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The immediate impact of intertidal pebble fork harvesting on the warty venus *Venus verrucosa* benthic community

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Abstract: Recreational clam digging is a traditional activity on the large intertidal zone of the western coasts of the Cotentin (western English Channel). A variety of fishing gears are used to harvest the target species the warty venus *Venus verrucosa* (Linnaeus, 1758). In this note, the immediate effect (i.e., four days) of fork harvesting was studied during the March 2012 spring tide, following a control-impact design with a control station and three impacted stations using pebble forks. An immediate significant decreases of coarse sand and gravel benthic macrofauna is observed in fishing area. In the future, it is recommended that pebble fork fishing should be prohibited to harvest this target species.

Résumé : *Impact à court terme de la pêche à la fourche à cailloux sur la communauté benthique à* Venus verrucosa. La pêche à pied est une activité récréative traditionnelle sur les larges estrans découverts lors des grandes marées de la côte ouest du Cotentin (bassin occidentale de la Manche). Une très grande diversité d'engins de pêches est utilisée pour pêcher la praire *Venus verrucosa* (Linnaeus, 1758). Dans cette note, les effets à court-terme de la pêche à la fourche à cailloux ont été étudiés lors de la marée d'équinoxe du mois de mars 2012 selon un protocole de comparaison entre stations impactées et une station de contrôle non impactée par la pêche à la fourche. Une décroissance significative de la macrofaune benthique de ces fonds sablo-graveleux est enregistrée en quatre jours dans les zones pêchées à la fourche. Il est proposé que cette technique de pêche destructive soit supprimée au profit d'outils de pêche moins pénalisant pour la faune benthique.

Keywords: Clam digging ● Fork fishing ● Warty venus ● *Venus verrucosa* ● Negative effects ● Western English Channel ● North-east Atlantic

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Introduction

A traditional activity done by the inhabitants of coastal cities, professional and recreational fishing have been developed for at least two decades on the French intertidal coast. Fishing concerned many target species, including crabs, fish, molluscs, and the warty venus *Venus verrucosa* (Linnaeus, 1758) among them. Over the years, due to the decline in available resources to be shared between an increasing of recreational and professional fishermen, national and regional regulations were set up to limit the pressure on the available natural stocks: limitation of the fishing period, limitation of the number of individuals authorized by target species, minimum size of the target species, and the list of the authorized fishing gears. On the list of fishing gears, the pebble fork is authorized in a small part of the western part of the Cotentin coast, and some of the recreational fishermen associations promoting sustainable fishing arose the question on the impact of such gear on the resource and the benthic habitat (Fig. 1).

The environmental effects associated with fishing are well documented for the subtidal communities (Jennings & Kaiser, 1998; Kaiser & De Groot, 2000). It appears that dredging has an immediate effect that changes the physical habitat and macrobenthic fauna. The degree of the impact could range from minor to severe, greatly depending on the gear used, water depth, substrate nature, impacted benthic communities, and fishing intensity (Jennings & Kaiser, 1998; Kaiser & De Groot, 2000). Several field experiments has focused on immediate and short-term effects of different types of dredges, but mainly on subtidal benthic communities (Hall et al., 1990; Kaiser & Spencer, 1996; Kaiser et al., 1996 & 2006; Bergman et al., 1998; Tuck et al., 2000; Lindegarth et al., 2000; Bradshaw et al., 2002; Chícharo et al., 2002; Hauton et al., 2003; Gislason, 2003; Aspden et al., 2004; Pranovi et al., 2004; Gilkinson et al., 2005; Munari et al., 2006; Constantino et al., 2009; Gaspar et al., 2009).

