INTRODUCTION

Fisheries management must ideally address the simultaneous optimisation of often conflicting biological, social and economic objectives. Co-viability analysis studies the evolution of dynamic systems under constraints (Oubraham & Zaccour, 2018) and has been applied to bioeconomic fisheries models (Gourguet et al., 2013; Maynou, 2014; Tserpes, Nikoloudakis, Maravelias, Carvalho, & Merino, 2016) to help identify the management strategies that ensure that a fishery is viable (under some conditions) simultaneously for two or more criteria. When strong or absolute co-viability (Baumgärtner & Quaas, 2007) cannot be obtained, the analysis allows, at least, for the ranking of different management measures in terms of biological, social or economic viability.

An application of viability theory to a bioeconomic fisheries model requires a good understanding of the biological status of the resource (stock assessment), an appropriate parameterisation of the economy of the fishing fleets and the distributional aspects of the value of the output (i.e. profits for the fishing enterprise and payment to the labour force). An earlier application of the viability framework to two Mediterranean fisheries by Maynou (2014) showed that available data are of sufficient quality for some Mediterranean
fisheries. However, the management regime of these fisheries has changed with the reform Common Fisheries Policy of 2013 (EU Reg. 1380/2013) and especially under Art. 15, which includes a landing obligation of all catches of regulated species, subject to exemptions for high survival of fish or de minimis situations. Here, viability theory is applied to a bioeconomic model of the demersal fishery in GSA06 (Mediterranean coast of Spain) under the new policy constraints. The results of different management measures directed to the implementation of the discard ban were examined.

In 2015, 85% of the stocks were exploited outside biologically safe limits (SOMFI, 2016), and it is unlikely that the situation will be reversed in the short term, despite ambitious policy goals such as “fish stocks producing the Maximum Sustainable Yield by 2020” (Descriptor 3 of Good Environmental Status of the European Marine Strategy Framework Directive: MSFD, 2008). It is unlikely that MSY by 2020 can be achieved in the Mediterranean Sea with the current exploitation pattern—based on strong fishing effort focused on juvenile fish—that has not changed significantly over the last decades, despite numerous studies alerting fisheries managers to the situation (Colloca et al., 2013; Lleonart & Maynou, 2003; Maynou, 2014).

According to recent stock assessment results (Scientific, Technical and Economic Committee for Fisheries: STECF, 2014, 2015a, 2015b, 2017), hake, Merluccius merluccius (L.), and blue whiting, Micromesistius poutassou (Risso), show the highest exploitation rates, with current fishing mortality 5–10 times the value of $F_{msy}$. Modal catch sizes of all species are in the range of 10–30 cm TL with regulatory mesh sizes (40 mm square mesh), producing large quantities of catches below minimum legal sizes (e.g. 20 cm TL for hake; Colloca et al., 2013).

In addition to the incorrect exploitation pattern of fish stocks, Mediterranean fisheries show poor economic performance (AER, 2017, Maravelias & Tsitsika, 2008; Pinello et al., 2018). The introduction of the discard ban in the reform CFP (Art. 15 of EU Reg. 1380/2013) should incentivise either the adoption of more selective fishing gear to avoid the production of undersized fish or establishing processing plants on land to process these unwanted catches. The objective of this study is to assess the impact of possible adaptations of the demersal fleet in GSA06 to comply with the landing obligation.

2 | MATERIALS AND METHODS

2.1 | Study fisheries

In GSA06, the main demersal fisheries are exploited by large-scale fleets (LSF) using bottom trawls in fleet segments VL1218 and VL1824. The total production of demersal fleets in 2015 was 21,687 t for a value of 153,200 million Euro. Small-scale coastal fleets (SSCF) produced 13% of the total demersal landings in volume and 15% in value (electronic data appendix to AER, 2017). The landings of bottom trawl fisheries comprise several dozen species (Lleonart & Maynou, 2003, and electronic data appendix to AER, 2017), but the main target species are groundfish, such as hake, red mullet, M. barbatus

