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Positive effects of the decrease of hydraulic dredging due to the SARS-CoV-2 pandemic on benthic fauna and clam harvesting in the northern Adriatic (Mediterranean Sea)

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Abstract: The Northern Adriatic Sea is historically subjected to intensive bottom trawling and hydraulic dredging for clam harvesting, which are known to have deleterious effects on benthic habitats. In order to gather information on the destructive impact of hydraulic dredging, we investigated the abundance and assemblage composition of soft-bottom macrofauna in a coastal area of the North Adriatic Sea (Mediterranean Sea), by comparing the year before and the year after the reduction of the fishing effort imposed by the SARS-CoV-2 pandemic. Our results indicate that macrofaunal assemblages changed significantly in abundance and composition. While bivalves doubled their abundance, other opportunistic scavenger taxa decreased or disappeared. Despite dredging intensity decreased more than 50% in 2020, the harvesting of *Chamelea gallina* increased from 18,706 tons in 2019 to 19,092 tons in 2020. Overall, it could be concluded that the decrease in clam fishing effort imposed by the lockdown resulted in an increase of the yearly clam harvesting. Our study points out that the recovery of soft-bottom macrofaunal assemblages due to the long-term decrease of clam harvesting has potentially important benefits, and that the establishment of long fishing stops, or of fishery restricted areas / marine protected areas could lead to a more sustainable fishery and the potential increase of the clam fishery yields.

Keywords: clam harvesting; hydraulic dredging; COVID lockdown; Adriatic Sea

INTRODUCTION

The Mediterranean Sea and, in particular, the northern Adriatic Sea are historically subjected to a significant fishing pressure, and most of the species of commercial interest are now exploited beyond maximum sustainable yields (Amoroso *et al*., 2018). The most significant impacts on benthic habitats are due to the bottom contact of the fishing gears. In particular, the Adriatic Sea is now one of the most trawled areas in the world (Romanelli *et al*., 2009; Amoroso *et al*., 2018), and severely impacted by hydraulic dredging for harvesting bivalves (especially *Chamelea gallina* (Linnaeus, 1758)) living within the soft sediments. This fishing practice appears to be particularly destructive for soft-bottom ecosystems (Morello *et al*., 2005; Petetta *et al*., 2021), as the dredge is deployed on the seafloor and high-pressure water injections are used to harvest the bivalves from the sediments. The heavy dredge towed by the fishing vessel along with the use of "water jets" has a significant impact on the sediment stratification and integrity where a high number of macro- and megabenthic species are present (Gilkinson *et al*., 2003). The effects are nearly instantaneous, with plumes of resuspended sediments and visible furrows on the seafloor. The extension of these physical impacts depends largely on the sediment type and gear's characteristics (the width of the dredge, the length of the teeth, the cutting depth of the blade and/or the pressure of the water jets) and the fishing effort (as number of vessels and number of days at work; Gaspar and Chícharo, 2007). The temporal persistence of the dredge furrows is strictly correlated with local sedimentation rates and sediment type, with a persistence from a few hours to several days for tows performed in sandy and sandy-mud sediments respectively (Gaspar and Chícharo, 2007). As a consequence of the disturbance induced by dredging, bioturbation activity significantly declines with consequent effects on benthic biodiversity, assemblage composition, nutrient fluxes and food webs (Olsgard *et al.*, 2008). Moreover, hydraulic dredging causes sediment resuspension, a change in the biochemical composition of the sediment organic matter (e.g., the protein to carbohydrate ratio) and a decrease of the bioavailable fraction of organic carbon (Pusceddu *et al*., 2005). In addition, at the end of the fishing, the cage is hauled up and the whole catch is dumped into a collecting box where it is sorted and the under-size individuals are discarded back into the sea (Moschino *et al*., 2003; Çolakoğlu 2020). The consequence is that the discarded specimens are generally partly damaged or stressed and thus subjected to an increased risk of predation (Urra *et al*., 2021). For this reason, the abundance of the commercial bivalves (especially *Chamelea gallina*) has shown a progressive decrease over time in the Adriatic Sea (Romanelli *et al*., 2009; Froglia, 2000; Carducci *et al*., 2020). In order to favor the restocking, the European Union adopted the Regulation 1967/2006, for which the use of hydraulic dredging is strictly forbidden within 0.3 nautical miles from the coast. However, despite restrictions, often the illegal fishery prevails. Another measure to protect the bivalve stocks is the temporary suspension of the fishing activity in summer (duration, generally, about 30 days).

