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Toward a Dynamical Approach for Systematic Conservation Planning of Eastern English Channel Fisheries

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Abstract:

In the past decade, systematic conservation planning tools have been increasingly and successfully used to set spatial conservation plans that meet quantitative protection targets while minimizing enforcement and socioeconomic costs. However, when applied to fisheries, systematic conservation planning fails to account for (1) changes in fleet dynamics induced by new conservation constraints and their associated feedbacks on conservation costs or (2) their influence on fish population dynamics and distributions, which may in turn alter the achievement of conservation targets. Such a static approach may therefore lead to short- or medium-term misestimates in forecasted costs and target achievements. In order to circumvent such limitations of systematic conservation planning, we present a first attempt to couple a conservation planning tool (Marxan with Zones) with a mixed fisheries dynamics simulation model (ISIS-Fish), applied to the Eastern English Channel fisheries. Broad principles and perspectives are discussed and anticipated future challenges of such an approach are presented.

Keywords : MPAs ; Systematic conservation planning ; Mixed fisheries dynamics ; Model coupling ; Eastern English Channel ; Marxan with Zones; ISIS-Fish

1. Introduction

The Eastern English Channel is an important ecological area that is experiencing growing human pressure, mainly exerted by the bordering countries, France and the United Kingdom, and is subjected to a wide range of uses such as fishing, sediment extraction and transport [1–3]. Spatial regulations, including Marine Protected Areas (MPAs) are now increasingly introduced to legislate these perturbations [4–7]. MPAs, to be successfully implemented, need to combine conservation objectives and socioeconomic features, such as fisheries [8]. Within this context, France and the United Kingdom are under obligations to create a consistent Marine Protected Area (MPA) network that complies with several conventions, especially the Convention on Biological Diversity [review in 9] and the Bird and Habitat European Directives, whilst ensuring a viable future for the wide range of uses within this area.

In the past decade, systematic conservation planning tools have been increasingly and successfully used to develop spatial conservation plans – involving MPAs – which meet quantitative targets (*e.g.* a given protected percentage of each species distribution or habitat area) while minimizing enforcement and socio-economic costs [10–13]. This approach thus provides a framework that is deemed suitable to design consistent MPA networks that are cost-effective and minimize social costs, hence increasing their likelihood of effective implementation [14]. However, systematic conservation planning applied to fisheries accounts neither for (*i*) changes in fleet dynamics induced by new conservation constraints and their associated feed-backs on conservation costs, nor (*ii*) their influence on fish population dynamics and distributions, which may in turn alter the achievement of conservation targets. Such a static approach may therefore lead to short- or medium-term mis-estimates in forecasted costs and target achievements.

Mixed fisheries simulation models are increasingly used to predict changes in fleet and fish population dynamics under various fishery management scenarios (*e.g.* [15, 16]), but lack, in most of case, the methodology to translate the results into advices to support spatial conservation measures.

In this context, coupling systematic conservation planning tools with mixed-fisheries models (or other types of simulation models, in accordance with the type of issue tackled) seems a promising approach to test scenarios and build advice for management of highly dynamic and complex systems such as coastal areas under intense human use.

2. Proposed approach

2.1. Overview of selected tools

2.1.1. Systematic Conservation Planning.

Several tools exist that are dedicated to systematic conservation planning (*e.g.* Marxan, Zonation) and can help to design MPAs. Most of them however rely on a binary and often unrealistic full protection strategy, therefore missing the complexity of management strategies which can be deployed through multiple types of MPAs. A recent tool, Marxan with Zones (MwZ) [17], allows this limitation to be overcome in an optimal way by extending the Marxan methodology (based on the minimum-set principle aiming to achieve given quantitative representation level of species and habitats at minimal cost) to multiple zone types. It provides the possibility of considering multiple, possibly concurrent, resource uses which are managed in different ways, while taking into account a variety of costs. It has been shown to be able to provide management scenarios that – compared to a standard Marxan analysis – ensure more equitable impacts among different uses while lowering the overall economic and social impact, and still meeting conservation targets, thus increasing the likelihood of effective implementation [18]. However, unlike Marxan, feedback on MwZ effectiveness remains scarce.

