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Looking for a Simple Assessment Tool for a Complex Task: Short-Term Evaluation of Changes in Fisheries Management Measures in the Pomo/Jabuka Pits Area (Central Adriatic Sea)

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Citation: Chiarini, M.; Guicciardi, S.; Zacchetti, L.; Domenichetti, F.; Canduci, G.; Angelini, S.; Belardinelli, A.; Croci, C.; Giuliani, G.; Scarpini, P.; et al. Looking for a Simple Assessment Tool for a Complex Task: Short-Term Evaluation of Changes in Fisheries Management Measures in the Pomo/Jabuka Pits Area (Central Adriatic Sea). *Sustainability* **2022**, *14*, 7742. https://doi.org/10.3390/su14137742

Academic Editor: Jose Carlos Báez

Received: 25 May 2022
Accepted: 22 June 2022
Published: 24 June 2022

Abstract: A Before–Intermediate–After Multiple Sites (BIAMS) analysis, namely a modified version of the Before–After–Control–Impact (BACI) approach, was used to evaluate the possible effects of fishery management measures implemented in the Pomo/Jabuka Pits area, a historically highly exploited ground for Italian and Croatian fisheries, whose impact may have contributed over the years to the modification of the ecosystem. Since 2015, the area was subject to fishing regulations changing the type of restrictions over time and space, until the definitive establishment in 2018 of a Fishery Restricted Area. These changes in the regulatory regime result in complex signals to be interpreted. The analysis was carried out on abundance indices (i.e., kg/km^2 and N/km^2) of five commercially or ecologically relevant species, obtained in the period 2012–2019 from two annual trawl surveys. BIAMS was based on the selection of a *Closure* factor, declined in three levels (i.e., BEFORE/INTERMEDIATE/AFTER) and accounting for regulation changes in time, and on three adjacent strata (i.e., "A", "B", and "ext ITA") a posteriori determined according to the latest regulations. BIAMS allowed us to identify early effects (i.e., changes in abundances), overcoming the unavailability of a proper independent control site; furthermore, the selection of adjacent strata allowed the inference of possible interactions among them.

Keywords: BIAMS; Adriatic Sea; FRA

1. Introduction

Industrial fisheries, in particular bottom trawling, are known to have important effects on marine ecosystems, potentially leading to alteration or degradation of habitats and overexploitation of marine resources [1]. Proper management is, therefore, crucial to ensure the sustainability over time of fishery resources and to protect the ecosystems [2,3]. Several management strategies can be adopted, such as the control of fishing effort, the application of rules concerning fishing gears, the definition of the minimum landing size, and closures in time and space [3].

It is well known that spatial closures to human activities (e.g., fishing, mining, dredging, and dumping) meant for the protection of sensitive marine ecosystems and/or vulnerable species [4–6] can also generate benefits for the productivity of commercially exploited fish stocks by protecting Essential Fish Habitats (EFH, i.e., areas in which fish spawning, breeding, feeding, or growth to maturity occur, Table S1 [7]) and by promoting export of adults and larvae to adjacent areas [8–10].

Marine Protected Areas (MPAs, Table S1) represent a classic and useful tool to protect marine biodiversity by limiting the effects of multiple human activities [6,11]. They may have various primary management goals (e.g., protecting biodiversity, safeguarding the ecosystem) and thus be implemented through different levels of regulation [12]. The consequent levels of protection established define various types of MPAs [6], which include, for example, no-take marine reserves (namely No-Take Zones, NTZs, Table S1), Partially Protected Areas (PPAs; Table S1 [13]), or multiple-zone MPAs, including areas subjected to different levels of protection [14]. Generally, all potentially damaging activities (e.g., fishing, anchoring, SCUBA diving) are prohibited in NTZs, thus representing the utmost precautionary approach [15]; differently, PPAs aim to find a compromise between habitat preservation and human interests [16].

Fisheries Restricted Areas (FRAs, Table S1) are instead geographically-defined areas in which restrictions on fishing efforts and/or fishery bans have been implemented specifically in order to manage some important resources and/or protect EFHs, with the final goal to contribute to the recovery and maintenance of fish stocks [11,17–20]. In FRAs, there can be temporary and permanent closures in addition to regulations specifically targeting particular fishing gears [12].

The persistence over time of spatial management measures can modulate the achievement of biodiversity restoration or re-stocking of exploited populations [6]. In fact, while some benefits may occur quickly after protection measures implementation (i.e., the short-term effect [21–23]), others might take longer periods (e.g., decades) to manifest (i.e., the long-term effect [24,25]). Short-term effects, such as marked increments in species diversity and abundances, occurring in the few years since the establishment of Mediterranean MPAs, are reported in the literature [22]. However, in general, to verify more stable effects on an ecosystem, such as restoration of commercial fish natural population age/size structures (especially for long-lived species), long-term observations are necessary [26]. Long-term effects may also include increments in rare and vulnerable species and recovery of degraded habitats [27]. To evaluate the possible effects over time of spatial management measures, different approaches can be adopted: identification of possible changes in the ecosystem composition, variations in the biological parameters of certain species such as growth or fecundity rate, or abundance indices of species of particular importance for the area under protection [12,28]. The choice between one or more of these indicators depends on the primary objectives of protection and the pre-existing knowledge of the area and the ecosystem [29]. For example, if the specific goal of a marine spatial closure is the recovery of target populations of commercial fish, indicators such as density and size, which are supposed to be affected by fisheries closures, should be used [30].

Before–After–Control–Impact (BACI) analysis [31] has usually been considered a rigorous design for assessing the impact of MPAs [13]. The general BACI design involves the measurement of an ecological variable of interest (i.e., ecological indicators) that is expected to be positively or negatively affected by management action before and after the implementation or a change in the management regime of a specific site and, as a comparison, in one or more not impacted control sites [31]. Unfortunately, scientists are not often in the position to adopt that ideal design (e.g., when the protected area is already established, or when sampling approaches are limited and do not allow temporal and/or spatial replications) [32]; therefore, to assess the effects of the management measures in place, they have to adapt sampling and analytical designs to the temporal and spatial framework of a protected area [33]. Historically, several alternatives to the general BACI design were used to evaluate the effectiveness of spatial closures in cases where the ideal design was not applicable [34–41]. For example, adopting deconstructed sampling designs with replicated controls as After-Control-Impact (ACI) designs, with temporal and spatial comparisons after the establishment of the spatial closure [42], or Control-Impact (CI) designs accounting only for spatial comparisons [43]. If a spatial control is lacking, the effects of spatial closures should be inferred only by sampling Before and After an impact (BA design [34]). Control sites should, indeed, ideally be ecologically and physically similar to the potentially impacted area and have the same type of species assemblages, but they must also be statistically independent and unaffected by spatial management measures [36,40]. However, the sea is spatially and temporally dynamic, and finding two locations that are statistically identical, subject to the same environmental conditions, and independent one to one another is often problematic, resulting in being one of the major limitations for the application of the BACI evaluation approach [44]. Nevertheless, alternatives to the classic BACI design were provided in the literature [44,45]; for example, Methratta et al. [46] suggested a Before-After-Gradient (BAG) design which entirely eliminates the need to identify a suitable and valid control by sampling multiple sites along a spatial gradient within and around a wind farm (or in and around a marine reserve [47]). Another limitation of the classic BACI design could be the binary temporal dimensions (i.e., before vs. after), which could mask potential changes occurring on a finer time scale induced, for example, by environmental variability over time (e.g., climate change) or implementation of simultaneous management approaches [34,36]. For example, periodic examination of data, when compared to before-after, could reveal the time at which an MPA starts to be effective [44].