A study performed using a BACI design (i.e., *Before vs After* and *Control vs Impact*) revealed a significant impact of hydraulic dredging on bivalve abundance (Morello *et al.*, 2005), with a consequent reduction of energy transfer efficiency to higher trophic levels (Libralato *et al*., 2010). While different studies were carried out on the effects of fishing on bivalve abundance and macrofauna assemblage (Gallmetzer *et al*., 2017; Vasapollo *et al*., 2020), limited information is available on the effects of dramatic reduction of fishing effort.

Here, we investigated the effects on the macrofauna assemblage in the Adriatic Sea, of the lockdown (i.e., three months) imposed by SARS-CoV-2 emergency in 2020, when a reduction of more than 50% of the fishing efforts happened and continued after the lockdown (plus 30 days of complete stop in August) instead of the usual 30 days requested by national regulations to preserve the clam stock (Russo *et al*., 2021). The importance of this study also forms an input to the existence of a strong debate about the possibility to establish a Marine Protected Area in the study area.

MATERIAL AND METHODS

Study Area and Sampling Design

The study area is located in the Portonovo Bay along the Italian coast of the Adriatic Sea (Central Mediterranean, Figure 1). Here the soft bottoms are characterized by well-sorted sandy sediments. The area hosts two precious habitats protected by European Union (European Union Habitat Directive 92/43/EEC): “Sandbanks slightly covered by sea water” (Habitat type 1110), which host the typical “Biocenosis of well-sorted fine sands” (identification code RAC/SPA III.2.2) and “Reef” (Habitat type 1170) hosting the “Biocoenosis of infralittoral algae” (identification code RAC/SPA III.6.1). Therefore, two Sites of Community Importance are present in the bay (IT5320005 and IT5320006).

To assess the changes in the macrofauna assemblage induced by the fishing stop, we adopted a Before-After design (i.e., Before vs After, July 2019 and June 2021 respectively). At the two sampling times, 4 transects (i.e., A, B, C and D) with three stations at three depths (i.e., 3, 6 and 10 m) were sampled (with the exception of transect D, where the sampling at 3 m depth was not possible due to the presence of hard substrates) with a maximum distance from the coast of about 1300 m depending on the transect. At each station, three replicas were collected with a Van-Veen grab and the sediment was sieved on a 500 µm mesh net to retain only the macrofaunal organisms. All specimens were preserved in a solution of 70% alcohol.

Macrofaunal Sorting and Identification

The samples were sorted under a stereo-microscope and organisms identified using an approach to taxonomic sufficiency. The identification at higher taxonomic level was chosen as macrofaunal responses to human impacts are more relevant when detected at higher taxonomic level compared to the species level, which is particularly susceptible to natural (nuisance) variability (Warwick, 1988; Bevilacqua *et al*., 2018).

Statistical analyses

To assess the differences between before and after the lockdown, a nMDS (based on Bray-Curtis similarity index on log(x+1) transformed data) was performed. In addition, to test the significance of the differences eventually encountered, a PERMANOVA analysis was performed. This method analyses