| Species | $F_{msy}$ in 2014 ($F_{msy}$ in parenthesis) | Landings (t, 2015) | Contribution to demersal landings (%) | Ex-vessel price (€/kg, 2015) | Value of landings (k€, 2015) | Contribution to value of landings (%) |
|---------|--------------------------------|-------------------|----------------------------------------|------------------------------|-----------------------------|---------------------------------|
| Merluccius merluccius | HKE (20 cm TL) | 5.35 (0.26 per year) | 1,594 | 10 | 7.95 | 12,672 | 10 |
| Lophius budegassa | ANK (no MLS) | 6.50 (0.15 per year) | 775 | 5 | 9.08 | 7,035 | 6 |
| Parapenaeus longirostris | DPS (20 mm CL) | 5.30 (0.28 per year) | 175 | 1 | 9.95 | 1,741 | 1 |
| Mullus barbatus | MUT (11 cm TL) | 3.27 (0.45 per year) | 355 | 2 | 22.14 | 7,860 | 6 |
| Aristeus antennatus | ARA (no MLS) | 2.08 (0.45 per year) | 689 | 4 | 28.96 | 19,965 | 16 |
| Nephrops norvegicus | NEP (20 mm CL) | 3.93 (0.23 per year) | 355 | 2 | 3.83 | 2,034 | 2 |
| Micromesistius poutassou | WHB (no MLS) | 9.50 (0.16 per year) | 531 | 3 | 3.83 | 2,034 | 2 |

*Bottom otter trawl.
L., anglerfish, *Lophius spp.*, or deep-water crustaceans, such as blue and red shrimp, *Aristeus antennatus* Risso, or Norway lobster, *Nephrops norvegicus* (L.), which reach high unit prices. The seven main demersal species of commercial interest for which stock assessments were available for 2014 are reported in Table 1 and represent 34% of the catches in volume but 54% in value. The disproportionate contribution in value is due to the high valued crustaceans, blue and red shrimp and Norway lobster, which contribute 22% of the demersal fish production. It is noteworthy that the contribution of OTB to the demersal landings was higher than 90% for all species and 100% for the valuable, deep-water crustaceans.

The management of Mediterranean fisheries is based on input measures that attempt to control fishing mortality by limiting the capacity of the fleets (license scheme) and the activity of the vessels, assuming a direct relationship between limitation of capacity or activity and effort limitation. Other technical measures include specifications of permitted fishing gear to control the selection pattern (Annex III of Reg. (EC) No. 1967/2006). In GSA06, fishing is not permitted at weekends, and the vessels must obligatorily return daily to their base port (maximum 12 working hours per day). Output management measures (i.e. Total Allowable Catch or Quotas) are not generally implemented in Mediterranean fisheries, with the exception of those for large pelagic species. These management measures have now been formalised and homogenised for the EU member states in the Western Mediterranean (Spain, France and Italy) within the Western Mediterranean Multi-Annual Plan for demersal fisheries (WMED MAP: COM/2018/0115 final–2018/050 [COD]).

The main stocks exploited by the demersal fleet are assessed by working groups of the STECF or the GFCM (General Fisheries Commission for the Mediterranean). Stock assessment results are of reasonable quality to parameterise a bioeconomic model, but due to the short span of the assessments (typically 10–12 years at most), the spawning stock/recruitment relationship is highly uncertain. This is a recurrent problem when attempting to build medium-term predictive models for Mediterranean fish stocks, although current research into historical data series may help produce more robust SSB/R models in the near future (EC project EASME/EMFF/2016/032). The economic parameters of the model were derived from economic data available for the period 2008–2015 from the STECF electronic appendix to AER (2017) (https://stecf.jrc.ec.europa.eu/reports/economic).