The Mediterranean basin offers plenty of cases for which the effectiveness of spatial management measures has been rarely demonstrated, mainly due to the lack of the basic requirements to develop appropriate sampling designs and/or assessments [12,48]. Among the Mediterranean ecoregions, the Adriatic Sea is recognised as a priority area for conservation purposes [49]; the reason behind this need for protection is the high fishing pressure which over time has caused the degradation of marine habitats, decline of target and non-target species, food-web alterations, and loss of biodiversity [50–53]. In fact, the Northern-Central part of the Adriatic Sea represents the European area most intensively fished by bottom trawlers [54]. In order to address issues related to this intense fishing pressure, a multiannual management plan for the sustainable fishing of some important demersal species was adopted in 2019 by the General Fisheries Commission for the Mediterranean (GFCM); the plan is the product of the collaboration of various involved countries (e.g., Italy and Croatia) and of the Subregional Committee for the Adriatic Sea [55].

In particular, the central part of the Adriatic Sea, characterised by 3 depressions delimited by the 200 metres bathymetry (having a maximum depth of about 270 metres [56]), together known as Pomo (or Jabuka in Croatian) Pits, is one of the main fishing grounds within this basin, shared by the Italian and the Croatian fleets [57,58]. According to Russo et al. [58], the main fishing zone for the Italian fleet targeting Norway Lobster and European Hake is the one located just south of the Pomo/Jabuka Pits (Figure 1). The complex topography of the area, combined with the oceanographic regimes of the Adriatic Sea, makes it a very peculiar environment in which the water exchange does not occur every year [59]. These conditions can influence the nutrient cycle, with consequences on local biodiversity (e.g., the discovery of rare species [60,61]) and on the trophic status of benthic communities [62]. This area is the main nursery for European Hake, *Merluccius merluccius* (Linnaeus, 1758), in this basin [63–66]. Furthermore, the presence of muddy bottoms and other exogenous factors make it an ideal habitat for Norway Lobster, *Nephrops norvegicus* (Linnaeus, 1758) [67]. Numerous studies reported that here the population of Norway Lobster is characterised by high densities of individuals smaller, and growing slower, than those from other areas of the Adriatic Sea [68–72]. Among the other crustacean species occurring in the area, a commercial and ecological relevance is attributable to the Pink Shrimp, *Parapenaeus longirostris* (Lucas, 1846), which in the last decade showed a relevant abundance increase in the Mediterranean Sea [73,74]. An abundance peak occurred in the Pomo/Jabuka Pits in 2017; furthermore, as described by Martinelli et al. [75], this species shows periodic fluctuations in the area, which could also be linked to environmental parameter changes (e.g., salinity and temperature [76]). A crustacean species shift also occurred in the Pomo/Jabuka Pits area: *Munida intermedia* (Milne-Edwards & Bouvier, 1899) was, in fact, almost completely replaced by *Munida speciosa* (von Martens, 1878), first observed in 2003 [77]. This species replacement was also observed in other areas of the Mediterranean and linked to climate change and to some intrinsic characteristics of the species (i.e., short life span compared to other *Munida* species, early maturation, and multiple spawning) [78]. Alteration in species assemblages and possible consequences on trophic and ecosystemic balances could probably be due to the synergistic action of fishing pressure and climate change [77,79,80]. Another gadoid species dwelling in the area, the blue whiting *Micromesistius poutassou* (Risso 1827), was proven to experience fluctuations in abundance over time as a result of environmental variations and fishing exploitation in other areas of the Mediterranean [81]. Capture production for the above-cited commercially important species reported by FAO [82] for the Adriatic basin from 2000 to 2019 is shown in Figure S1.

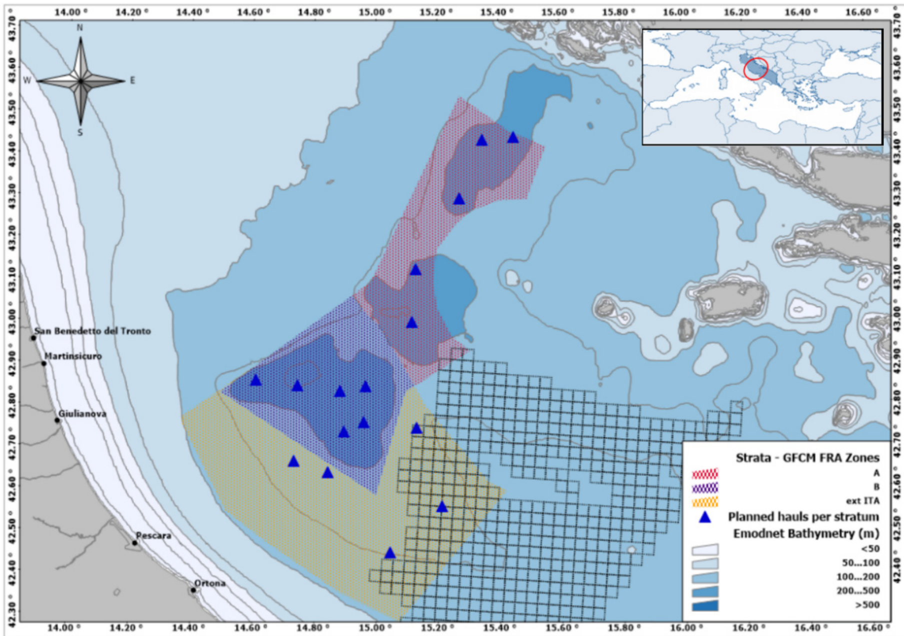

Figure 1. Study Area. In the up-right rectangle the position of the study area within the Mediterranean basin is highlighted (red circle). The main map shows: central Adriatic Sea bathymetry (source: [56]) and stratification in use within this study (dotted areas; zone "A", "B", and "ext ITA"); position (triangles) of the trawl hauls considered within this study; main fishing area (black grid) for the Italian fleet targeting Norway Lobster and European Hake, according to Russo et al. [58].

Ultimately, decades of exploitation of commercial stocks by bottom trawling had most likely contributed to changes in the demographic structure and in some biological parameters of the populations of commercial species resident in the Pomo/Jabuka Pits [83]. Hence, appropriate management of the area could be very important for the conservation of many species, including those of high commercial interest (*M. merluccius*, *N. norvegicus*, and *P. longirostris*) [3]. Therefore, the area has long been the subject of discussions regarding the possibility of establishing here a fishing ban [84,85]. Starting from 2015, some protection measures have been implemented both by Italian and Croatian authorities (changing various times in area closed and restriction measures). From 26 July 2015 to 16 October 2016, a part of the Pomo/Jabuka Pits area (Figure 2a) was closed to Italian bottom trawlers [86,87]. Subsequently, most of the previously defined area was reopened to trawlers, but with precautionary measures (limited number of licences and fishing days), and a ban was established for each fishing activity for an area ([88,89]; Figure 2b). After the yearly Italian seasonal fishery closure of 2017 [90], with another ministerial decree [91], a fishing ban for the Italian fleet from 1 September 2017 was established in two areas (one including the western Pit and another portion of the sea located close to Croatian territorial waters; Figure 2c) and a ban from 1 September to 31 October 2017 in the area including Italian territorial waters. A limited number of fishing authorizations were released for the area closest to the Italian coast with a series of additional management measures (e.g., the number of fishing days allowed for each vessel). Likewise, the Croatian authorities have intervened with specific regulations for the Croatian fleet and over the waters under their jurisdiction. Finally, in October 2017, the GFCM established an FRA in the Pomo/Jabuka Pits area (in force from 1 September 2017 and initially until 31 December 2020) in order to contribute to the protection of vulnerable marine ecosystems and essential habitats for important demersal stocks in the Adriatic Sea such as European Hake and Norway Lobster [92]. The FRA is made up of three different zones: zone "A" is closed to any fishing activity, and zones "B" and "C" are subject to fishery restrictions (Figure 2d). The FRA was ratified in 2019 by the Regulation 2019/982 of the European Parliament and of the Council [93]. With Recommendation 44/2021 GFCM [94], the FRA "Pomo/Jabuka Pits" was made permanent. Therefore, altogether, the aforementioned management measures resulted in a change in the intensity and distribution of the fishing effort exercised in the area over time.