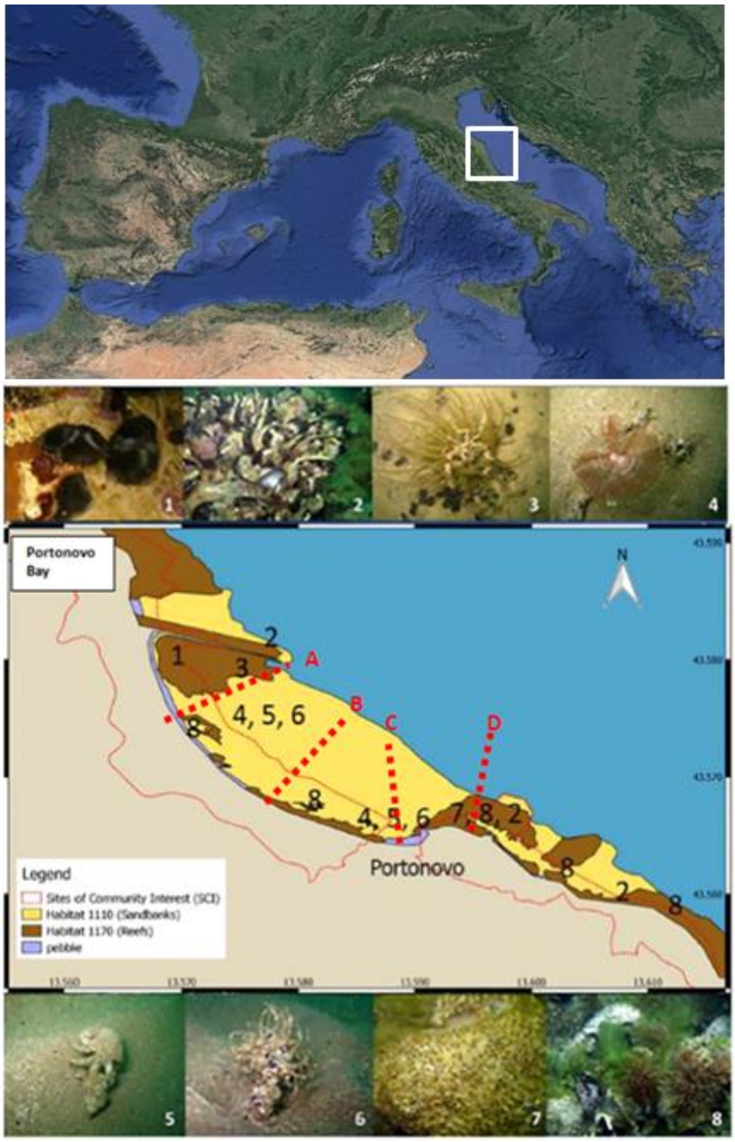

Figure 1. Location of the study area (a) and extension of the different habitats (b) with the locations of the four transects (A, B, C, D). Legend of organisms: 1: *Pholas dactylus* Linnaeus, 1758; 2: *Mytilus galloprovincialis* (Lamarck, 1819); 3: *Pholas dactylus* with *Anemonia viridis* (Forsskål, 1775) and *Inachus sp*.; 4: *Megalomma cf. vesiculosum* (Montagu, 1815); 5: *Diogenes pugilator* (Roux, 1829); 6: *Lanice conchilega* (Pallas, 1766); 7: *Sabellaria cf. alcocki* Gravier, 1906; 8: *Scinaia furcellata* (Turner) J. Agardh 1851, *Ulva rigida* C. Agardh, 1823

the variance of multivariate data explained by one or more explanatory factors and gives p-values calculated using all possible permutations. All statistical analysis were carried out using the Primer 6 software (Clarke and Warwick, 1994). The statistical design included two fixed orthogonal factors: "before vs after" (two levels before and after) and "station" (with 11 stations). The stations were named combining the letter of the transect (A, B, C and D) and the depth, which were named 1, 2 and 3 corresponding to 3, 6 and 10 m respectively (e.g., A1, A2 and A3). The significance of the interaction "before vs after x station" indicates that the change is not the same in the different stations. The absence of the station D1 does not allow to include the factor "transect" in the statistical analysis. In addition, when necessary, a univariate PERMANOVA analysis was performed to test the significance of difference between before and after lockdown of some taxa.

RESULTS AND DISCUSSION

The lockdown imposed by the COVID19 emergency in spring 2020 caused a prolonged stop or decrease of several human activities and related pressures (approximately 2.5 months of complete stop from mid-March to early June). This stop has been reported to have positive effects on air and water

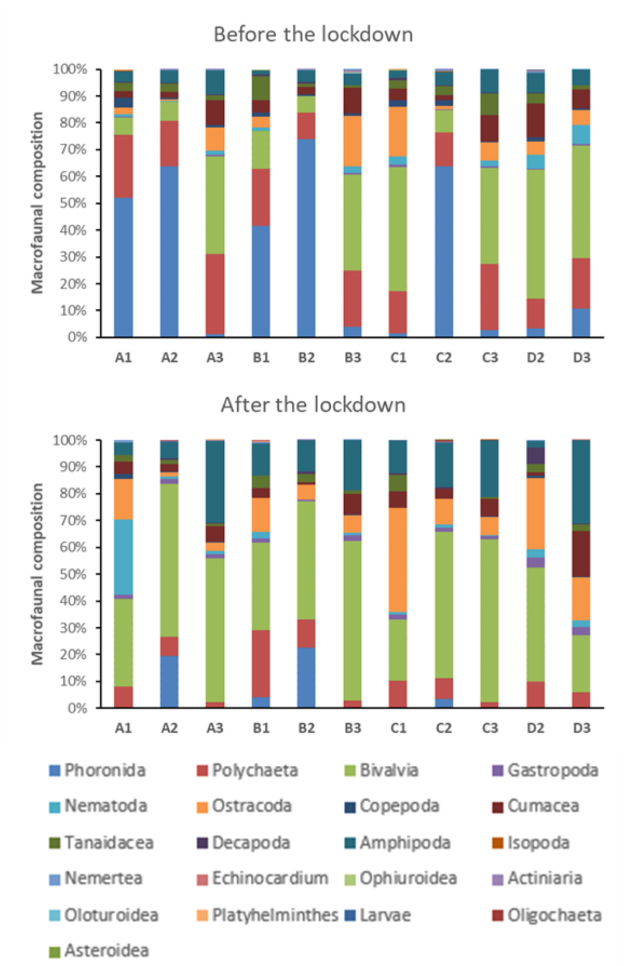

Figure 2. Relative abundance of the macrofaunal taxa before and after the dredge lockdown

