos

During the earlier trials, useful underwater videos have been produced, both to monitor the mechanical actions of the innovations and, above all, to verify the escaping behavior of vagile species due to the dissuasive action of the added blowing nozzles. Two video collages (for traditional and innovative dredges) representing the frontal view of the dredge opening (6× slowed) are reposted as Supplementary Materials.

4. Discussion

In this study a traditional hydraulic dredge was compared to an innovative vibrating hydraulic dredge, in order to verify the capability of the latter to reduce the fishing impact on undersize clams. A simple random distribution has been assumed for its simplicity against a random stratified (by age) design, or a maybe truer double Poisson, patchy modelization.

First, non-significant differences were observed between the total takes of MP Luigi Padre and those of MP Dora without vibrating panel, therefore the disparities on entire weights subsequently recorded between the two boats can be attributed to the different type of dredge and not to any potential variability induced by the vessels. On the other hand, significant (albeit weak) differences were observed in the capture of undersize clams, in favour of the innovative non-vibrating dredge.

The hydraulic dredging seems to have a negative influence on clam growth performance, as a higher growth rate in areas not impacted by fishing with traditional hydraulic dredges than those exploited with this gear has been observed in the Black sea [33]. The effects of mechanical impact have also been studied in the Northern Adriatic Sea [34], identifying the different types of damage suffered by shells and the disturbance in growth.

Analyzing the amount of discard taken on board, significant differences were observed to the detriment of the innovative dredge with inactivated vibrating panel compared to the traditional one. In summary, the innovative dredge retained significantly fewer undersize clams than the traditional gear, with undoubted advantages for resettlement and subsequent sorting operations too, in conformity with the finding of Rambaldi et al. [21].

In addition to the differences when in non-vibrating mode, the comparisons demonstrated the high selectivity of the vibrating panel of the innovative dredge. In particular, this is a result in favor of the innovative dredge, which catches significantly more clams of commercial size than the traditional gear, as previously reported also by Rambaldi et al. [21]. Highly significant differences were observed between the biometric measurements, in favor of clams caught with the innovative dredge. The number of undersize clams is significantly higher with the traditional gear and this is a further element that benefits the innovative dredge.

Over 600 vessels commercially exploit bivalve stocks by means of hydraulic dredges in the Adriatic. A study carried out in 2002 by Morello and collaborators [35], highlighted the impact of the traditional hydraulic dredge used to fish clams (*C. gallina*), but has also revealed a low selectivity of the gear which resulted in considerable quantities of undersized clams and other benthic invertebrates being caught. These are then rapidly returned to the sea, after passing through the vibrating mechanical sieve used to sort the target species by size on board the vessels. It appears that the two dredges recaptured similar quantities of (small) commercial clams while the innovative dredge retained fewer undersize clams than the traditional gear. It was also observed that both gears caused some clams to break, but in minimal quantities [36].

This study revealed a high selectivity of the innovative dredge which produced minimal quantities of undersized clams and other benthic invertebrates captured. Moreover, significant differences appear between the two fishing gears in favour of the innovative dredge, which collected less discard than the traditional one. Low amounts of discard are an indication of the effectiveness of the vibrating panel, as its abundance can interfere with the fishing capacity of the gear and, in any event, involves additional work for the fishermen [35,37]. This behavior appears even more interesting considering that the innovative dredge mounted on MP Dora, when the vibration was not operating, collected more discard than the traditional dredge mounted on MP Luigi Padre. Drastic reductions in abundances of faunal organisms are widely reported as a consequence of mechanical, suction and hydraulic dredging [38,39]. Shifts in benthic community structure in favor of a few dominant opportunistic species have been observed in shallow waters [40,41] and for deep-sea benthos after similar physical disturbance e.g., underwater crawler tracks after long deployments on muddy bottoms [42,43]. This is a condition that Warwick [44] associated with disturbance. The innovative dredge caught significantly fewer vagile organisms than the conventional one.

The result obtained with the innovative dredge on the vagile fauna is of major importance: in fact, bycatch minimization is among the most sought-after grails for reducing the environmental impact of fisheries, and in particular in bottom trawling and dredging [37,45–47].

In short, speaking of the importance of these results for fisheries, it can be said that each of the parameters taken into consideration seems to benefit the innovative dredge, at varying degrees.