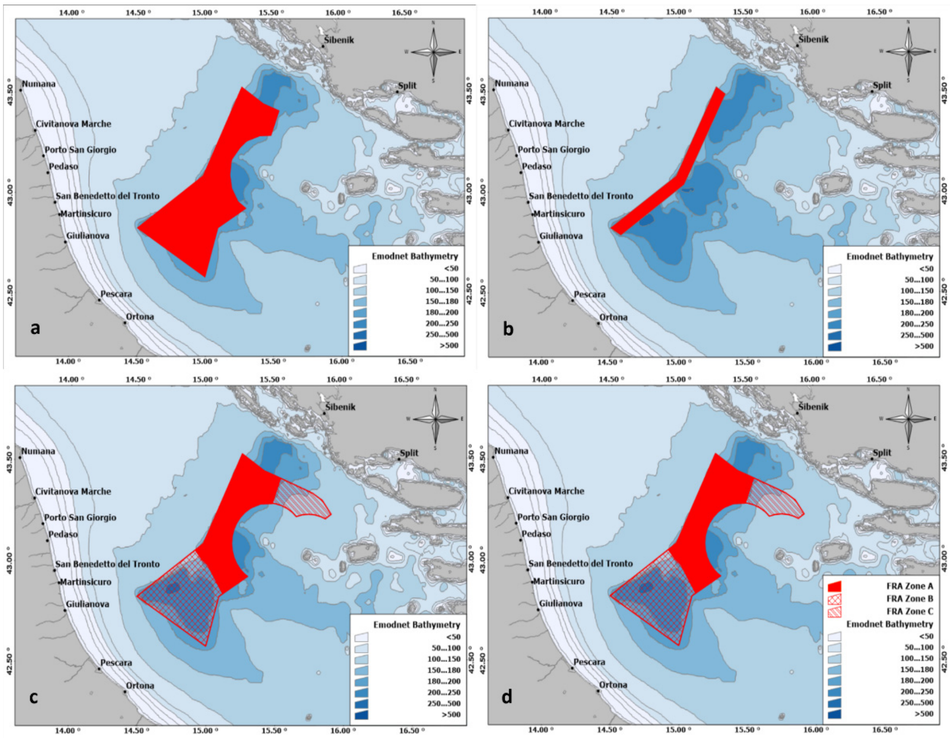

Figure 2. Management measures implemented in the Pomo/Jabuka Pits area since July 2015. Panel (**a**) shows (in red) the area closed to trawl fishery from 26 July 2015 to 16 October 2016, other types of fishing activities such as longlines are permitted throughout the area. Panel (**b**) presents (in red) the area subjected to a ban on all fishing activities and an area (red sparse grid) where a limited number of licences and fishing days for trawlers are allowed from 1 October 2016 to 31 August 2017. Panel (**c**) reports (in red) the area closed to all fisheries from 1 September 2017 and the areas (red sparse grid) closed to all fishing activities until 31 October 2017 and then managed through special licences. Panel (**d**) refers to the establishment of a fishery restricted area: Zone "A" (in red) is closed to all fisheries, zone "B" (red sparse grid) where the closure to fishing activities is from 1 September to 31 October, then fishing is regulated with licences and with two days of permits per week (one for the twin nets), and zone "C" (red sparse grid) where the closure to fishing activities is from 1 September to 31 October, trawling is authorised through special licences on Saturdays and Sundays from 5.00 am to 10.00 pm, gillnets, pots, and longlines authorised, can fish there, from Monday at 5.00 am to Thursday at 22.00 pm.

The aim of this study is to present a simple alternative to the classic BACI analytical approach, which can be a posteriori applied in rather complex frameworks to overcome issues such as the absence of a proper control site and variations over space and time of conservation measures to be evaluated. A new approach was developed and applied to the "Pomo/Jabuka Pits" (central Adriatic Sea) study area where changes in fishery management strategies were implemented in 2015; the proposed tool allowed the detection of signals interpreted as early effects on the abundance of some commercially and ecologically important species.

2. Materials and Methods

2.1. Sampling

From 2009 to 2019 (except for 2011 and 2018), the National Research Council Institute of Marine Biological Resources and Biotechnologies (CNR-IRBIM) of Ancona (Italy) carried out jointly with the Institute of Oceanography and Fisheries (IOF) of Split (Croatia) an annual spring "UnderWater TeleVision" ("UWTV", hereafter referred to simply as spring) survey covering the entire area of the three meso-Adriatic depressions [57,95]. The survey was carried out under the auspices of the FAO–ADRIAMED project. From 2012 to 2016, it was also sponsored by the Italian National Flagship Program RITMARE and, for the experimental trawl fishery part (see below), from 2015 to 2018, also by the Italian Ministry of Agricultural, Food, and Forestry Policies (MIPAAF). Originally, this fishery independent survey was aimed to quantify *N. norvegicus* burrows through video analysis of seabed footage [57], but meanwhile, experimental trawling activities were also carried out in order to obtain additional demographic data on this and other important species inhabiting the area [75,96]; in this study, only catch data from these trawling activities are taken into account. Norway Lobster is, indeed, a sedentary bottom-dweller that digs complex burrows in muddy sediments within which it spends most of its lifetime [97]; animals inside or at the entrance of their burrows easily avoid capture by retracting themselves when trawling nets approach [98–100]. This burrowing behaviour heavily affects fishery leading to high variability in the catch, as an indication of fluctuation in the numbers of individuals undertaking emergence from their burrows [101–104]. Therefore, trawl hauls were always carried out at sunset and sunrise, corresponding to the maximum peak of emergence from burrows [105,106]. At the same time, these trawl hauls also provided information on the abundance and distribution (as well as length frequency distributions) of other commercially or ecologically relevant demersal species living in the area, such as *P. longirostris*, *M. merluccius*, *Micromesistius poutassou*, and *Munida* spp. [75,96]. Therefore, the trawl data obtained by means of the spring surveys represent a very useful time series allowing comparisons between the period before fishery restriction implementation in the Pomo/Jabuka Pits area and the subsequent one [75]. Furthermore, following the enforcement of the first management measures in the area, within a series of agreements with the Italian the Ministry of Agricultural, Food, and Forestry Policies (MIPAAF), in 2015, CNR-IRBIM of Ancona started an additional autumn trawl survey (namely the "ScamPo" survey, hereafter referred to simply as the autumn survey) covering the western Pit and a larger buffer area [75]. In order to obtain data comparable to those collected before the management measures implementation, the same standard procedures used during the spring surveys were adopted, and all cruises were carried out on board the RV Dallaporta (LOA 35.30 m, 258 GT, 1100 HP). Both surveys occurred in a consistent time period each year: April and May for the spring survey and September, October, and November for the autumn survey; the same trawling protocol and general sampling design were adopted in overlapping areas (Figure 1; [75,96]). In particular, haul duration was fixed at one hour, starting almost half an hour before the sunset/sunrise, and, since 2012, all hauls were conducted by means of the same experimental net (22 mm mesh size in the body and 12 mm in the cod end) and thus their catches can be compared over time; SIMRAD® trawl monitoring sensors were used to follow the fishing equipment behaviour during the hauls [75]. The net was equipped with two spread sensors on each wing end to measure the average horizontal opening; a trawl-eye sensor was used to monitor the net while approaching the bottom. It was thus possible to record the real time of starting/ending of the haul and the vertical opening of the net. Through a GPS system, the positions of the ship during the fishing operations were recorded minute by minute; the ship's position was then used as a proxy of the net's position for the purpose of calculating the effective swept area [75]. The total catch of each haul was weighed, and, in case of very high weights, a representative sub-sampling was carried out in order to allow the correct reconstruction of the total catch by species; all organisms and, in particular, the principal species of commercial or ecological interest were identified at the lowest possible taxonomic level, weighed, and counted [75]. Norway Lobsters and Pink Shrimps were divided by sex; the carapace length was recorded for each collected specimen at the lower mm using a caliper. For European Hake and blue whiting, the total length of each individual was measured, at the lower half cm, by means of a graduated splint. For all the other species, including *Munida* spp., the total weight and the total number of individuals were recorded.