### 2.2 Simulation scenarios

A bioeconomic model following Maynou (2014) (Annex S1) was built to assess co-viability under simulation scenarios (Table 2), based on three types of management measures that should help to reduce fishing mortality or mitigate the production of unwanted catches, tested against a business-as-usual scenario continuing with “status quo” (Scenario 0), which projects the average fishing mortality vectors of the three most recent years into the future. Scenario 1 simulated a reduction of 10% fishing effort per annum. In Scenarios 2a and 2b, restriction of access to fishing grounds with the presence of undersized individuals was simulated by converting the age structure of the population to the length structure at each iteration and setting to 0 the fishing mortality of all undersized individuals in Scenario 2a and to 0.5 in Scenario 2b. Thereafter, the equivalent fishing mortality by age class was computed (Annex S4).

| Scenario | Conditions | Objective |
|----------|------------|-----------|
| Scenario 0 | Status quo, based on the average Fbar for 2012–2014 | Project the current conditions of the fisheries |
| Scenario 1 | Interannual reduction of 10% of fishing mortality, following the policy in place for the member state for the period 2013–2017 | The policy objective was to reach $F_{msy}$ for as many stocks as possible by 2020 |
| Scenario 2a | Restricting access to nursery grounds | Reduce fishing mortality of undersized individuals. For two fish stocks with no MLS at EU level (ANK, WHB) the local MLS was adopted (30 cm TL and 15 cm TL, respectively) to define undersized individuals. For ARA, without EU or local MLS, the same MLS as for DPS was used (20 mm CL) |
| Scenario 2b | Same as Scenario 2a, but assuming 50% compliance | Same as Scenario 2b |
| Scenario 3a | Adoption of a new net design with more selective properties, assuming full compliance () | Decrease the production of unwanted catches, reduce fishing mortality of the juvenile fraction of the stocks |
| Scenario 3b | Same as Scenario 3a, but assuming 50% compliance (i.e. only half of the fishing units would adopt the new net design) | Same as Scenario 3a |

### Table 2

Characteristics of the scenarios tested for the mixed demersal fishery in GSA6. Control variables are effort (Scenario 1) and fishing mortality (Scenarios 2 and 3).
size conversion algorithm was based on Hordyk, Ono, Valencia, Loneragan and Prince (2014). For Scenarios 3a and 3b, a notional trawl net was simulated (new net) with the selection properties corresponding to an average for diamond meshes of 50–60 mm for each species, based on the results from the literature (compiled in Deliverable 2.4 of the MINOUW project1, see references in Annex S4). Additionally, for hake and red mullet, the results of Sola and Maynou (2018a) with a T90 panel and Vitale et al. (2018) with sorting grids were used. For Lophius budegassa, no useful selectivity studies were found, and no changes in selectivity were simulated. The parameters of the current selection pattern (regulation net square mesh, 40 mm) are shown in Annex S4 and were derived from sources cited. Note that for M. barbatus and N. norvegicus, the current regulation net already ensures L 50 in line with MLS (11 cm TL and 20 mm CL, respectively), while for A. antennatus, the new selection pattern is essentially identical to the current one. This means that for these three species, the benefits of adopting a more selective net are not expected to be very important in terms of improving the retention pattern. The simulations were carried out for the period 2015–2030, taking 2014 as the most recent year with an available assessment. Each scenario was run 1,000 times, allowing for uncertainty in the stock/recruitment relationship. The simulations were carried out with FLR using the built-in biological libraries of the model (particularly FLCore and FLBRP, see http://www.flr-project.org/). The economic submodel (Annex S1) was codified in R for this work based on the economic submodel of MEFISTO (Maynou, 2014; Sola & Maynou, 2018a, 2018b).

### 2.3 | Co-viability model

In viability theory, the actual variables and constraints that are selected for analysis are arbitrary and left to the choice of the modeler. When used for fisheries bioeconomic models, it is common to choose a measure of stock biomass as a state variable, for example, see Oubraham and Zaccour (2018). In fisheries, the natural choice for a control variable is an indicator of harvest pressure, such as fishing mortality. Candidates for viability constraints are chosen depending on the objective of the study, but indicators of labour productivity or profitability of the fishery have often been used (Oubraham & Zaccour, 2018).