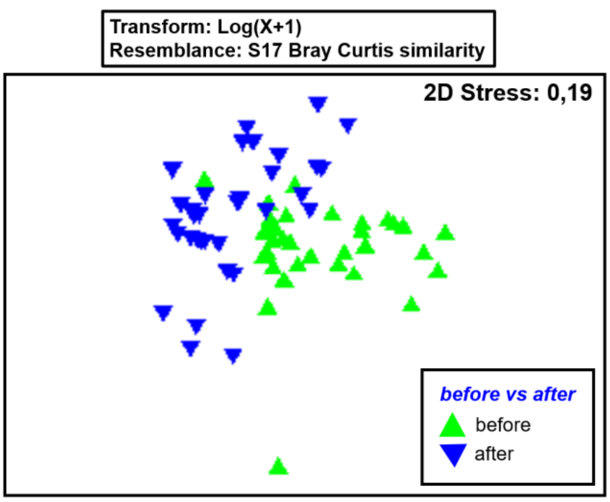

Figure 3. Output of the nMDS performed on macrofaunal assemblages

quality, noise pollution (Braga *et al.*, 2020; Lamprecht *et al.*, 2021; Čurović *et al.*, 2021) and resulted in an overall increase of the environmental quality (Lal *et al.*, 2021; Abubakar *et al.*, 2021), but information on its effects on benthic marine assemblages is non-existent to the best of our knowledge.

Here we report that the assemblage composition of macrofauna displayed remarkable differences before and after the lockdown (Fig. 2), with a clear shift of the most abundant taxa (i.e., bivalves, phoronids and polychaetes). A clear separation of samples collected before and after the lockdown was also highlighted by nMDS analysis (Fig. 3). The statistical significance of such change is confirmed by PERMANOVA analysis (Table 1). In particular, the interaction “before vs after x station” (p<0.001) indicates that the change is not equal among stations. Pairwise tests indicated that all the stations at 3 m depth are significantly different from before to after the lockdown (p<0.05). At 6 m depth, all stations are significantly different from before to after (p<0.05), with the exception of station D2. Finally, at 10 m depth all stations are significantly different before to after lockdown (p<0.05) with the exception of A3 (p= 0.05). The most evident change is the dramatic increase of bivalves (p<0.001), from 801±95 to 2076± 303 individuals m^{-2}, before and after the lockdown, respectively (Fig. 4a). At the same time, an opposite pattern was detected for polychaetes that decreased from 648± 67 to 246± 21 individuals m^{-2} (p<0.001; Fig. 4a). Also, Phoronida showed a significant decrease (p<0.001), from 1148± 244 to 160± 52 individuals m^{-2} (Fig. 4a). Furthermore, copepods significantly decreased from 46 ± 8 to 10± 2 individuals m^{-2} (p<0.001; Fig. 4a) as well as tanaids from 112± 13 to 73± 8 individuals m^{-2} (p<0.05; Fig. 4a). In contrast, ostracods significantly increased from 200± 35 to 400± 45 individuals m^{-2} (p<0.01; Fig. 4a) and amphipods from 185± 20 to 792± 144 individuals m^{-2} (p<0.001; Fig. 4a). Finally, cumaceans, did not show significant changes in abundance. The number of individuals of other taxa such as the large and widespread echinoid *Echinocardium cordatum*, typical of these substrates, the holothuroids, the platyhelminths, the oligochaetes and the asteroids were typically very low (i.e., on average < 2 individuals m^{-2}; Fig. 4a). The taxa that showed the major percentage of variation (in terms of abundance) are Bivalvia, Gastropoda and Amphipoda (159, 474 and 323% respectively, Fig. 4b).