2.2. Data Analysis

All the collected information was entered into a database built by means of the Geographic Information System (GIS) Manifold® System Release 8 (http://www.georeference.org/doc/manifold.htm, accessed on 1 March 2022), through which the Global Positioning System (GPS) data were verified and then processed in order to calculate the swept area of each haul [75]. The swept area was calculated by multiplying the distance covered by the net on the seabed and the average value of the net mouth opening for each haul. Finally, Catch-Per-Unit-of-Effort (CPUE) estimates for *N. norvegicus*, *P. longirostris*, *M. merluccius*, *M. potassou*, and *Munida* spp. (and other species in this study) were calculated as the total weight of the caught individuals divided by swept area (kg/km^2; hereafter referred to as biomass index) and the number of caught individuals divided by the same swept area (N/km^2; hereafter referred to as density index), according to Martinelli et al. [75]. No transformation was required to conduct the subsequent analyses because the CPUE data were normally distributed.

Considering data from 2012 onward, in order to assess the CPUE response as a potential effect of the management measures implemented over time and space, the possibility of a-posteriori applying a variant of the classic "before-after-control-impact" model design (BACI [44,45,107]) was explored. The considered variant could be summarised as a BIAMS (Before/Intermediate/After Multiple Sites) approach.

In order to perform this, three different strata (or sites) to be tested were a-posteriori selected within the study area: "A", "B", and "ext ITA" (Figure 1). The adopted stratification follows the "A" and "B" FRA zones, where fishing effort levels changed in time according to the implemented management measures, and an additional buffer external area, "ext ITA", adjacent to zone "B" and located to the south-west, where no fishery limitations were implemented (except for the yearly seasonal trawl fishery closures regulated by national governments). Even if the peculiar bathymetry and oceanography of the area do not actually allow us to a-posteriori define a proper "control" (i.e., having the same bathymetry compared to the other impacted areas [108]), the "ext ITA" area was meant to serve as a comparison with grounds where fishing activity was limited or banned through time and space. It was thus used to build an analytical spatial framework for a modified BACI analysis with the aim to evaluate the management measures' performances. According to the original sampling design, the number of available hauls per area is five in strata "A" and "ext ITA" and six in "B". Unfortunately, not all the planned hauls were performed every year due to technical issues such as limited ship availability, bad weather conditions, etc. From 2012 to 2019 (except 2018), an average of 7.2 ± 1.3 stations were sampled during the spring surveys in the 3 considered areas, while from 2015 to 2019, an average of 6.6 ± 2.5 hauls were carried out during the autumn surveys.

In addition, the temporal variations of the management measures from 2015 to 2018 (and their limited duration over time) further complicated the verification of their short/medium/long-term effects. Therefore, a temporal dimension was added to the proposed modified BACI framework, following the scheme type "BEFORE/INTERMEDIATE/AFTER" defined as (i) the period prior to the implementation of the first management measures in 2015 (BEFORE, from 1 January 2012 to 1 July 2015); (ii) the intermediate stage in which management measures have changed over time following the application of two decrees ([86,89] INTERMEDIATE, from 02 July 2015 to 31 August 2017); (iii) after the application of the latest decree [91], thus considered as a period of application of the measures relating to the FRA until the end of 2019 (AFTER, from 1 September 2017 to 1 January 2020). Each of these time steps was considered as the level of the *Closure* factor, which, therefore, includes all the fisheries management measures adopted in the study area from 2012 to 2019.

The examination of fish response to protection measures in terms of biomass and length could be hampered by small sample sizes [13]. Hence, with the aim to consider a big enough sample size for the subsequent significance tests, the possibility of aggregating the data of the two cruises was explored. First, the homogeneity of variance was assessed by a Levene test. In case of homoscedasticity, a classic *t*-test was applied on both CPUE (i.e., biomass and density indices). In case of heteroscedasticity, the *t*-test applied was that of Welch. The preliminary *t*-tests were applied to the biomass and density indices for each of the target species and considering areas "B" and "ext ITA" (area "A" was not considered because it was sampled only during the spring surveys); the *t*-tests were developed to assess a possible difference between the CPUE for the two cruises (i.e., spring and autumn surveys). In case of no significant difference, data from the two cruises could be pooled.

Afterwards, for each of the target species, in order to assess the effect of the *Closure* factor on the CPUE for each considered area ("A", "B", and "ext ITA"), the following analyses were performed: (i) a Levene test to verify the homogeneity of variances; (ii) a parametric one-way analysis of variance (ANOVA); (iii) the appropriate pairwise post hoc tests (according to Tukey, in case of homoscedasticity, or according to Games-Howell, in case of heteroscedasticity). Indeed, Levene's test is robust also in case data are not normally distributed [109], while Tukey and Games-Howell statistics are commonly used to test differences between sites (e.g., control-impact) in BACI analyses [110,111], as well as for response variables such as CPUE [112,113]. The reference *p*-value to determine significance was set at 0.05 (p values < 0.05 and >0.01 were considered marginally significant). All the statistical tests and the relative graphics were made using the statistical software R [114,115] with associated packages car, ISwR, rpart, and ggplot [116–119].

3. Results

3.1. *t*-Test between the Spring and Autumn Surveys

Levene's tests conducted on the abundance indices of the two scientific surveys indicated homogeneity of the variance in all cases. Only the biomass index for *P. longirostris* from area "B" showed a marginal significance level (F test = 5.180, df = (1, 41), *p*-value = 0.029). The results of the *t*-test for the biomass index were significant only for *M. merluccius* both in area "B" (t = −2.3183, df = 41, *p*-value = 0.026) and "ext ITA" (t = −2.2007, df = 22, *p*-value = 0.039). For the density index, the only significant difference was that for *M. poutassou* in area "ext ITA" (t = 2.8584, df = 14.167, *p*-value = 0.013). Since only 3 marginal significant differences were observed between the 2 cruises out of 20 tests, in the following analyses the catch data of the 2 surveys were considered as belonging to a single data population and used as an aggregate for the subsequent ANOVA analyses.