For the intertidal zone, the mechanical harvesting of intertidal bivalves at high tide creates strong disturbances and a negative effect on the associated fauna. Spencer et al. (1998) estimated that suction dredging of the target species *Venerupis philippinarum* (Adams & Reeve, 1850) caused a reduction of infaunal species and their abundances by approximately 80%. In the same vein, Piersma et al. (2001) studied the long-term indirect effects of suction-dredged



Figure 1. Photograph of fishermen using pebble forks to catch the target species *Venus verrucosa* and the three main fishing gears used for warty venus fishing (photographic credit: Jacques Gallet and Denis Galbadon, APP2R).

edible cockles, *Cerastoderma edule* (Linnaeus, 1757), on the associated bivalves' biodiversity and abundances. They concluded that suction dredging has a long-lasting negative effect on bivalve recruitment in sandy parts of the Wadden Sea basin, particularly on the target species.

The effects of hand harvesting in the intertidal zone is less well documented (Kaiser et al., 2001 and references therein). Kaiser et al. (2001) examined the effects of hand raking on the macrofauna associated with intertidal cockle, *Cerastoderma edule*, in the River Dee estuary in the Liverpool Bay (UK) during a 503-day experiment. The abundance of all the taxa examined changed immediately after a disturbance; then there was a colonised phase as in other physical disturbances. Similarly, for five weeks, Griffiths et al. (2006) compared experimentally the infaunal composition of beaches in the San Juan Islands (Washington, USA) between reserves in which there was a prohibition of recreational clam digging and other beaches supporting significant recreational and professional shellfish harvests, especially for clams. They demonstrated a negative impact for digging clams on the non-target fauna, resulting both by disturbances of the sediment habitat and increased post-digging predation.

In Ria Formosa (South Portugal), Leitão & Gaspar (2007) compared the immediate impact of two fishing gears - the harvesting knife and the hand dredge - used to harvest the cockle *C. edule* for the macrobenthic communities. For both gears, the effects were similar and very low, but both gears affected only the superficial zone of the sediment. In the same area (Lagos, South Portugal), Carvalho et al. (2011) studied the impact of the razor clam, *Ensis siliqua* (Linnaeus, 1758), fishing for the macrofauna within a controlled impact experimental design from 1-120 days survey after fishing. After 1-3 days fishing, the fished areas showed lower mean values of abundances for the macrofauna than the control group.

In the literature, most of the studies on the impact of the fishing gears for the macrofauna concern bivalve fishing. Nevertheless, Carvalho et al. (in press) tested the short-term impact (one, four and seven days) of bait digging on intertidal macrobenthic assemblages of two south Iberian Atlantic systems in the Ria Formosa (Portugal) and Bay of Cadiz (Spain). They showed a significant decrease of abundance, especially those of sedentary polychaetes after digging. In summary, apart from the study of Leitão & Gaspar (2007), all the other studies showed an immediate local impact of fishing for the surrounding macrobenthic assemblages.

The aim of this study is to estimate for the first time in the English Channel, the immediate impact for the pebble fork fishing of the waty venus *Venus verrucosa* on the macrobenthic species during March spring tide on the west coast of Cotentin in the Ronquet tower zone at Agon-Coutainville (France) in the western part of the English Channel, within a controlled impact design with a control station and three stations impacted by pebble fork fishing.

Materials and Methods

Sampling site

Located in the Normano-Breton Gulf, the large intertidal zone in Agon-Coutainville is situated around the Ronquet tower (49°00'04"N-1°38'00"W) (Fig. 2), where the shore is a mix of rocky and sandy areas. In this location, the littoral coastline, composed of sandy dunes, is subject to heavy-duty erosion (Robin et al., 2009). The sampling was done about four kilometres from the water line on a gravely substratum, which is accessible only during spring tide.

The sampling was done with a stainless-steel hand corer, 20 cm in diameter, corresponding to a sampled surface about 1/32 m². The depth of sampling was about 15 cm. Eight replicates were done for each station, representing 0.25 m², which is the surface recommended by the program REBENT for the intertidal zone (*Réseau Benthique*, http: // www.rebent.org/). The sampling was made on three stations (i.e., F1, F2 and F3) in zones in which the fishermen used the pebble fork to capture the target species *Venus verrucosa* and a control station (C) in which the fishing with the pebble fork is normally forbidden (Fig. 2). The pebble fork is a gear with a maximum teeth length of 35 cm and a maximum width of 28 cm, with a total of nine teeth spaced out at least by 3 cm (Fig. 1).