Overall, comparing the before vs after macrofaunal assemblages, the most evident result is the significant increase of bivalve abundance, which was associated with a shift in macrofaunal assemblage composition. Our results pointed out that

Table 1. Output of PERMANOVA analysis performed on macrofauna assemblage

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
before vs after	1	3355.3	3355.3	33.585	0.0001	9942
station	10	8082.7	808.27	8.0904	0.0001	9873
before vs after × station	10	4633.2	463.32	4.6377	0.0001	9868
Res	44	4395.8	99.904			
Total	65	20467				

after the reduction of the hydraulic dredging effort, due to the COVID pandemic, bivalve abundance displayed a clear resilience. However, approximately three months without any clam harvesting have been previously reported to be insufficient for the recovery of bivalve abundance (Dimitriadis *et al.*, 2014). The effects of the decrease of dredging were apparent also for several other components that are typically favored by sediment disturbance, such as Ophiuroidea and polychaetes (Vasapollo *et al.*, 2020). Other observed changes (e.g., changes in phoronid, ostracod and amphipod abundances) could be associated to the interannual variability in the recruitment or other environmental factors (Targusi *et al.*, 2018). Assessing the impact on benthic assemblages of hydraulic dredging on soft bottoms has been always difficult due to the lack of appropriate controls (Morello *et al*., 2005; Vasapollo *et al.*, 2020).

However, our results suggest that the reduction of clam harvesting resulted in an evident and well measurable resilience of macrofaunal structure, though not homogeneous across stations as shown by the analysis of the “before vs. after x station” interaction. Interestingly, the positive effects of the lockdown on bivalve abundance lasted, also after the restart of fishing activities (as evident from the results obtained in 2021). Since the lockdown was adopted for the whole Adriatic coastline the recovery of the bivalve stocks observed in the Portonovo bay can be an effect at the whole basin scale (Haselmair *et al.*, 2021).

The Annual Fishing Relations of 2019 and 2020 (data from the Italian Ministry of Agricultural and Forestry Policies) pointed out that, due to the lockdown, the number of fishing days decreased from about 1,300,000 in 2019 to 1,050,000 in 2020 (i.e., by approx. 19.2%). During the entire 2020, 58% of Italian fishing vessels was underused, 25% moderately used and only 15% fully used (Vessel Use Indicator i.e., VUI). Therefore, according to Russo *et al*. (2021), cumulatively, the lower number of working days, coupled with the reduced intensity of dredging in the remaining part of the year resulted in a decrease of fishing intensity of approx. 50% in 2020. At the same time, available data reported that the harvesting of *Chamelea gallina* increased from 18,706 tons in 2019 to 19,092 tons in 2020. Overall, it can be concluded that the reduction by approx. 50% of fishing intensity resulted in an increase, although of limited extent, of clam harvesting in 2020.

The limited temporal extension of the experimental design does not allow assessing the importance of the temporal variability in macrofaunal and clam populations over the long term. Nonetheless, an additional retrospective temporal analysis, dated back to 2017, revealed that in the same sampling period and in the same stations Bivalvia showed an average abundance of 433±451 ind. m^{-2} (Danovaro, unpublished data), which is not significantly different from the values reported in 2019, also due to the high variance observed in 2017. The analysis of the long-term patterns of clam fisheries revealed a continuous decrease in overall catch from 2011 to 2017 (overall decrease: 51.6%; Decree Director General Italian Ministry MIPAF n.9913, 2019). These results suggest the lack of evident natural fluctuations in clam populations and the progressive impact of the overfishing on this component. In addition, a temporal analysis based on higher taxa (as the one used in the present study) limits the amplitude of the temporal variability related to the blooms of single species (Warwick, 1988; Bevilacqua *et al*., 2018). These results suggest that the patterns observed in the present study could reflect the effects of the reduction of dredging activities in the area.

The results obtained from an exceptional situation (i.e., the lockdown imposed by the SARS-CoV-2) offered a unique opportunity to test the possible effects of (future) stricter protection measures (e.g., the zone A of marine protected areas or a fishery restricted area). The results of this study, indeed, led us to hypothesize that the reduction of clam harvesting can have a positive effect on the bivalve abundance and assemblage structure. Since the Adriatic Sea is one of the most intensively dredged areas of the world (Amoroso *et al*., 2018), the enforcement of the fishery stops, the creation of MPAs and/or the creation of fishery restricted areas in this region could be a suitable solution for