Marxan with Zones uses a simulated annealing algorithm to work as an optimization tool which meets complex constraints such as combinations of overall percent and/or absolute values of each feature (often species or habitats) to be protected in each type of “zone” (with varying protection levels corresponding to which human use are maintained). The objective function it minimizes has the form:

$$\sum_{PUs} Cost + \underbrace{BLM \times \sum_{Z}\sum_{PUs} BoundaryCost}_{Connectivity\,costs} + \sum_{Ft} FPF \times FeaturePenalty \quad (1)$$

Where *Cost* represents the sum of various costs associated with the selection of a “planning unit” (*PU*, the smaller spatial unit). These costs can be of any kind found to be relevant to each case study, for instance surface area, enforcement or socioeconomic costs [14]. Additionally to these inherent costs, connectivity costs – of which the boundary length modifier (BLM) controls the overall contribution to the objective function value – allows control of the level of aggregation/fragmentation of conservation zones or increases the co-selection of connected PUs [18]. The “connectivity” between conservation zones is also controlled in this term by zone boundary costs, which are formally multipliers of PU boundary costs between each combination of adjacent zones[1]. The last term of eq. (1) refers to penalties for failing to achieve targets, summed over features (*Ft*; or species) and is controlled through feature penalty factors (*FPF*); the higher the *FPF*, the more likely the fulfillment of the target [17].

MwZ has been selected for this study owing to its ability to both reproduce complex management scenarios and include use-specific costs in a flexible way, which more accurately reflect mixed-fisheries properties than other existing tools.

2.1.2. Mixed fisheries simulation model.

ISIS-Fish has been chosen because it is a modelling tool suitable for investigating the consequences of alternative policies on the dynamics of fish resources and fisheries [19]. This spatially explicit model allows quantitative policy screening for fisheries with mixed-species harvests [19, 20]. It may be used to investigate the effects of combined management scenarios including a variety of policies: total allowable catch (TAC), licenses, gear restrictions, effort controls but also alternative ones such as the introduction of marine protected areas [16, 21, 22] or individual quotas [23], etc. Fisher's response to management may be accounted for by means of decision rules based on population and exploitation parameters or explicit dynamic model with endogenous (*e.g.* fixed fish prices and variable costs, that can be explicitly modelled) or exogenous variables (not affected by the model). This fishery model is based on three submodels *(i)* a fishing activity dynamics model, *(ii)* a fish population dynamics model and *(iii)* a management dynamics model.

Each submodel is spatially and seasonally explicit, with a monthly time step to account for seasonal dynamics. The three submodels interact only if they overlap in space and time. The modelled area is represented by a grid, the resolution of which, in latitude and longitude, is chosen with respect to the dynamics being described and the available knowledge of the studied fishery. Within this region, zones (i.e. sets of grid cells) are defined independently and delimit the spatial scope for each population, each fishing activity and each management measure. Finally, bioeconomic outputs can be simulated and their properties (including uncertainties) statistically analyzed to produce indicators of the relevance of management strategies [24].

2.2. Models scopes and implementations

Here we present the first highlights of an ongoing study which aims to couple a systematic conservation planning software package with a mixed-fisheries model to evaluate the relevancy for fisheries management of the MPA network being implemented in the Eastern English

[1] Note that a PU can pertain to only one conservation zone at a time.

Channel (**Fig. 1**). And, where relevant, provide advice for management strategies.

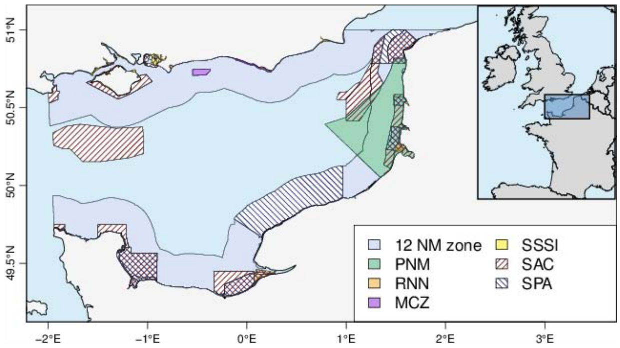

Fig. 1. MPAs (actual or planned) in the ICES VIId zone. PNM: natural marine park (France); RNN: national natural reserve (Fr.); APPB: prefectural biotope protection (Fr.); MCZ: marine conservation zone (UK); SSSI: site of special scientific interest (UK); OSPAR: OSPAR convention zone; RAMSAR: RAMSAR convention zone; SAC: special area of conservation (Natura 2000, habitat convention); SPA: special protected area (Natura 2000, bird convention).