The state variables SSBᵢ, wageᵢ, and πᵢ were monitored at each iteration to derive their mean and 95% quantile indicators. Following Baumgartner and Quaas (2007), the viability of GSA06 demersal fisheries is guaranteed if the different components and functions of the system (i.e. the bioeconomic dynamic, stochastic model) that describe these fisheries remain, at any future time, within the domain of existence with sufficiently high probability (here 90% or higher). As a proxy for the biological viability of the stocks, the proportion of iterations among the 1,000 trajectories simulated that satisfy the following constraint in each year t in each scenario was computed:

$$SSB_{i,t} \geq SSB_{i,pa}^{pa}$$  \text{ (i = 1…7),} \tag{1}$$

where $SSB_{i,pa}^{pa}$ is the precautionary spawning stock biomass for each species (Annex S2: Table A.2). Given that formal reference points are not available for most Mediterranean stocks, 1.5 $SSB_{loss}$ as the precautionary reference point was used, where $SSB_{loss}$ is the lowest observed spawning stock level for each stock (Cadima, 2003).

The average monthly wage of the crew was used as a proxy for social viability, considering that the fishery would be viable when the wage does not go below 700 €/month (minimum salary in the member state in 20172) because of lack of manpower, that is, at the annual scale:

$$wage_{i} \geq 700 \times 12$$  \tag{2}$$

The economic viability of the fleet was assessed in each scenario as the proportion of iterations that satisfy positive annual profits:

$$\pi_{i} > 0$$  \tag{3}$$

The co-viability of the fishery is ensured when the three constraints are met simultaneously each year in the simulation period of 2015–2030 (Table 3). For each scenario Sc: $p(Sc) = p$constraint[1] AND constraint[2] AND constraint[3]).

A Scenario Sc can be considered viable biologically, socially and economically or co-viable if $p(Sc)$ is higher than a proportion established by the researcher or the policy maker (here 90%).

### 3 | RESULTS

As can be expected, due to the short time series available, the functional formulations to the SSB/R relationship are highly uncertain (Figs A3.1–7 and Table A3.1 in Annex S3). The Beverton and Holt

| Viability criterion | State variable | Control variable | Viability constraint |
|---------------------|----------------|-----------------|---------------------|
| Biological          | $SSB_{i,t}$   | Fishing mortality (F) | $SSB_{i,t} \geq SSB_{i,pa}^{pa}$ |
| Economic            | Net profits $\pi_{i}$ |                                      | $\pi_{i} > 0$ |
| Social              | wageᵢ (proxy) |                                      | wageᵢ ≥ 700*12 |

Abbreviation: SSB, spawning stock biomass; t, time; i, stock (i: 1…7).

1http://www.minouw-project.eu

2https://www.sepe.es/contenidos/comunicacion/noticias/SMI_2017.html
SSB/R models trialled for hake, red mullet and blue and red shrimp resulted in a basically linear model, while for black-bellied angler and deep-water rose shrimp, the selected models yield practically constant recruitment. In the case of Norway lobster and blue whiting, only a geometric mean model was attempted due to the shortness of the series.

With this important limitation in the SSB/R relationship, the seven stocks under study were projected under the conditions of the six scenarios (Annex S4 and Annex S5: Figs A5.1-7). Under all projection scenarios, the biological indicators recruitment and spawning stock biomass of hake (Annex S5: Figs A5.1) are expected to increase notably, even under the constant fishing mortality or status quo scenario. The decrease in fishing mortality in the first policy scenario (decrease by 10% per annum) would be insufficient to reach \( F_{\text{msy}} \) by 2020, but would allow the target to be reached by 2030, assuming constant natural mortality. In all scenarios except the status quo, catches would increase significantly, with the catch increase provided by the adoption of the new net slightly better (but not statistically significant) than the increase in catches due to the adoption of FRA or the decrease of 10% in fishing mortality per annum. Note that in all cases, full compliance with the scenario always performs better than 50% compliance, but the difference is not statistically significant.