Table 1. Number of fishermen by category accounted for in a rectangle of about 1.2 km x 1 km (Fig. 2) around the Ronquet tower. NW: North-West; NE: North-East; SW: South-West and SE: South-East (Fig. 2).

	Fishermen with pebble forks					**Fishermen with other gears**					**Total**				
	NW	NE	SW	SE	**Total**	NW	NE	SW	SE	**Total**	NW	NE	SW	SE	**Total**
3/8/12	5	3	5	9	**22**	2	4	2	10	**18**	7	7	7	19	**40**
3/9/12	47	110	26	102	**285**	34	21	66	98	**219**	81	131	92	200	**504**
3/10/12	39	103	47	65	**254**	27	40	68	51	**186**	66	143	115	116	**440**
3/11/12	17	32	6	33	**88**	13	9	3	29	**54**	30	41	9	62	**142**
Total	108	248	84	209	**649**	76	74	139	188	**477**	184	322	223	397	**1126**

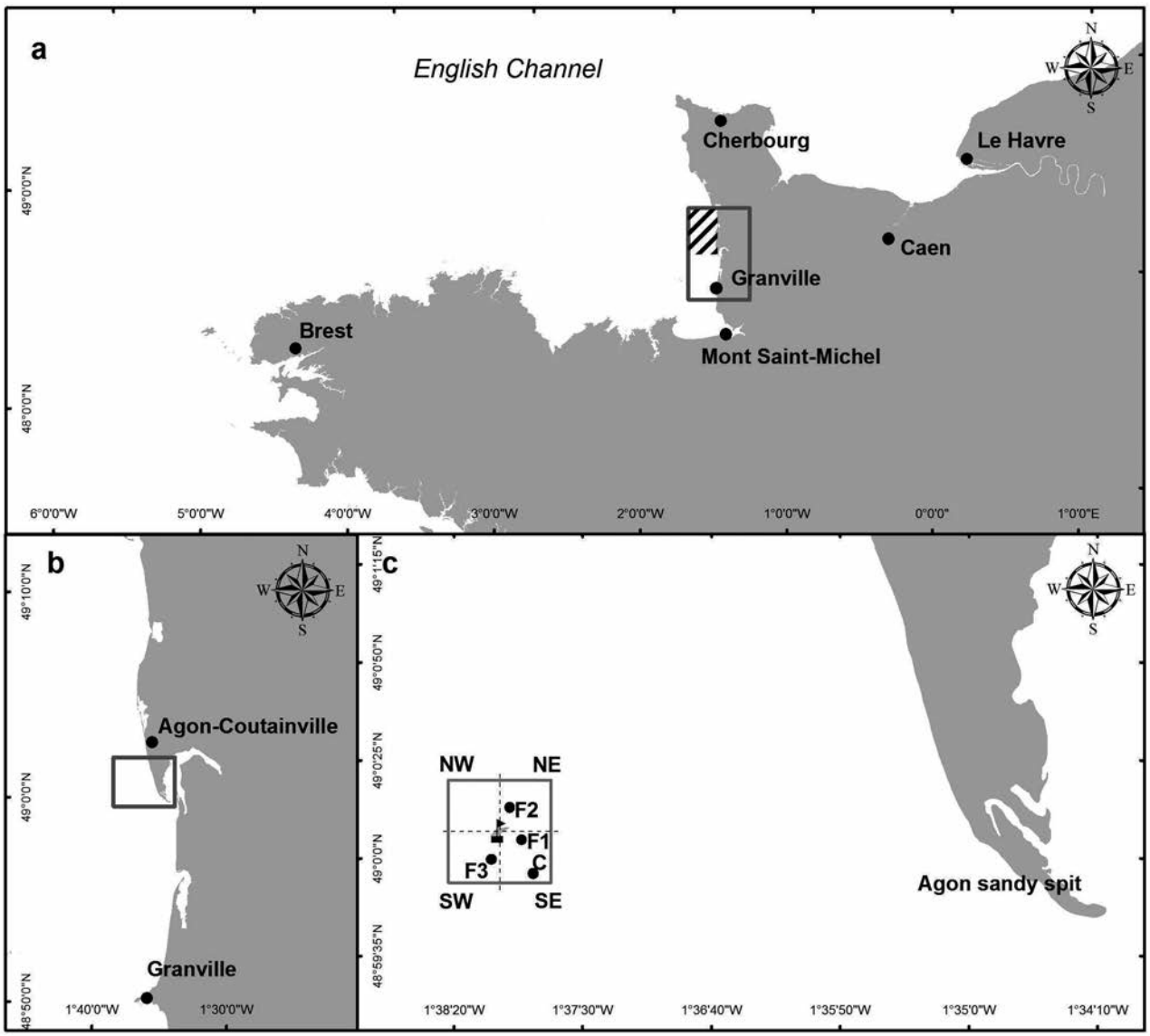


Figure 2. Location of the sampling stations around the Ronquet tower, Agon-Coutainville on the western coast of Cotentin: **A.** General map of the western English Channel. **B.** Central part of the western coast of Cotentin. **C.** Location of the four sampling stations (the flag corresponds to the location of the Ronquet tower). C: control stations; F1, F2 and F3 stations with pebble fork fishing.

At the same time, the fishermen were present around the Ronquet tower in four geographical sectors (i.e., North-West; North-East, including station F2; South-West, including station F3; and South-East, including stations F1 and the control station) in a rectangle of about 1 km in the North-South direction and 1.2 km in the West-East direction (Fig. 2). They were counted at low tide by manual counters, according to two categories: 1) fishermen with pebble forks, fishing *Venus verrucosa* and 2) fishermen with other gears [i.e., with small digging shovels or forks with two or three teeth (Fig. 1)], fishing *Venus verrucosa* (Table 1).