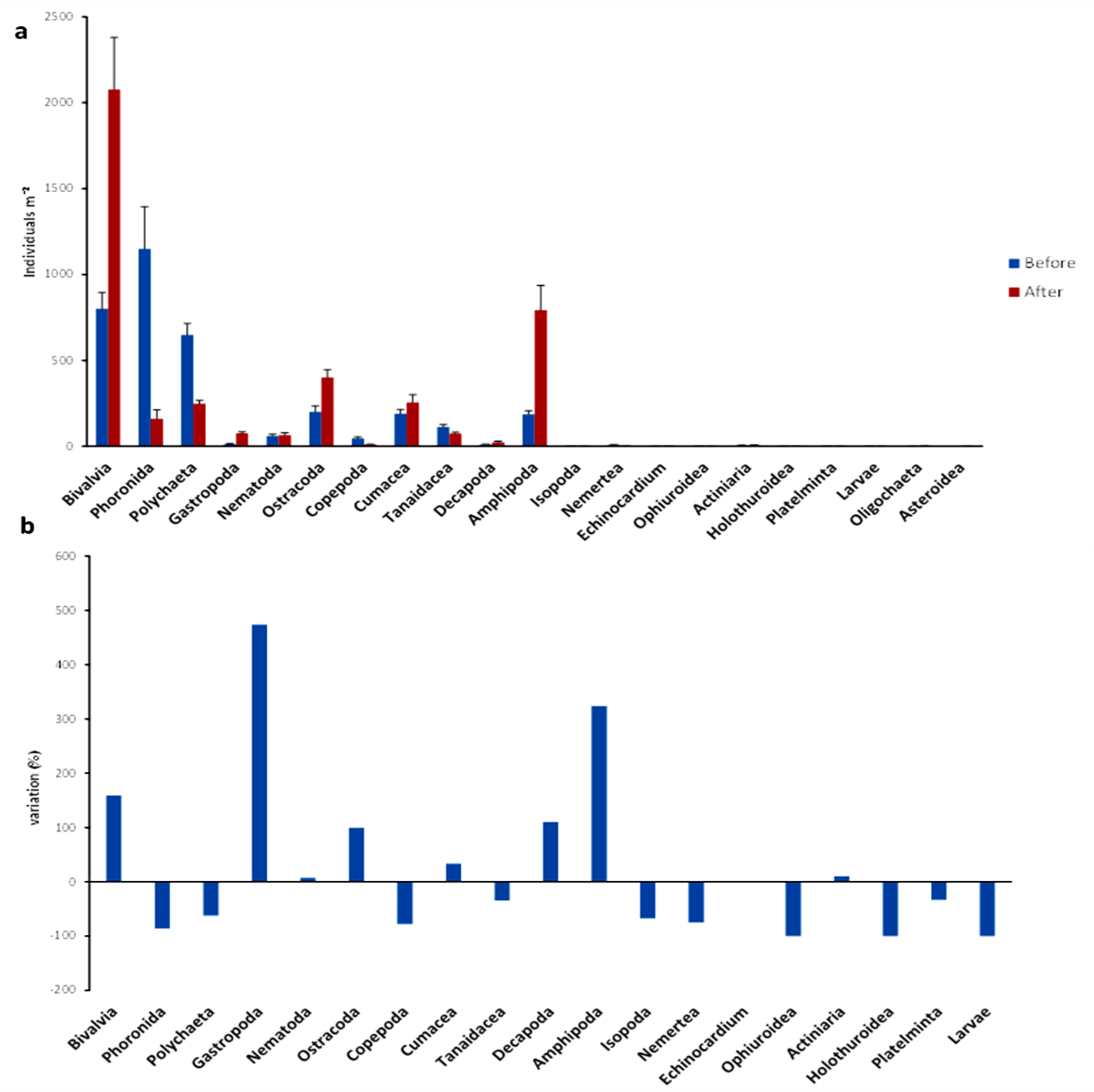

Figure 4. a) Abundance of the main taxa (average ± standard error) and b) the variation of each taxa abundance before and after the lockdown (2019 vs 2021) expressed as percentage

protecting and restocking the bivalve abundance, while maintaining (or even increasing) the clam harvesting. Similar management plans should be a priority for developing a sustainable clam fishery in this region (Bastari *et al*., 2016).

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REFERENCES

ABUBAKAR, L., SALEMCITY, A.J., ABASS, O.K. and OLAJUYIN, A.M. (2021) The impacts of COVID-19 on Environmental Sustainability: A Brief study in World Context. *Bioresource Technology Reports*, 100713.

AMOROSO, R.O., PITCHER, C.R., RIJNSDORP, A.D., MCCONNAUGHEY, R.A., PARMA, A.M., SUURONEN, P., EIGAARD, O.R., BASTARDIE, F., HINTZEN, N.T., ALTHAUS, F., BAIRD, S,J., BLACK, J., BUHL-MORTENSEN, L., CAMPBELL , A.B., CATARINO, A., COLLIE, J., COWAN JR.J.H., DURHOLTZ, D., ENGSTROM, N., FAIRWEATHER, T.P., FOCK, H.O., FORD, R., GÁLVEZ, P.A., GERRITSEN, H., GÓNGORA,