In the case of black-bellied anglerfish (Annex S5: Fig. A5.2), with the parameterisation used, recruitment would continue to decrease in all scenarios, with some probability of zero recruitment under Scenarios 0, 2b and 3b. SSB would decrease in all scenarios except in Scenario 1. For this stock, the probability of collapse (SSB = 0) is non-negligible in Scenarios 0, 2a and 2b. Note that for this species, no selectivity pattern could be established from existing studies; hence, the scenarios based on the introduction of a new net (Scenarios 3a and 3b) do not provide different results than the status quo scenario (Scenario 0). In the case of deep-water rose shrimp, (Annex S5: Fig. A5.3) with a practically constant recruitment model, SSB would be higher in all scenarios than in the status quo scenario, particularly for Scenario 1. The catches would be similar to the catches observed in the historical series, except for Scenario 1, where the strong decrease in fishing mortality would result in underutilisation (exploitation below MSY) towards the end of the simulation horizon. For red mullet (Annex S5: Fig. A5.4), all scenarios forecast an increase in recruitment, SSB and catches, although in Scenarios 0, 2a and 2b, these increases are lower than in Scenarios 1, 3a and 3b. Note how under Scenario 1 the fishing mortality reached by 2030 would be below \( F_{\text{msy}} \) (underexploitation) with the introduction of AIS/VMS that prevent illegal activity in the area. In the case of blue and red shrimp (Annex S5: Fig. A5.5), all scenarios forecast an increase in recruitment, SSB and catches, although Scenarios 3a and 3b, based on net selectivity, would result in higher values of these indicators than scenarios based on spatial restrictions to fishing. In any case, the status quo scenario would perform worse than the other scenarios. For Norway lobster (Annex S5: Fig. A5.6), with the available parameters, the risk of stock collapse is apparent in all scenarios except Scenario 1. Catches would decrease importantly in all scenarios, including Scenario 1. Similarly, for blue whiting (Annex S5: Fig. A5.7), the projections provide non-zero probability of zero recruitment or stock collapse, except in the case of Scenarios 3a and 3b, based on the adoption of a new net, where SSB would increase importantly after 2020. In all cases, regardless of the scenario, catches would decrease to half the level of historical catches.

In the mid-term (2020), catches are not expected to increase by more than 20%-30% with respect to 2015, with the highest volume of landings for human consumption under Scenario 2b (partial compliance with FRA; Table A6.1 in Annex S6). The main species contributing to this increase are hake and red mullet. In the long term, total landings of target species are expected to increase in all scenarios, with the highest catches obtained in Scenario 1 at the end of the simulation horizon (24,972 t in 2030 compared with 5,855 t in 2015; Annex S6: Table A6.1). This important increase in catches is essentially due to hake and red mullet, whose production would increase several times under all scenarios. For all other species, catches for human consumption would remain practically constant or even decrease.

The largest amount of unwanted catches would be produced for hake and red mullet, and for both species, the amount of unwanted catches is expected to increase in the mid- and long term due to the parameterisation of the SSB/R model, which projects higher recruitment of both species in the future (Table A6.2 in Annex S6). Note how the mortality reduction across all ages resulting from Scenario 1 or for juvenile ages only (Scenarios 2 and 3) would result in even higher unwanted catches for both stocks, with no significant difference between Scenarios 2 and 3. Conversely, for the two regulated crustacean species, the amount of unwanted catches would decrease under any of the management scenarios (Annex S6: Table A6.2). Note that the amount of unwanted catches would double or triple, depending on the scenario, from the current value of 1,300–1,400 t to 3,000–5,000 t. These volumes represent ~30% of the catches in Scenario 0, 15% under Scenario 1 and ~20% of the catches under Scenarios 2–3.