Each station was located with a GPS and has been visited twice during the spring equinox tide. The first time was on 8 March 2012 (tidal coefficient given by tide tables was 99, denoted A) and the second time was on 11 March 2012 (tidal coefficient given by tide tables was 110, denoted B) after the passage of the fishermen, two days after the spring tides of 9 and 10 March 2012 (tidal coefficients given by tide tables were 108 and 112, respectively). The total number of individuals sampled in each replicate and at each station (mean ± SD) and for both dates were given in the Table 2.

Samples were sieved through a sieve with a 1 mm mesh size, fixed with buffered formalin 10% and stained with Rose Bengal to facilitate the sorting. Then, the species were sorted and identified until the main zoological group in the

Table 2. Total number of macrofauna individuals sampled at each station on 8 March (A) and on 11 March 2012 (B) in the four stations. Location of the stations: Control stations: 48°59'34"N-1°37'30"W; Station F1: 49°00'03"N-1°37'32"W; Station F2: 49°00'05"N-1°37'42"W; Station F3: 49°59'36"N-1°38'03"W. SD: Standard-Deviation.

Replicate	CA	CB	F1A	F1B	F2A	F2B	F3A	F3B
1	55	64	64	29	33	45	43	23
2	96	74	180	42	37	73	34	32
3	67	82	32	81	32	21	37	18
4	118	33	40	68	62	24	36	32
5	131	30	26	109	44	11	29	26
6	44	60	68	43	40	12	71	38
7	92	125	56	79	35	18	24	33
8	106	128	44	23	42	27	40	29
Total	**709**	**596**	**510**	**474**	**325**	**231**	**314**	**231**
Mean	**88.6**	**74.5**	**63.8**	**59.3**	**40.6**	**28.9**	**39.3**	**28.9**
SD	**± 30.74**	**± 36.82**	**± 49.25**	**± 29.77**	**± 9.62**	**± 20.77**	**± 14.16**	**± 6.33**

laboratory and stored in 70% ethanol. A supplementary core is taken at each site twice on the 8 and 11 March 2012 to study the sediment's particle-size classes.