3.2. One-Way ANOVA for Biomass and Density Indices by Closure Factor for Each Stratum ("A", "B", and "ext ITA")

The Levene's tests performed after survey aggregation on the biomass and density indices for each stratum and species indicated, in most cases, homogeneity of the variance; the only exceptions were detected for *P. longirostris* in strata "B" (*p*-value = 0.002) and "ext ITA" (*p*-value = 0.002) for the biomass index and for *Munida* spp. in stratum "ext

ITA" for the density index only (p-value = 0.005). The one-way ANOVA generated several significant results, indicating that the *Closure* factor had an effect on both CPUE indices in each of the strata (Tables S2–S6). The results of the post hoc pairwise comparisons are summarised in Figures 3–5 and here below.

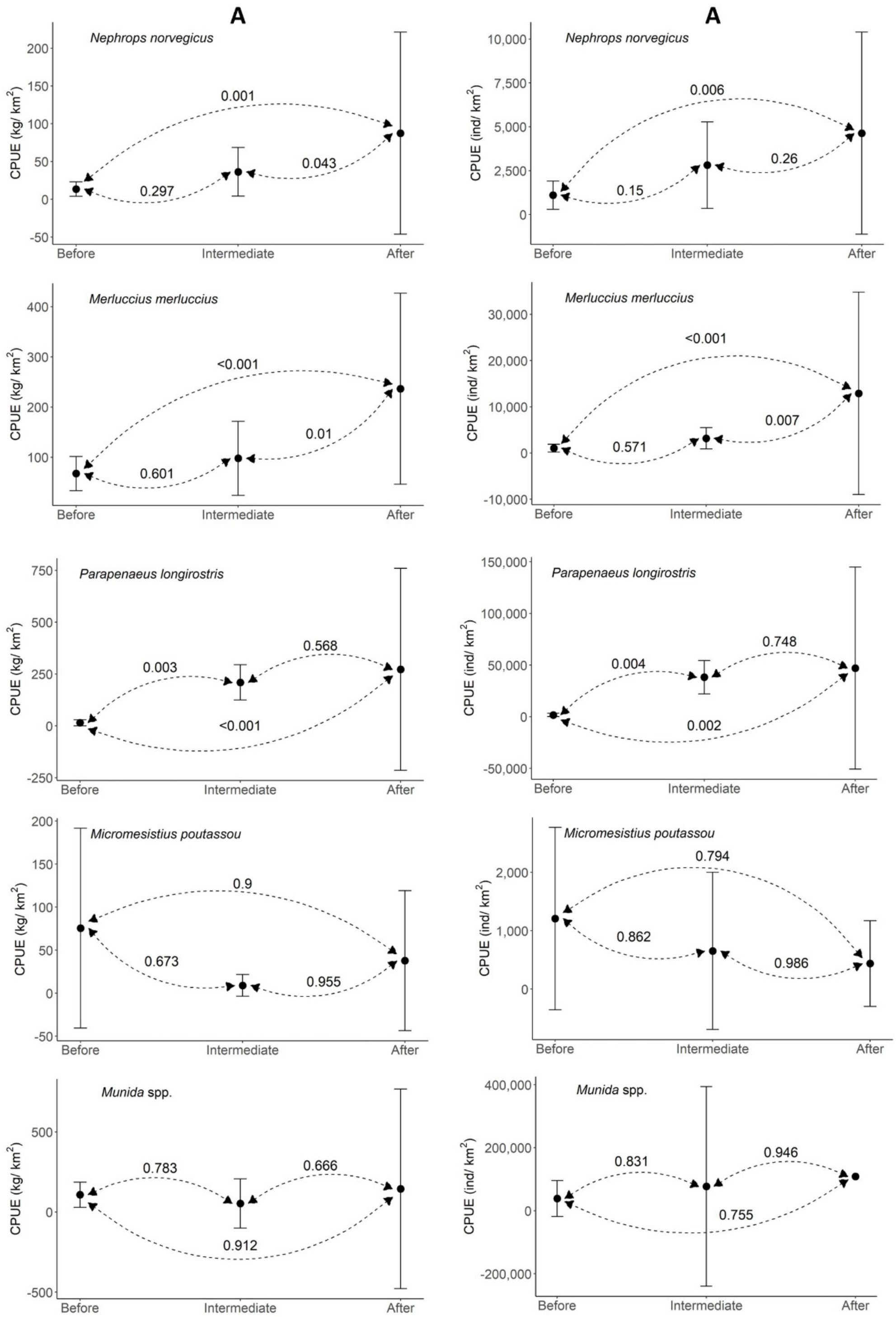

Figure 3. Plot of catch per unit effort (CPUE) by species (rows) and type of index (columns) as a function of the *Closure* factor levels (BEFORE, INTERMEDIATE, AFTER) for stratum "A". Points and error bars represent means and 95% confidence intervals, respectively. Dotted arrows indicate the post hoc pairwise comparisons and the number above is the respective p-value. Tukey's post hoc test was carried out on all pairwise comparisons.