This study therefore focuses on ecosystem and socioeconomic features which are linked to fishing activities, restricted to professional fishing owing to data availability.

2.2.1. Marxan with Zones features to protect are:

- abundance distributions (mean over 1990-2012) of two of the main targeted species (those accounted in the fleet dynamics model), common sole (*Solea solea*; **Fig. 2a**) and plaice (*Pleuronectes platessa*; **Fig. 2b**) assessed from the Channel ground fish surveys (CGFS) data.

- eighteen benthic habitats, on which towed gears can have a negative impact. Data used are those from Delavenne *et al.* [11].

- thirteen pelagic habitats, which contain communities that can be affected by most pelagic gears. The typology used is the one defined by Delavenne *et al.* [25].

Among feature types, only exploited species distributions are planned to be dynamically linked to the simulation model, habitats being handled as a static part of the system.

As for costs, hours fished by type of gear and zone, estimated from data collected by Vessel Monitoring System [26] are used as proxies of value losses when a protection unit is selected for a type of zone which bans or limits some uses (**Fig. 2c & d**). As a first approach, costs will not be processed in a dynamic way because the selection of a PU would eliminate its cost on the next step (no or less fishing).

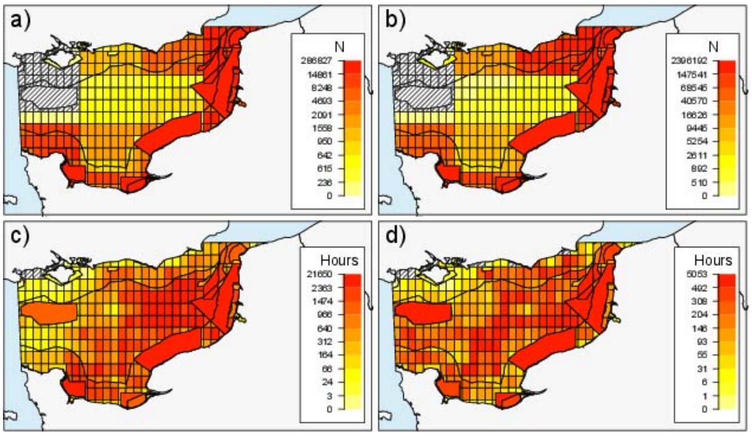

Fig. 2. Mean abundances (N, decile scale) by PU of *Solea solea* (a) and *Pleuronectes platessa* (b) estimated from the CGFS survey data and aggregated efforts by PU (hours fished, decile scale) from French (2008) and English (2007) VMS data for ground-towed gears (c) and all other types of gears (d). PUs with lacking data are hatched.

The spatial grid was defined so that each MPA was divided into as many subareas of unique administrative status and that remaining available areas were separated according to the same grid as the ISIS-Fish model (1/32nd of ICES statistical rectangle; **Fig. 2**) and further divided according to the 12 nautical miles zone.

A scenario was tested with only two kinds of protection zones – no ground-towed gears and no-take (all activities prohibited) – and where the 12 nautical miles zone was considered already contributing to conservation (limited access to vessels >24m). Already planned MPAs were constrained to always apply one of the two protection levels. Zone contributions to conservation (**Table 1**) and costs multipliers (**Table 2**; formally corresponding to proportion of effort reduction within protected zones) were set arbitrarily but should ideally be derived from quantitative study of the impact of each use on different features. Here, all benthic habitats were treated homogeneously with the removal of ground-towed gear fully protecting them (no impact of other gears) whilst this measure is supposed to have no impact on pelagic habitats and yield a 50% protection to target species (that can be also caught with other gears such as tremels). The exclusion of large vessels (mostly trawlers) from the 12 nautical miles zone is not expected to supply more than a 10% protection to features impacted by ground-towed gears, since there are few such large vessels operating in the study area.

The results of this drastic scenario (few choices for management strategies, all of which prohibited ground-towed gears) are reported in **Fig. 3**.