Statistical analyses

Two non-parametric tests were used to test the difference between the abundances estimates in the cores: 32 replicates on 8 March and 32 replicates on 11 March. A Kruskal-Wallis test was used to compare the abundances from all stations, before and after fishing. Then, a Wilcoxon-Mann-Whitney test was used to test abundances of all samples before fishing against the samples after fishing, excluding control stations (C) (i.e., a total of 48 replicates) to show a potential impact of fork fishing.

Results

Fishing pressure on the target species, Venus verrucosa

Fish pressure varies between days and sectors. Most of the fishermen (84%) fish during two days (9 and 10 March). Fishermen with pebble forks dominated, representing 58% of the fishermen, with very few variations throughout the four days from 55 to 62% (Table 1). Two sectors - SE, including station F1, and NE, including station F2 - accounted for most of the fishermen with pebble forks. There are also the sectors with higher fish pressure. The offshore sectors NW and SW, including station F3, accounted a lower number of pebble fork fishermen. The lower value was in the NE sector for fishermen with other gears. It is clear that there is a concentration of fish pressure on the warty venus *V. verrucosa* in two main sectors (NE and SE).

Sediment composition

In the sediment, there was a very small proportion of fine particles (< 63 μm), representing between 0.01 and 0.43%, except at the station C-B, where it reached 1.16%. Sand (63-500 μm) formed between 4 to 25% of the total sediment, which is dominated by coarse sand (500-2000 μm) (9 to 74%) and gravel (> 2000 μm) (21 to 85%). The sediment was dominated by gravel (56 to 85%), except for the control stations (C-A, 21 %) on 8 March, which was dominated by coarse sand (74%). No significant statistical differences between stations and between dates were identified. The differences between analyses can be due to the high local natural variability of sediment in the gravel habitat.

General composition of the macrofauna

In such sandy-gravel environment, three main zoological groups dominated the macrofauna: polychaetes; crustaceans, mainly decapods and amphipods; and molluscs, mainly bivalves and gastropods. Other groups, such as echinoderms, ascidians and cnidarians, represented less than 3% of the recorded individuals (Table 3). Polychaetes dominated, forming between 85 and 96% of the macrofauna. Polychaetes were less dominant at station F2 (85 to 86%) than in the other stations. Crustaceans formed between 2 to 9% of the individuals, and the molluscs between 2 to 6%. There are no significant statistical changes for the zoological composition between the two dates (A and B). The data estimation showed an abundance of the warty venus between 4-6 ind.m^{-2} all size included (Table 3).

Immediate impact of fork harvesting

First, all control station abundances were higher before and after the fourth day of fishing than in the other stations, 709 and 596 recorded individuals, respectively (Table 2). The abundance at station F1 was also higher than in stations F2 and F3. For each station, the total abundances were higher

Table 3. Proportion (%) of zoological groups sampled in the four stations on 8 March (A) and 11 March (B) and number of warty venus collected at each date and each station (number.0.25 m^{-2}). C: Control stations; F1, F2 and F3 stations with pebble fork fishing (Fig. 2).