M.E., GONZÁLEZ, J.A., HIDDINK, J.G., HUGHES, K.M., INTELMANN, S.S., JENKINS, C., JONSSON, P., KAINGE, P., KANGAS, M., KATHENA, J.N., KAVADAS, S., LESLIE, R.W., LEWIS, S.G., LUNDY, M., MAKIN, D., MARTIN, J., MAZOR, T., GONZALEZ-MIRELIS, G., NEWMAN, S.J., PAPADOPOULOU, N., POSEN, P.E., ROCHESTER, W., RUSSO, T., SALA, A., SEMMENS, J.M., SILVA, C., TSOLOS, A., VANELSLANDER, B., WAKEFIELD, C.B., WOOD, B.A., HILBORN, R., KAISER, M.J. and JENNINGS, S. (2018) Bottom trawl fishing footprints on the world's continental shelves. *Proceedings of the National Academy of Sciences*, 115(43), pp. E10275-E10282.

BASTARI, A., MICHELI, F., FERRETTI, F., PUSCEDDU, A. and CERRANO, C. (2016) Large marine protected areas (LMPAs) in the Mediterranean Sea: the opportunity of the Adriatic Sea. *Marine Policy*, 68, pp. 165-177.

BEVILACQUA, S., MISTRI, M., TERLIZZI, A. and MUNARI, C. (2018) Assessing the effectiveness of surrogates for species over time: Evidence from decadal monitoring of a Mediterranean transitional water ecosystem. *Marine Pollution Bulletin*, 131, pp. 507-514.

BRAGA, F., SCARPA, G. M., BRANDO, V.E., MANFÈ, G. and ZAGGIA, L. (2020) COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon. *Science of the Total Environment*, 736, 139612.

CARDUCCI, F., BISCOTTI, M.A, TRUCCHI, E., GIULIANI, M.E., GORBI, S., COLUCCELI, A., BARUCCA, M. and CANAPA, A. (2020) Omics approaches for conservation biology research on the bivalve *Chamelea gallina*. *Scientific Reports*, 10(1), pp. 1-15.

CLARKE, K.R. and WARWICK, R.M. (1994) Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Natural Environment Research Council, UK (144 pp).

ÇOLAKOĞLU, S. (2020) Bycatch and discards from two types of bivalve dredges targeting *Donax trunculus* and *Chamelea gallina* used in the southern coast of the Marmara Sea, Turkey. *Fish Science*, 86(6), pp. 995-1004.

ČUROVIĆ, L., JERAM, S., MUROVEC, J., NOVAKOVIĆ, T., RUPNIK, K. and PREZELJ, J. (2021) Impact of COVID-19 on environmental noise emitted from the port. *Science of the Total Environment*, 756, 144147.

DECREE DIRECTOR GENERAL MIPAF (2019) Piano di gestione nazionale per le attività di pesca con il sistema draghe idrauliche e rastrelli da natante così come identificati nella denominazione degli attrezzi di pesca in draghe meccaniche comprese le turbosoffianti (HMD) e draga meccanizzata (DRB). Allegato 1 - Pesca con draghe idrauliche. MIPAF, n.9913, 18 pp.

DIMITRIADIS, C., KOUTSOUBAS, D., GARYFALOU, Z. and TSELEPIDES, A. (2014) Benthic molluscan macrofauna structure in heavily trawled sediments (Thermaikos Gulf, North Aegean Sea): spatiotemporal patterns. *Journal of Biological Research-Thessaloniki*, 21(1), pp. 1-10.

FROGLIA, C. (2000) Il contributo della ricerca scientifica alla gestione della pesca dei molluschi bivalvi con draghe idrauliche. *Biologia Marina Mediterranea*, 7(4), pp. 71-82.

GALLMETZER, I., HASELMAIR, A., TOMASÏOVYÂCH, A., STACHOWITSCH, M. and ZUSCHIN, M. (2017) Responses of molluscan communities to centuries of human impact in the northern Adriatic Sea. *PLoS ONE*, 12 (7), e0180820.

GASPAR, M.B. and CHÍCHARO, L.M. (2007) Modifying dredges to reduce by-catch and impacts on the benthos. In: Kennelly, S.J. (ed.) By-catch Reduction in the World's Fisheries Springer, Dordrecht. (pp. 95-140)

GILKINSON, K.D., FADEB, G.B.J., GORDON JR., D.C., CHARRON, R., MCKEOWN, D., RODDICK, D., KENCHINGTON, E.L.R., MACISAAC, K., BOURBONNAIS, C., VASS, P. and LIU Q. (2003) Immediate and longer-term impacts of hydraulic clam dredging on an offshore sandy seabed: effects on physical habitat and processes of recovery. *Continental Shelf Research*, 23, pp 1315–1336.