Table 1. Conservation zone contributions to the protection of various types of features. These are proportions of feature potentially protected under different types of restriction of fishing access.

Features \ Zones	Unprotected	12nm zone	No ground-towed	No-take
Benthic habitats	0.0	0.1	1.0	1.0
Pelagic habitats	0.0	0.0	0.0	1.0
Target species	0.0	0.1	0.5	1.0

Table 2. Cost multipliers by zone and gear type. These are the proportion of effort reduction applied to each gear type under different types of restriction of fishing access.

Gears \ Zones	Unprotected	12nm zone	No ground-towed	No-take
Towed	0.0	0.1	1.0	1.0
Other	0.0	0.0	0.0	1.0

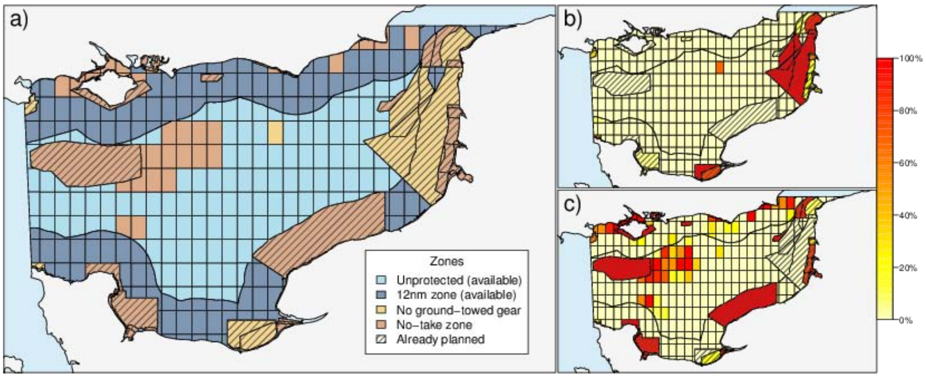

Fig. 3. Marxan with Zones results on 100 runs: best solution (a) and selection frequencies of “no ground-towed gear” (b) and “no-take” (c) conservation zones. Available cells are those not selected for any purpose.

2.2.2. ISIS-Fish.

The model used is an improved version of the one developed by Gasche *et al.* [27], characterizing population and exploitation dynamics of sole and plaice, with:

1. a finer spatial resolution of 0.125° (latitude and longitude) that allows for a more realistic depiction of biological and exploitation processes.
2. better account of populations distributions across life stages – with several feeding grounds (three), nurseries (six) and reproduction (three) zones for each species (*i.e.* 12 zones for both plaice and sole) – according to [28, 29].
3. fishing activities updated according to Lehuta *et al.* ([30]).

The model was tested over 12 years under two different scenarios *(i)* one with only total allowable catches (TAC) as management measure (forced by 2008-2011 actual TACs, then dynamically set by an harvest control rule that aims at reaching F_{MSY} in five years following ICES advices) and *(ii)* another with additional spatial conservation measures (**Fig. 4**) consistent with MwZ outputs (**Fig. 3**). No effort reallocation across metiers (defined by one target species on one zone with one gear) is assumed.

Results show very little differences between scenarios with TACs and TACS+MPAs for abundances (**Fig. 5 left**) and landings (**Fig. 5 right**) of both Plaice and Sole during the transition period towards management at F_{MSY} (years three to seven). However, differences in landings become more substantial afterward (when the TAC is less constraining), although no clear difference appears in trends.

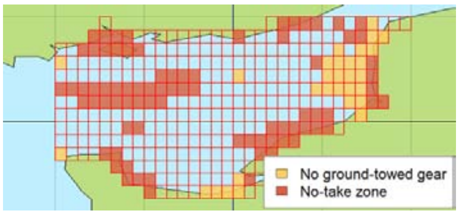

Fig. 4. ISIS-Fish grid and management zones defined in the model. These are an attempt to broadly reproduce MwZ outputs (**Fig. 3**).