As the amount of unwanted catches produced under each scenario would increase in the mid- and long term (Annex S6: Table A6.2), their economic value would also increase in absolute terms (Annex S6: Table A6.3). If a market for industrial utilisation could be found, the value of unwanted catches could increase from <300,000 €/year at present to between 600,000 and 1,000,000 €/year by 2030. Conversely, if no market could be found and the product brought to land had to be destroyed as animal waste, at a cost to the producer, the losses would range from 700,000 € at present to between 1.5 and 3 million € by 2030 (Annex S6: Table A6.3). Note that in all cases, even if these amounts are non-negligible, they represent <5% of the income of the demersal fishery in GSA06 (Table A6.4 in Annex S6).

Income is expected to increase under all scenarios, especially in the long term (2030; Annex S6: Table A6.4). The highest increase in the short term (2020) is expected for Scenarios 3a and 3b (adopting a more selective device), where total income might increase by 8%. Note how the income from unwanted catches (positive or negative) is always a fraction of the order of 1%-5% (depending on scenario).
of the total income. Labour costs (and wages) are forecast to increase in all scenarios, with very high values in the long term. This analysis, however, does not take into account possible changes in the share-based structure of remuneration if a higher workload is imposed on workers due to the handling of unwanted catches. In all cases, net profits of the demersal fleet are expected to increase. It is important to note that gross value added (GVA) and net profits do not vary significantly in relation to the income related to unwanted catches.

The trajectories of net profits for the different management scenarios (Figure 1) suggests that, despite the wide confidence intervals, the scenario producing the lowest profits is maintaining the status quo (Scenario 0). The implementation of a new net with a better selection pattern would perform better in terms of net profits than a fisheries restricted area (FRA). Note, however, that both the FRA and the adoption of a new net would entail short-term losses immediately after their adoption (2019 in this model application).

The results of the co-viability analysis (Table 4) showed that practically all future trajectories are socially and economically co-viable, with values higher than 99% for the labour indicator (monthly wage $>700$ €) and higher than 97% for the economic indicator (positive profits). The lowest levels of economic viability, approximately 98%, were produced for Scenarios 2a and 2b (adoption of FRA), which were of the same order as economic viability under Scenario 0. Conversely, the deep-water rose shrimp, the black-bellied angler, the blue whiting and the Norway lobster stocks showed very low levels of viability (always <90% and for Norway lobster, in some scenarios 0%, Table 3). The viability of hake (88%–92%) was higher than in these species, but was lower than 90% under Scenarios 0 and 1.

In general, Scenario 0 showed the lowest levels of biological viability for all species (except Norway lobster, where Scenarios 2a, 2b and 3b were also 0%). With these results, the demersal fishery in GSA06 is not co-viable due to the low viability of some stocks, particularly the black-bellied angler and the Norway lobster stocks.

4 | DISCUSSION

Co-viability analysis in fisheries management is a useful framework to accommodate objectives of different nature (Oubraham & Zaccour, 2018) that often result in conflict among different types of stakeholders, such as conservationists, fishers or fisheries managers. The results showed that under the scenarios explored, the demersal fishery in GSA06 is not co-viable and that the limiting factor is non-viability of certain target stocks of the fishery. From the social (labour) and economic (net profit) perspectives, the fishery is viable under the simulation conditions used here, mainly because the target stocks modelled account for 56% of the total income, that is, the fleet relies, to a large extent, on non-assessed stocks whose production has been considered constant for...
the time of this model application. To a large extent, the results agree with Tserpes et al. (2016), who applied viability theory to a mixed demersal fishery in the Aegean Sea and found that most stocks would not be viable in a business-as-usual scenario and that a strong decrease in fishing effort would be necessary to ensure economic viability.