Group	CA	CB	F1A	F1B	F2A	F2B	F3A	F3B
Polychaetes	96	94	91	94	86	85	93	93
Crustaceans	2	3	3	4	8	9	2	2
Molluscs	2	3	3	2	5	6	5	5
Others	0	0	3	0	1	0	0	0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
warty venus	0	2	1	0	2	2	3	0

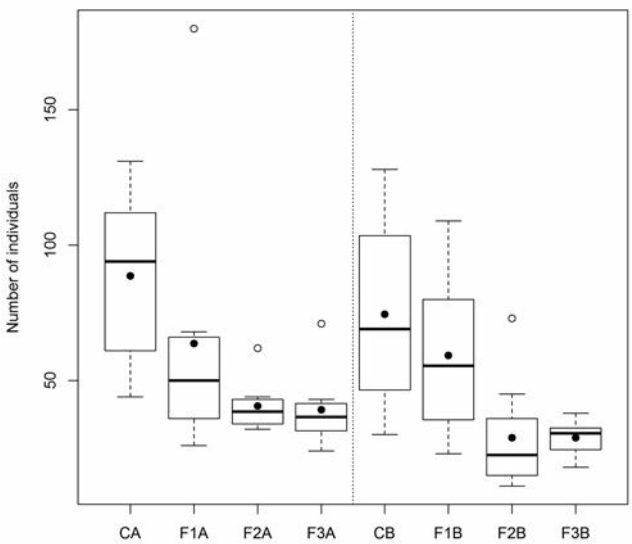


Figure 3. Box plots of total macrofauna abundances identified by phyla in the four stations [C: control station; F1, F2 and F3 stations with pebble fork fishing (Figure 2)] sampled on 8 March (**A**) and 11 March 2012 (**B**). Box plot diagrams display 1st quartile, median, 3rd quartile and the minimum and maximum abundance value at each site. The mean are represented by a black point, the median by a thick line and the extreme values by a empty circle.

before the fishing (A) than after (B) (Fig. 3). There was a larger range of abundance values for the C control station and the F1 station than for the two other stations (Table 2). The Kruskal-Wallis tests showed that there was a significant difference between the abundances recorded in the four stations between fishing ($p < 0.005$) and after fishing ($p < 0.004$). The control station showed higher abundances before and after fishing, which the pebble fork stations impacted. A Wilcoxon-Mann-Whitney test showed that there was significant difference between abundances before and after fishing for the three impacted stations by pebble fork fishing ($p = 0.05$). The control station was excluded, as it showed higher abundances than in the three other stations; it was not impacted by pebble fork fishing.

Discussion and Perspectives

The objective of this study was to demonstrate the immediate effect of pebble fork harvesting of the warty venus, *Venus verrucosa*, on the surrounding macrofauna. Coarse sand and gravel dominated largely the sediment composition, and no statistical changes could be identified between the sediment samples before and after the fishing and between the four stations.

Fishing the warty venus with a pebble fork was allowed only on a short length of the western littoral of Cotentin: approximately 20 km (Fig. 2). The area around Ronquet tower is a famous fishing place for the warty venus. Consequently, in this sector, fishermen had a high fishing pressure on this target species along the western Cotentin. It is an easily accessible place for fishermen and large channels retaining water at low tide. Numerous channels, which were the single habitat where the use of pebble forks are authorized at low tides, occurred in this area. Thus, this area is an excellent candidate to test the effect of pebble fork pressure on macrofauna.

The fauna was mainly dominated by polychaetes; among polychaetes, the more abundant families were the Capitellidae, Cirratulidae. Dorvilleidae, Glyceridae, Spionidae and Syllidae. The fauna appeared very similar to those found in subtidal coarse sand community from the western part of the Channel (Dauvin, 1988). At both dates, the abundances estimated at the control stations were significantly higher than those estimated in the three stations before and after fishing.

This suggests that the macrofauna in the zones under an active fork fishing (Fig. 1) were affected by the type of destructive gear than those fishing by other types of gears, such as small digging shovels or forks with two or three teeth. The fact that the abundances in the four stations were lower at the end of the spring tide indicated that the entire fishing zone in which the *Venus verrucosa* fishing, including the control stations in which fishermen have been observed, but without pebble forks. The abundances after four days of fishing were significantly lower than those observed at the beginning of the spring tide. Therefore,

there was an immediate impact of the *V. verrucosa* fishing on the macrofauna.