Table 6 summarizes the percentage variations between the results obtained by MP Dora, equipped with an innovative dredge, in relation to MP Luigi Padre that used a traditional hydraulic gear; if the variation is considered advantageous for the fishery and/or for the environment, it is marked with the + sign, and with the − sign in the opposite case (the number of signs corresponding to the significance of the result).

Table 6. Synopsis of the advantages of traditional vs. innovative dredge.

Parameter	Variation %	Fixed	Vibrating
entire take	86	+	−
undersized capture	32	− − −	+ + +
commercial catch	124	− −	+ +
biometry	n.a.	− −	+ +
discard collection	76	−	+
presence of vagile fauna	44	− − −	+ + +

Therefore, the innovative gear: (a) operates almost like the traditional one; (b) retains much less undersize clams; (c) consequently, more commercial product arrives on board,

(d) which is also of superior quality; (e) at the same time, it collects less discard and (f) lowers the capture of vagile fauna. In a nutshell, five of six parameters examined show values favouring the use of the innovative dredge.

The effective application of the vibrating dredge requires the optimization of the prototype performance from both a technical and an economic point of view, together with an in-deep evaluation of its potential impact on the marine environment. The hydraulic solution adopted in the prototype seems the most practical and economic, mainly on boats currently in use, as it does not require substantial modifications of the equipment which already includes an oil tank and a pump which operates the dredge vibration and the vibrating sorter at the same frequency. However, making these two functions independent could increase the overall work efficiency; moreover, the presence on board of hydraulic fluid presents a risk of pollution arising from oil leakages in the hydraulic systems. This hazard might be reduced using, for example, new fluids based on vegetable oils (or on esters synthesized from vegetable oils) combined with suitable additives, featuring high biodegradability (>90%) [48]. Alternatively, to the hydraulic solution, the dredge oscillation could be generated by a pneumatic system or an electric motor fit for marine application. Both solutions may be more eco-friendly since the air compressor or the electric generator could be powered by biofuels. Due to the costs and volumes required by such extra components, the pneumatic and electric solutions do not seem suitable to be applied in boats already operating; nevertheless, they could be conveniently integrated in boats of new construction, adapting the available space and, even better, choosing an engine suitable to furnish the boat propulsion and at the same time the air compressor (or the electric generator). These aspects be studied and verified in the future through new scientific and technological research initiatives.

5. Conclusions

The Common Fisheries Policy (CFP) is a set of rules of the European Union aimed at ensuring the long-term exploitation of the marine living resources through management measures which should guarantee their conservation, emphasizing also the protection of marine environments.

From this perspective, the perturbing action that hydraulic dredges exert on the resource and on the substrate constitutes a problem in terms of environmental impact. The effects are visible both on the seabed during fishing, and on the clams at the moment of capture; even the subsequent release of the organisms back to the sea implies a strong stress for the undersize fraction and the bycatch, which often represent together over 50% of the entire take.

This applied research made it possible to experimentally evaluate the effectiveness and efficiency of less impacting gear, with technical modifications mainly to the cage (vibrating bottom, "warning" devices), according to three lines of intervention: to reduce bycatch, to increase the selectivity during the fishing phase, and to improve the sorting operations.

The results of the comparative tests that were presented above show that the innovative solutions proposed bring benefits in terms of selectivity of the dredge, reduction of bycatch and improvement of the product quality. The outcome obtained from this pilot experience can be put into practice by the entire fishing fleet belonging to Co.Ge.Vo. Abruzzo (82 boats), and the same could be easily transferred to the other 17 Co.Ge.Vo.s existing in Italy (with over 700 hydraulic dredges in operation).

Implementing the study also helped to strengthen relations between fishers and researchers, highlighting the importance of reasoning with scientific and not arbitrary assumptions, in a rigorous but sufficiently flexible way in order to solve the practical issues in the management of clam fisheries.

The experiment carried out, in addition to solving the sought-after issues, has brought out new questions, oriented both towards improving the pilot gear and towards testing further innovations, also in resource management. These aspects be studied and verified in the future through new scientific and technological research initiatives.

Supplementary Materials: The following video are available online at https://www.mdpi.com/article/10.3390/agriengineering4010001/s1: Video S1: Innovative dredge frontal view; Video S2: Traditional dredge frontal view.

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