For mixed fisheries such as the one studied here, it is not possible to recommend a single management measure as the "best" policy option, although the strong reduction of fishing effort by 10% per annum ranked first in terms of co-viability (Table 4). For some stocks, such as blackbelly angler or deepwater rose shrimp, reducing fishing mortality across all ages by a generic policy aimed at decreasing fishing effort by 10% per annum (Scenario 1) might provide the best results. In other cases (hake), implementing fisheries restricted areas (Scenarios 2a and 2b) might be more appropriate to delay the age at first capture, while in other cases (blue whiting but also hake), the adoption of more selective fishing gear should be recommended. Hake would benefit equally from a spatially based restriction to fishing or a new net configuration. This result is comparable to Khoukh and Maynou (2018), who found that full protection of an important nursery area in the Catalan coast would be equivalent, in terms of increased catches, to a reduction of 20% in fishing effort. These results confirm the difficulty of optimally managing several species simultaneously in mixed fisheries (Dolder, Thorson, & Minto, 2018).

The impact of the landing obligation in the reformed Common Fisheries Policy (Art. 15 of EU Reg. 1380/2013) appears to be low in the model application. The absolute number of discards would not change significantly depending on the outlet of unwanted catches; labour, probability that remuneration is higher than the minimum salary; p(NP1) and p(NP2), probability that net profits are positive when unwanted catches can be sold or must be destroyed. Codes for species names are shown in Table 1. Values equal to or larger than 90% are shaded.

| Scenario     | Labour p(NP1 > 0) | p(NP2 > 0) | ANK | ARA | DPS | HKE | MUT | NEP | WHB | Co-viability |
|--------------|------------------|------------|-----|-----|-----|-----|-----|-----|-----|--------------|
| Status quo   | 99.56%           | 98.19%     | 97.81% | 100% | 0%  | 100% | 0%  | 100% | 0%  | 0%           |
| 10% red      | 100.00%          | 99.94%     | 99.94% | 56.38% | 100% | 65.44% | 87.75% | 100% | 13.44% | 79.38% | 11.38% |
| FRA 50%      | 99.81%           | 98.00%     | 97.50% | 26.13% | 100% | 55.63% | 91.94% | 100% | 0%  | 71.00% | 0.00% |
| New Net      | 99.88%           | 99.00%     | 98.94% | 8.81%  | 100% | 55.06% | 91.94% | 100% | 0.25% | 68.06% | 0.00% |
| New Net 50%  | 99.88%           | 99.31%     | 99.00% | 18.8%  | 100.00% | 8.63% | 91.94% | 100.00% | 0.00% | 85.88% | 0.00% |

Note: Co-viability, joint probability that labour, profits and stocks are viable, the value did not vary significantly depending on the outlet of unwanted catches; Labour, probability that remuneration is higher than the minimum salary; p(NP1) and p(NP2), probability that net profits are positive when unwanted catches can be sold or must be destroyed. Codes for species names are shown in Table 1. Values equal to or larger than 90% are shaded.
management measure aimed at increasing the age of first capture, even if it is only by 1 year and not fully enforced, is better than the status quo. Continuing with an interannual effort reduction of 10%, as in the fisheries management plan of 2013–2017, would result in a strong decrease in fishing mortality by 2030, with risk of underutilisation for some stocks (i.e. deep-water rose shrimp) and strong socio-economic impacts (large reduction in capacity or activity).

The parameterisation of some stocks, viz. Norwegian lobster and blue whiting, resulted in projections of questionable reliability (Annex S5: Figs A5.6, A5.7). For these species, catches were projected to be lower than historically observed catches, regardless of the scenario. The contribution of these two species to the production of demersal fleets in GSA06 is 8% in terms of value, which probably does not affect the overall results of this model application. A more important limitation of the application of viability theory to bioeconomic models in Mediterranean fisheries is the uncertainty in the stock/recruitment relationship, which implies a low reliability on the evolution of the population state variables (Oubraham & Zaccour, 2018). The only solution to this problem is obtaining longer data series with the hope of fitting better population models or switching to other types of biological models altogether (for instance, biomass surplus models).

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CONFLICT OF INTEREST

None.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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