Our results were comparable to those observed for the intertidal benthic assemblages under the pressure of various bivalve fishing gears (Spencer et al., 1998; Piersma et al., 2001; Kaiser et al., 2001; Griffiths et al., 2006; Carvalho et al., 2011), showing a short-term negative impact of the macrofauna. Only one study (Leitão & Gaspar, 2007), comparing the immediate impact of the harvesting knife and the hand dredge used to harvest the cockle, *Cerastoderma edule*, showed very limited impact of such fishing activities on the macrobenthic communities.

Effects generated essentially physical disturbances on the intertidal benthic environment and a negative impact on biodiversity have been shown experimentally in case of clam digging or cockle hand raking (Kaiser et al., 2001; Griffiths et al., 2006). Human trampling on bivalve dynamics had been also tested on an intertidal mudflat of Paulina Polder (The Netherlands). The negative impact on both the clam, *Macoma balthica* (Linnaeus, 1757), and the cockle, *C. edule*, have been observed, probably due to death by smothering (Rossi et al., 2007). Dernie et al. (2003) showed on intertidal experiment that clean sand communities showed the most rapid recovery rate following disturbances, while muddy sand habitats showed the slowest physical and biological recovery rates. In addition, Griffiths et al. (2006) demonstrated that intertidal reserves where clam digging was prohibited play an important role in sustaining the local and regional biodiversity.

Fishing the warty venus with a pebble fork remains a very negative practice for the benthic macrofauna. However, it is easy for inexperienced fisherman, permitting a rapid collection of 100 warty venus (authorized number per day and per fisherman in 2012) during a low tide. Other less destructive gears can be promoted as they are similarly efficient for experienced fisherman, recording one hundred individuals at each low tide during the spring tide. The fishing of warty venus around the Ronquet tower is possible only during highest spring tides (tidal coefficient given by tide tables > 100). In 2012, during the authorized period (January to April and September to December), there are 25 accessible days. With a mean number of 280 fishermen (Table 1), 7000 fisherman days per year were able to catch a maximum of 700,000 warty venus throughout 2012 (100 individuals per day and by fisherman).

The wet weight of an individual can be estimated to 50 g (personal observation). The length > 43 mm corresponds to a life span at least 7 years; the longevity is 18-20 years for a maximum length of 70 mm. A maximum weight of 35 t for one year was collected around the Ronquet tower. This is a significant catch for a very limited area (about 1.2 km² and about 1.7 warty venus per m² per year), corresponding to about 10% of the 341 t unloaded at the Granville harbour. This catch represents 80% of the French national fishery catch (http://www.granville.cci.fr/fileadmin/Espace_presse/CP_2012/Bilan_2011_des_ports_de_Granville.pdf).

This preliminary study can be completed in the future, and we propose two adjustments of the sampling design. First, increasing the size of the corers permits us to assess the abundance of the target species (i.e., the warty venus) and probably to minimize the small scale heterogeneity in the abundance estimation for the non-target macrofauna. Second, as the fishing is closed each year from 1 May to 31 August during the main reproductive period of *Venus verrucosa* and other intertidal invertebrates, sampling at the beginning of the fishing period during the first spring tide of September and at the end of the fishing period during the last spring tide in April permits us to evaluate the negative effect of fishing on the macrofauna during all the fishing period.

This preliminary study will provide the French administration with objective data to exclude pebble fork fishing in this part of the western coast of Cotentin (approximately 20 km of seashore) and promote other gears to catch the target species, *Venus verrucosa*. Such a decision will also have an impact to limit the total number of fishermen during spring tide and, as a result, to limit the pressure on the warty venus. In fact, to support a great fishing effort of 700,000 individuals a year, it is necessary to have a high annual recruitment and a high percentage of survival of the juveniles to ensure a life span at least > 7 years. For the moment, there are no data on the *Venus verrucosa* stock and dynamic of this intertidal population. In the future, another research project can be proposed to acquire objective data on harvesting this species and to establish a true control station without warty venus fishing pressure.

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