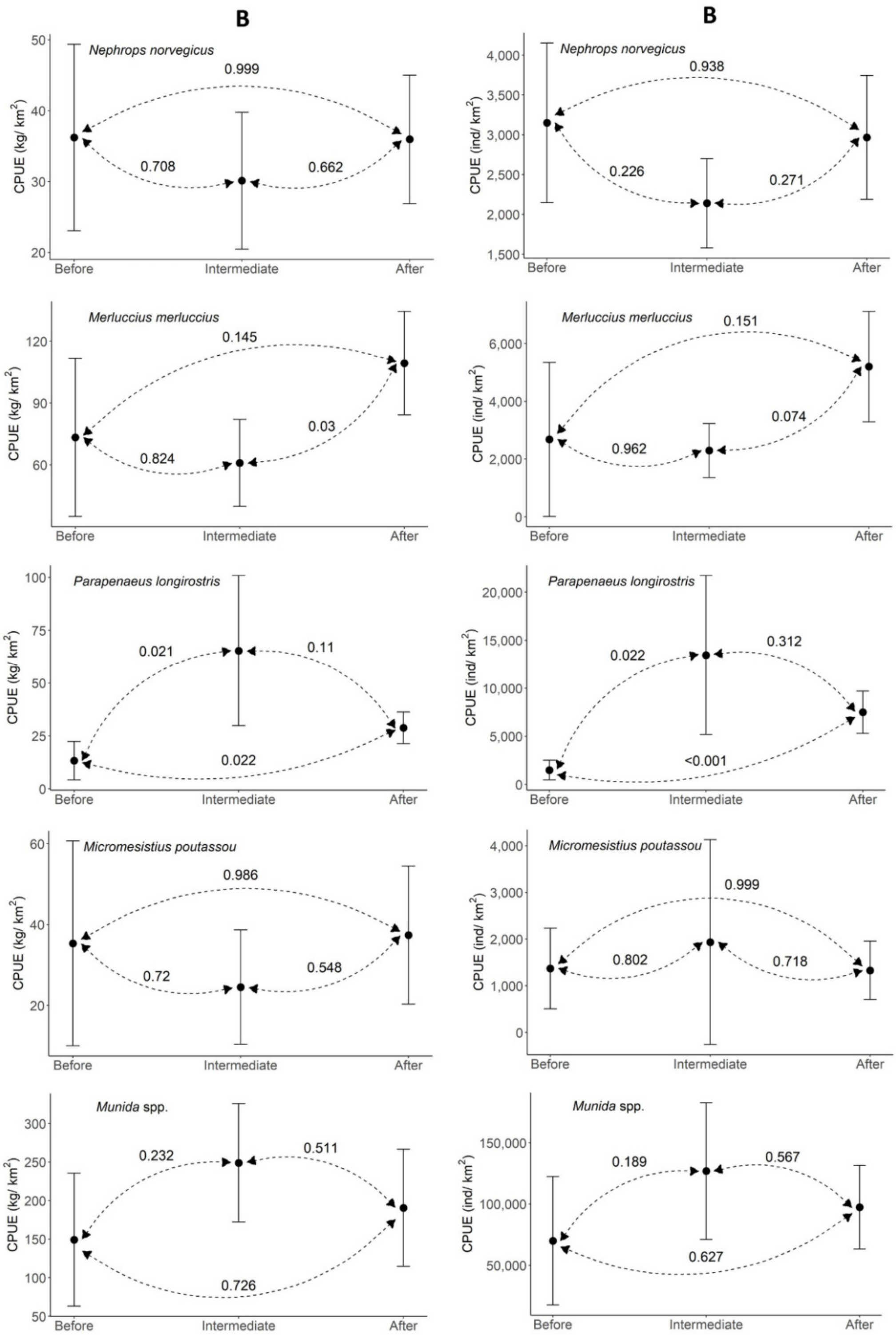

Figure 4. Plot of catch per unit effort (CPUE) by species (rows) and type of index (columns) as a function of the *Closure* factor levels (BEFORE, INTERMEDIATE, AFTER) for stratum "B". Points and error bars represent means and 95% confidence intervals, respectively. Dotted arrows indicate the post hoc pairwise comparisons and the number above is the respective *p*-value. Tukey's post hoc test was carried out on all pairwise comparisons except for the biomass index (kg/km^2) related to *P. longirostris*, on which the Games-Howell post-hoc test was applied.

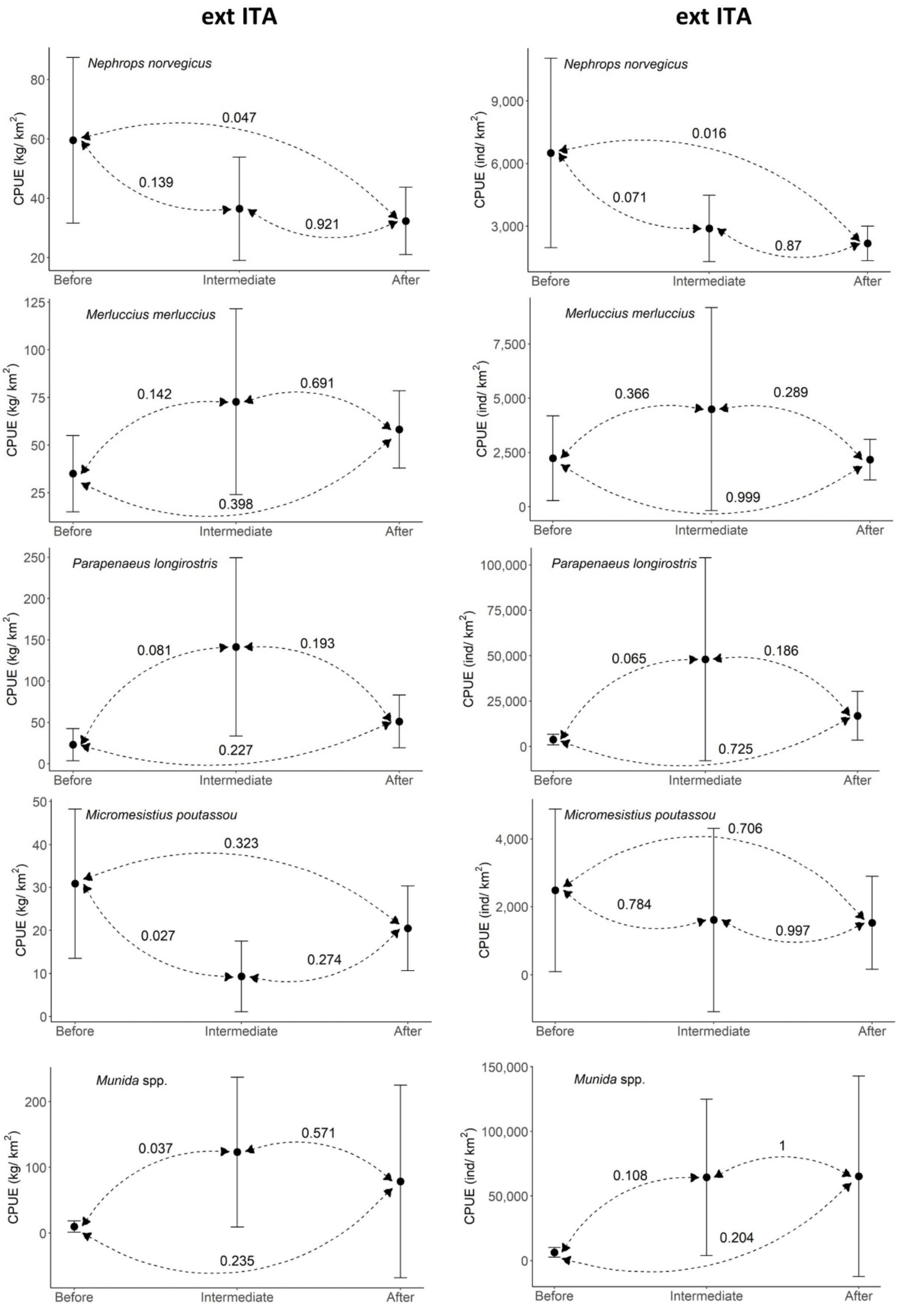

Figure 5. Plot of catch per unit effort (CPUE) by species (rows) and type of index (columns) as a function of the *Closure* factor levels (BEFORE, INTERMEDIATE, AFTER) for stratum "ext ITA". Points and error bars represent means and 95% confidence intervals, respectively. Dotted arrows indicate the post hoc pairwise comparisons and the number above is the respective *p*-value. Tukey's post hoc test was carried out on all pairwise comparisons except the biomass index (kg/km^2) of *P. longirostris* and the density (ind/km^2) of *Munida* spp., on which the Games-Howell post-hoc test was applied.

3.2.1. Stratum "A"

For *M. poutassou* and *Munida* spp., there is no evidence of a significant effect of the *Closure* factor on both CPUE (Figure 3). For *N. norvegicus,* there is strong evidence that the 2 indices were higher for the level "AFTER" of the *Closure* factor if compared to "BEFORE" (biomass index p-value = 0.001, density index p-value = 0.006); moreover, there is also very marginal evidence that the biomass index is higher for the *Closure* level "AFTER" when compared to "INTERMEDIATE" (p-value = 0.043). For *M. merluccius*, there is strong evidence that the 2 indices were higher when "AFTER" was compared to "BEFORE" (biomass index p-value < 0.001, density index p-value < 0.001) and to "INTERMEDIATE" (biomass index p-value = 0.01, density index p-value = 0.007) even if, in the case of biomass index, this last evidence is marginal. For *P. longirostris*, there is strong evidence that both indices were higher when "AFTER" was compared to "BEFORE" (biomass index p-value < 0.001, density index p-value = 0.002) and were also higher when "INTERMEDIATE" was compared to "BEFORE" (biomass index p-value = 0.003, density index p-value = 0.004).