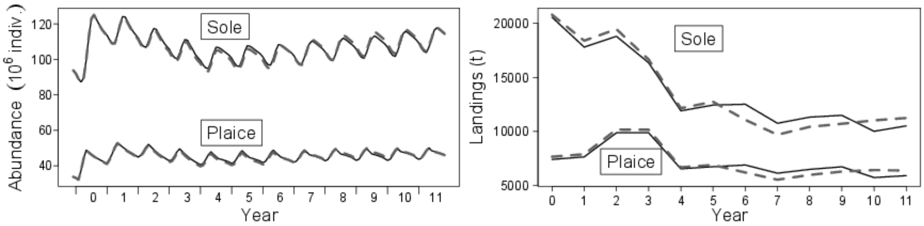

Fig. 5. ISIS-Fish model outputs of monthly abundances (left) and yearly landings (right) compared between TAC only (black solid lines) and TAC+MPAs (grey dashed lines) scenarios.

2.3. Explicit model coupling in practice

Marxan with Zones is a command-line software which works with text input files, all listed in a main input file and with fairly simple and documented structures [31]. It is therefore easily controlled through any platform which allows running commands and is able to handle data and text files (*e.g.* we have easily controlled all the MwZ analysis sequence, from data formatting to output representation, with R; `http://cran.r-project.org`). Principal Marxan input files which would be subject to dynamical updates are:

- the planning unit file, and more particularly the costs given to each planning unit (PU).

- the features (here exploited species) versus PUs file which gives amount of each feature within each PU.

Files such as those containing boundary lengths/connectivities between protection units, or “zone boundary costs” pertain to the original design and are unlikely to be modified by iterative runs (except for sensitivity analysis).

As for ISIS-Fish, control from a third-party tool seems more difficult since most parameters are stored in embedded data-bases, with internal referencing of objects, as spatial units or populations for instance. Therefore, even though ISIS-Fish simulations themselves can be run from command-line calls, the management zones of the model cannot be directly controlled through text files. However, ISIS-Fish is an open-source modeling platform, with an active development team, hence highly extendable.

For instance, concerning the translation from MwZ outputs to ISIS-Fish management strategies, the ISIS extensive scripting (Java script) abilities will be used to:

1. load formatted MwZ outputs (preferably preprocessed by R scripts for easy handling).
2. define as many management zones as different effort reductions by gear, calculated from MwZ outputs (pre-simulation script).
3. apply for each cell an effort reduction by métier from its overlap with management zones for the gear used at each time step.

The second point raises the issue of transferring costs, features and optimized spatial management measures between two possibly different spatial scales. Indeed, there is no requirement for the spatial grid in MwZ to be regular, as it is the case for the one in ISIS-Fish. In fact, it is even convenient to keep existing – intricately shaped – MPAs as separated PUs (*e.g.* **Fig. 3**) for MwZ analyses. Therefore, even under simple homogeneity assumption regarding amounts within grid cells, the transfer of data from a grid to another requires extensive calculations, among which assessment of cell surface overlap between the two model spatial grid layers (that only needs to be calculated once) and pro rata reallocation rates from one grid to the other. This is easily done with R scripts which can notably calculate an accurate effort reduction in ISIS spatial unit (cell) by gear, from a given MwZ solution, since gears limitations are given for each kind of conservation zone.

As for the automation of the coupling, two options emerge:

1. in order to iteratively run both of the tools and operate the data format conversion between them, a first step will be to use an external third-party tool. As suggested above, R is a good candidate because of its extended data-handling abilities and its capacity to interact with other software packages through so-called “system calls”.
2. it is nevertheless considered to further develop a module within ISIS-Fish to control MwZ directly from within simulation iterations, hence

getting quick cost assessments and zoning optimizations to enhance the dynamic properties of the whole system. The existing ability of ISIS to connect to R could in particular be used to run scripts controlling the whole MwZ loop, from data preparation to processing of output to provide management zones that can be handled by ISIS. This way, costs and feature amounts could be updated from ISIS-Fish to MwZ and, as a feedback, zoning in ISIS-Fish could be updated according to MwZ outputs.

2.4. Types of scenarios to be tested

Coupling these two tools would open the opportunity to test a wide range of scenarios regarding the dynamics of spatial conservation plans. The following propositions are far from exhaustive but focus on types of analyses already planned in the context of this study.