HASELMAIR, A., GALLMETZER, I., TOMAŠOVÝCH, A., WIESER, A. M., ÜBELHÖR, A. and ZUSCHIN, M. (2021) Basin-wide infaunalisation of benthic soft-bottom communities driven by anthropogenic habitat degradation in the northern Adriatic Sea. *Marine Ecology Progress Series*, 671, pp. 45-65.

LAL, P., KUMAR, A., BHARTI, S., SAIKIA, P., ADHIKARI, D. and KHAN, M.L. (2021) Lockdown to contain the COVID-19 pandemic: an opportunity to create a less polluted environment in India. *Aerosol and Air Quality Research*, 21(3), 200229.

LAMPRECHT, C., GRAUS, M., STRIEDNIG, M., STICHANER, M. and KARL, T. (2021) Decoupling of urban CO2 and air pollutant emission reductions during the European SARS-CoV-2 lockdown. *Atmospheric Chemistry and Physics*, 21(4), pp. 3091-3102.

LIBRALATO, S., COLL, M., TEMPESTA, M., SANTOJANNI, A., SPOTO, M., PALOMERA, I., ARNERI, E. and SOLIDORO, C. (2010) Food-web traits of protected and exploited areas of the Adriatic Sea. *Biological Conservation*, 143(9), pp. 2182-2194.

MORELLO, E.B., FROGLIA, C., ATKINSON, R.J. and MOORE, P.G. (2005) Impacts of hydraulic dredging on a macrobenthic community of the Adriatic Sea, Italy. *Canadian Journal of Fisheries and Aquatic Sciences*, 62(9), pp. 2076-2087.

MOSCHINO, V., DEPPIERI, M. and MARIN, M. G. (2003) Evaluation of shell damage to the clam *Chamelea gallina* captured by hydraulic dredging in the Northern Adriatic Sea. *ICES Journal of Marine Science*, 60, pp. 393–401.

OLSGARD, F., SCHAANNING, M.T., WIDDICOMBE, S., KENDALL, M.A. and AUSTEN, M.C. (2008) Effects of bottom trawling on ecosystem functioning. *Journal of Experimental Marine Biology and Ecology*, 366(1-2), pp. 123-133.

PETETTA, A., HERRMANN, B., VIRGILI, M., BARGIONE, G., VASAPOLLO, C. and LUCCHETTI, A. (2021) Dredge selectivity in a Mediterranean striped venus clam (*Chamelea gallina*) fishery. *Fisheries Research*, 238, 105895.

PUSCEDDU, A., GRÉMARE, A., ESCOUBEYROU, K., AMOUROUX, J.M., FIORDELMONDO, C. and DANOVARO, R. (2005) Impact of natural (storm) and anthropogenic (trawling) sediment resuspension on particulate organic matter in coastal environments. *Continental Shelf Research*, 25(19-20), pp. 2506-2520.

ROMANELLI, M., CORDISCO, C.A. and GIOVANARDI, O. (2009) The long-term decline of the *Chamelea gallina* L.(Bivalvia: Veneridae) clam fishery in the Adriatic Sea: is a synthesis possible. *Acta Adriatica*, 50(2), pp. 171-205.

RUSSO, E., ANELLI MONTI, M., TONINATO, G., SILVESTRI, C., RAFFAETÀ, A. and PRANOVI, F. (2021) Lockdown: How the COVID-19 Pandemic Affected the Fishing Activities in the Adriatic Sea (Central Mediterranean Sea). *Frontiers in Marine Science*, 1083.

TARGUSI, M., LA PORTA, B., LATTANZI, L., LA VALLE, P., LOIA, M., PAGANELLI, D., PAZZINI, A., PROIETTI, R. and NICOLETTI, L. (2018) Beach nourishment using sediments from relict sand deposit: Effects on subtidal macrobenthic communities in the Central Adriatic Sea (Eastern Mediterranean Sea-Italy). *Marine Environmental Research*, 144, pp. 186-193.

URRA, J., MARINA, P., GARCIA, T. and BARO, J. (2021) Damage assessment and survival estimates in the wedge clam (*Donax trunculus*) caught by mechanical dredging in the northern Alboran Sea. *Marine Biology Research*, 17(3), pp. 295-310.

VASAPOLLO, C., VIRGILI, M., BARGIONE, G., PETETTA, A., DE MARCO, R., PUNZO, E. and LUCCHETTI, A. (2020) Impact on Macro-Benthic Communities of Hydraulic Dredging for Razor Clam *Ensis minor* in the Tyrrhenian Sea. *Frontiers in Marine Science*, 7, 14.

WARWICK, R.M. (1988) The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. *Marine Pollution Bulletin*, 19(6), pp. 259-268.