3.2.2. Stratum "B"

No evidence of a significant difference was observed for the CPUE indices of *N. norvegicus*, *M. poutassou*, and *Munida* spp. (Figure 4). For *M. merluccius*, there is only marginal evidence that the biomass index is higher when "AFTER" is compared to "INTERMEDIATE" (p-value = 0.03). For *P. longirostris*, there is evidence, marginal for biomass index and strong for density index, that both were higher when "AFTER" was compared to "BEFORE" (biomass index p-value = 0.022, density index p-value < 0.001); both indices were also higher when "INTERMEDIATE" was compared to "BEFORE" but, in this case, the evidence was marginal (biomass index p-value = 0.021, density index p-value = 0.022).

3.2.3. Stratum "ext ITA"

For *M. merluccius* and *P. longirostris*, there was no evidence of a *Closure* effect (Figure 5). For *N. norvegicus*, there is marginal evidence that both indices were lower when "AFTER" was compared to "BEFORE" (biomass index p-value = 0.047, density index p-value = 0.016). For *M. poutassou*, there is only marginal evidence that the biomass index is lower when "BEFORE" was compared to "INTERMEDIATE" (p-value = 0.027). For *Munida* spp., there is only marginal evidence that the biomass index was higher when "INTERMEDIATE" was compared to "BEFORE" (p-value = 0.037).

4. Discussion

4.1. General Framework and BIAMS Application

Fishing activities and changes in fishing pressure may cause relevant variations in abundance indices [3,120]. On the other hand, Petza et al. [18] reported how valid the establishment of an FRA could be for managing fish resources. The Pomo/Jabuka Pits area was subject to numerous changes in time and space of the management measures adopted since 2015; these changes eventually resulted in the establishment of the currently in place FRA.

The time series produced by the two surveys conducted by the CNR-IRBIM of Ancona within the Pomo/Jabuka Pits area represent a reliable data series crossing the various management measures implemented from 2015 to 2019. In order to investigate possible discrepancies over time and space between their response to the considered management changes, within this study, both available abundance indices (i.e., kg/km^2 and N/km^2) were considered for five commercially and/or ecologically important species as *N. norvegicus*, *M. merluccius*, *P. longirostris*, *M. poutassou,* and *Munida* spp. In fact, for species such as *N. norvegicus*, there could be possible differences between trends due to the fact that density may be size-dependent [121].

In this study, a variant of the classic BACI analysis, defined as BIAMS, was adopted to assess the early effect of different management regimes implemented over time and space on some commercially and ecologically important species in the complex framework of the Pomo/Jabuka Pits' FRA establishment. Indeed, the various changes in protection levels in space and time from 2015 (when fishery management measures were implemented for the first time) until 2017 (when a more stable management regime was applied) and the absence of an available and previously defined proper control site do not allow the application of traditional and user-friendly tools as the classic BACI approach. Hence, the BIAMS was conceived as a simple and easy-to-use tool to allow the evaluation of the management measures impact and, in particular, the early effects of the FRA within an appropriate spatial and temporal framework.

Therefore, a three-zone a-posteriori stratification, partially based on the spatial extent of the zones defined in the GFCM/41/2017/3 recommendation, was adopted in the analysis (Figure 2) [92]. In fact, the spatial extent of the various management measures, as well as the defined FRA zones, were actually primarily designed for the recovery and maintenance of fish stocks through the identification of EFHs, but without considering an appropriate analytical framework for future evaluations. Furthermore, the applied spatial boundaries mainly followed the bathymetry of the area, resulting in the absence of an adequate control site. Therefore, the adopted a-posteriori stratification, including zone A and B (defined by the FRA) and an external buffer area (i.e., "ext ITA") intended as a proxy control site, was also meant to fulfil this lack by identifying a stratum in which no specific management measures were implemented, to be compared with grounds where, since 2015, fishing activity was limited or banned. In addition, the use of three adjacent strata instead of geographically independent sites may allow the detection of possible interactions among areas for mobile species (e.g., movement of fishes from a nursery to adjacent grounds).

Furthermore, a multi-level temporal dimension was added to the classical two steps BACI framework, including three levels for the *Closure* factor, in order to allow comparisons between different periods; level "BEFORE" refers to the period in which no fishery restrictions were in force, level "INTERMEDIATE" starts from 2015 when management measures were implemented and modified in time and space various times, and level "AFTER" starts from 2017 when the fishing activity was regulated in a more stable way. The choice of these time intervals was made in accordance with regulations that followed each other (Figure 2). Globally, the period considered within this study for the BIAMS approach application ranges from 2012 to 2019. Therefore, the three adopted time steps are relatively short and allow us to detect only the early effects of changes in management measures [22,23]; this is especially true for the last considered time step relative to the establishment of the FRA regime, which is still in place nowadays. However, in future studies, this scheme could be implemented in order to assess possible medium or long-term effects, thus it would be important to carry out more surveys and maintain the time series.

4.2. Detected Early Effects of the Implemented Management Measures on Abundance Indices

No particular differences were observed in the response of the two different CPUE (i.e., biomass and density indices) for each stratum and species combination. In a few cases, the BIAMS analysis resulted in the marginal significance of the biomass indices not reflected in the response of the respective density indices; this condition was found: (i) in stratum "A" for *N. norvegicus* in the "INTERMEDIATE-AFTER" comparison, (ii) in stratum "B" for *M. merluccius* in the "INTERMEDIATE-AFTER" comparison, (iii) in stratum "ext ITA" for *M. poutassou* and *Munida* spp. in the "BEFORE-INTERMEDIATE" comparison. The only exception with a marginal significance of the biomass index in contrast to the significance of the respective density index was found in stratum "B" for *P. longirostris* in the "BEFORE-AFTER" comparison.

For *N. norvegicus* and *M. merluccius*, the mean CPUE, for both biomass and density indices, in stratum "A" showed a gradual increase over the three different levels of the *Closure* factor. These results suggest that the establishment first of some management measures in 2015 and then of a stable no-take zone in area "A" in October 2017 had positive effects on the target species. These findings are in agreement with those described by Martin et al. [122] in northern Spain, where a decrease in fishing effort positively influenced the populations of *N. norvegicus* and *M. merluccius* present in the area. Following the establishment of the first management measures from 2015 to 2017 (i.e., "INTERMEDIATE-AFTER"), a significant positive effect on biomass indices resulted only for *N. norvegicus* and *M. merluccius,* suggesting an early positive effect probably due to the implementation of the first fishing bans. For *P. longirostris*, this positive effect was not significant, while both the indices in the "BEFORE-INTERMEDIATE" comparison showed a significant increase that could be related not only to the implementation of management measures but also to other variables such as possible changes in environmental conditions (e.g., temperature and/or salinity) that may favour this species [73,74]. In fact, the effects of salinity on the spawning of this species and of temperature on its catch rates were already reported in the literature [74]. The mean CPUE for *Munida* spp. in stratum "A" over the fishery *Closure* levels was quite stable, hence the establishment of a fishery ban in the area appears to have no evident effects on this species.

In area "B", where the fishery was subject to a series of limitations since 2015, the only significant effect resulted for density indices of *P. longirostris* in accordance with the "BEFORE-AFTER" comparison for area "A". It is interesting to note that in this area also the mean CPUE for *M. merluccius* increased after the application of the latest management regime (i.e., "INTERMEDIATE-AFTER"), but this increment is marginally significant only for the biomass index. No significance was observed in the comparison "BEFORE-INTERMEDIATE"; actually, this was expected, especially for *M. merluccius*, because after the establishment of the first decrees (i.e., "INTERMEDIATE"; see Figure 2), the management of this species was different from the other considered and bottom longline fishing was allowed for a certain period, with European Hake as its main target. For the other considered species, the mean CPUE is more variable even by comparing the two indices for the same species. Hence, in general, the establishment of limitations to fishery, other than a fishery ban, may not be sufficient for an actual increase in CPUE in a relatively short time for some species.