A first and fairly obvious type of analysis would consist of testing what the dynamics of the main fleets and fish populations would be under different conservation scenarios, and how they would influence targets achievement (no feedback, only the evaluation of species abundance proportions within protected areas after the simulated period), and then testing for the robustness of the MPA network through the stability in species representation. This would only require a one way coupling from MwZ to ISIS-Fish that does not really require explicit and automated translation of a common MwZ analysis protected zones outputs to management scenarios within ISIS-Fish. Achievement of targets would be easily assessed from ISIS-Fish outputs in terms of species abundance distributions. More realistic economic costs, although completely independent at this stage from those used in MwZ, could also be assessed by comparison of simulated landings at the beginning and the end of the simulation period.

From the previous analysis, it may be possible to test whether any proposed MPA network with a particular set of conservation measures is suitable to ensure medium to long-term viability of fleets and of the fish populations they harvest. At present, in the Eastern English Channel, enforcement measures are still to be defined in most proposed MPAs and it may be very relevant to use MwZ on its own to provide near optimal management scenarios within the already planned MPA network. The addition of the ISIS-Fish simulations would enable the evaluation of the management strategy under which the fishing fleets will remain viable. For that purpose, the methodology proposed by Lehuta *et al.* [24], based on bioeconomic indicators and their uncertainty to evaluate management strategies, could be used.

Other types of analyses would require a more intricate and fully dynamic coupling of the two tools than the preceding ones. It is for instance planned to test the effect of the chronological sequence of enforcement, and how it could be optimized. Indeed, it would involve running

ISIS-fish over a given interval of time (*e.g.* one year), then testing which would be the best enforcement addition to the network using MwZ and running ISIS-Fish again from where it stopped, etc. Such an approach would have to be tested over various time lags.

All these types of analysis would benefit by also testing whether different near-optimal solutions, which differ noticeably in term of selected sets of PU-zone pairs but not in term of cost, would lead to different dynamics and viabilities of fleets and harvested populations. Such analyses would have to account for confidence in data. From a more general point of view, a sensitivity analysis on optimization and model parameters would be necessary.

3. Perspectives and future challenges

Challenges raised by this coupling approach pertain to *(i)* finding a relevant design and level of detail regarding processes embodied in each model, *(ii)* getting a proper parameterization of both models and *(iii)* keeping an overall consistency, instead of technical issues regarding the coupling itself.

First of all, the methodology promoted here will be extended to a more representative set of the Eastern English Channel fisheries. For that purpose, the MwZ number of features will be extended to include seven target species, in order to be coupled with the ISIS-FISH model developed by Lehuta *et al.* ([30]) and which includes five additional target species: Cod *Gadus Morhua*, Whiting *Merlangius merlangus*, European seabass *Dicentrarchus labrax*, Squids *Loligo spp.* and Scallop *Pecten maximus*. Another possible improvement of the ISIS-Fish model can be to add benthic and/or pelagic habitats to provide a dynamic description of habitat state impacting by human activities (including sediment extraction) like in Gasche *et al.* [32].

Additional features such as birds or seals colonies, highly sensitive habitats or endangered species known locations may also be added to increase the spatial constraint on the MwZ solutions and to better represent the local biodiversity and not only the exploited species.

The definition of management scenarios that are likely to be implemented is also of high importance. This raises the need for identification of more realistic management measure regarding either the administrative status of zones (*e.g.* is it desirable to ban ground-towed gears from large zones designated under the bird directive only?) or the local characteristics of an MPA itself (*e.g.* in the case of particularly discrete natural bivalve beds where dredging cannot be banned without deep economic impacts). In that context, a consultation of managers is underway to move towards more realistic constraints on MwZ inputs.

Contributions of different zone types to the preservation of various features will also have to be characterized in a more explicit way, based on observed and quantified gear impacts, proposed effort reduction (by gear within the zone) and overall effort partition among gears.

This approach could also be improved by moving fishing activities from costs to features that also have to be protected (*e.g.* with a 90% target on value landed by each type of activity, that is no more than 10% loss). This would ensure a better equitability of the conservation effort among métiers by applying a high penalty to scenarios inducing a larger loss than the one set by target for at least one type of activity.

These combined improvements should enhance our capacity to provide valuable diagnostics and advice regarding the effectiveness of MPA networks for management of mixed fisheries.

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