Instead, in the "ext ITA" area, *N. norvegicus* mean CPUE (both indices) decreased in the "BEFORE-AFTER" comparison; this result may be explained by a combination of elements: (i) the species shows a sedentary behaviour, usually not travelling long distances far from its burrow, in fact, tag-recapture experiments carried out in other no-take marine reserves indicated a minimal spill over of biomass outside the managed areas [123]; (ii) as reported in Bastardie et al. [3], a displacement of the fishing effort from the area where fishery bans or restrictions were implemented (i.e., "A" and "B") to adjacent areas where no fishery limitations are in place (i.e., "ext ITA") may occur. For *M. merluccius*, no such sharp decrease in mean CPUE was observed in the "BEFORE-AFTER" comparison. This equilibrium condition may have been reached as a result of a combined effect of a possible spill over from the no-take zone (i.e., stratum "A"), which also includes part of the area of maximum persistence of the main nursery area for *M. merluccius* within the Adriatic basin [124], and the displacement of the fishing effort. Indeed, it is expected that as the duration of the management measures increases, a highly mobile species such as European Hake may show evidence of spill over effects in areas adjacent to a zone closed to fisheries [4,125]. It would be thus interesting to include in future evaluations of medium-long term effects of the FRA impact changes in the distribution of fishing effort estimated by means of Vessel Monitoring Systems [126], Automatic Identification System [127,128], or a combination of both [129].

As previously stated, the catch rates of some commercial species, such as *P. longirostris*, could be influenced by possible changes in environmental conditions, which may thus mask the effects of the management measures. According to Marini et al. [59], the Pomo/Jabuka Pits area is characterized by a peculiar oceanographic regime which can strongly influence the status of the ecosystem [60]. Therefore, also thanks to the availability of relevant time series of oceanographic data specific to the study area [130,131], future studies which aim to investigate and possibly quantify the combined effect of the FRA and changes in environmental conditions, as well as to detect possible long-term effects, should be carried out. The investigation of spatial distribution and/or occurrence of marine species could also be achieved through more complex approaches (e.g., Generalized Additive Models, Maximum Entropy models, Boosted Regression Tree) which include environmental parameters (e.g., temperature, salinity, oxygen, chlorophyll-a) [132–135]. Furthermore, the next actions could also integrate into these analyses the length-frequency distributions to determine possible effects of management regimes cohorts and recruitment.

5. Conclusions

The overarching goal of this study was to perform a short-term evaluation from 2012 to 2019 of the effects on some commercially or ecologically important species of changes in fisheries management measures implemented within the Pomo/Jabuka Pits area since 2015 (Adriatic Sea). The variant of the classical BACI analysis here proposed, and called BIAMS, showed, globally, a positive effect on the target species with a significant increase in biomass and density indices, in particular, following the establishment of a no-take zone in stratum "A". With regards to areas subjected to fishery limitations (i.e., area "B"), the analysis did not show a significant increase in average CPUE. However, a probable spill over effect from the no-take zone was evidenced for *M. merluccius*. Furthermore, for *P. longirostris*, a significant increase in the average CPUE for both indices was observed regardless of the adoption of the management measures; this could be thus related also to changes in environmental conditions which are known to affect this species (e.g., temperature, salinity). The mean CPUE, in particular for *N. norvegicus*, suffered a decrease in the stratum that was never subject to particular fishery limitations and adjacent to the FRA (i.e., "ext ITA"); probably, this can be attributed to a displacement of the fishing effort following the implementation of the management measures. It was noticed that, instead, for species such as European Hake, the decrease is less evident in the same stratum; the reason behind this could be identified in a combined effect of the spill over and the displacement of the fishing effort, which possibly led to a balance on the average CPUE. Hence, even if it is a rather simple tool when compared to other powerful approaches, the proposed BIAMS allowed us to easily identify a series of early effects of the implementation of different management measures over time and space in a complex and very relevant framework (i.e., the Pomo/Jabuka Pits area). Therefore, this approach could also be retrospectively applied for the assessment of short-term effects of conservation measures implemented in other relevant areas with similar conditions (e.g., lack of an adequate control site, adjacent areas with different regulatory levels that change over time), but it could also be used to define experimental designs to monitor newly implemented AMPs, PPAs, or FRAs, or even adapted by including a different number of strata or modulating the adopted time steps. In addition to overcoming some monitoring problems, this type of approach also has the advantage of allowing the evaluation of interactions across adjacent differently managed (or not) sites (e.g., spill over effects, fishery effort displacement effects) and of simplifying the detection of the responses over time of the observed variables within complicated timeframes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14137742/s1, Figure S1: FAO-GFCM Adriatic Capture production (in tons) from 2000 to 2020 for European Hake (grey), Norway Lobster (yellow), Pink Shrimp (red), and Blue Whiting (blue); Table S1: Acronyms table; Tables S2–S6: Parametric one-way ANOVA for biomass (kg/km^2) and density (N/km^2) indices of *Nephrops norvegicus*, *Merluccius merluccius*, *Parapeneus longirostris*, *Micromesistius poutassou*, *Munida* spp. by *Closure* factor for strata "A", "B", and "ext ITA".

Author Contributions: Conceptualization, M.M.; Data curation, M.M., S.G. and M.C.; Formal analysis, S.G. and M.C.; Funding acquisition, M.M. and A.S.; Investigation, F.D., G.C., S.A., A.B., C.C., G.G., P.S., M.C., L.Z., D.M., I.I. and M.M.; Methodology, S.G. and M.M.; Project administration, M.M., F.D., G.C. and D.M.; Supervision, M.M., I.I., and N.V.; Writing—original draft M.C., L.Z., S.G. and M.M.; Writing—review & editing M.M., M.C., L.Z., S.G. All authors have read and agreed to the published version of the manuscript.

Funding: Funding was provided for the collection and processing of the data used in this study by the Direzione Generale della Pesca Marittima e dell'Acquacoltura of the Italian Ministry of Agricultural, Food, and Forestry Policies (through a series of agreements with the Institute for Marine Biological Resources and Biotechnologies of the Italian National Research Council; CUP J52I15003990001, J53C17000540001 and J41F19000080001), the RITMARE Flagship Project of the Italian Ministry of University and Research, and the FAO AdriaMed regional project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Most of the catch data and fishing activity information related to the considered trawl hauls and used to calculate CPUE values were collected under confidentiality agreements between the Italian Ministry of Agricultural, Food, and Forestry Policies (MIPAAF) and the Institute for Marine Biological Resources and Biotechnologies of the National Research Council (CNR IRBIM). A portion of the dataset was also collected with permits of the Croatian Institutions. The authors received formal authorization to use the data for scientific purposes, but no special access privileges were granted. All data are stored at CNR IRBIM Ancona and can be shared on reasonable request upon prior authorisation by MIPAAF; the interest of qualified researchers may be expressed to pemac1@politicheagricole.it.

Acknowledgments: This work represents partial fulfilment of the requirements for the doctoral project of M.C. carried out in the framework of the International PhD Program "Innovative Technologies and Sustainable Use of Mediterranean Sea Fishery and Biological Resources (www.FishMed-PhD.org, accessed on 15 June 2022). The authors would like to thank Roberto Cacciamani, Federico Calì, Ratko Cvitanić, and the crew of RV Dallaporta for their precious help during the surveys.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, the collection, analyses, or interpretation of data, the writing of the manuscript, or in the decision to publish the results.

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