MSP Challenge 2050 food web review

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Contents

1. MSP Challenge 2050 food web review

1.1. Introduction

Jeroen Steenbeek of Ecopath International Initiative Research Organization (Barcelona, Spain) has been commissioned to review the implementation of the marine food web in Marine Spatial Planning (MSP) Challenge 2050. Jeroen is a core programmer of the Ecopath with Ecosim (EwE) food web model, and leads the technical committee of the Ecopath Research and Development Consortium.

The MSP Challenge 2050 serious game is being developed with the aim to provide maritime spatial planners the means to assess the environmental consequences of planning decisions in the marine and coastal ecosystem in space and time. The structure of the food web embedded in the MSP Challenge 2050 is a simplification of an EwE model of the North Sea (Mackinson and Daskalov, 2007), and model logic is loosely based on the Ecosim temporal model.

This review has been commissioned to answer four questions:

1. What are the advantages and disadvantages of the current food web model in the MSP Challenge 2050?
2. Is it correct that once the ecosystem in the food web model starts displaying a dropping trend, it is difficult to counter this trend? What could be done to fix this?
3. What type of (spatial) measures could enable players to benefit the ecosystem?
4. Other suggestions.

This review contains suggestions for modifications of the MSP Challenge 2050 software to mitigate problems. Please note that these suggestions, unless explicitly stated, aim to address structural computational issues without making the game more complex to play.

1.2. Resources

For this review the following resources were used:

- Deltares 2013 report “A conceptual pressure-response and a simple food web model for the Maritime Spatial Planning Challenge 2050 serious game”.
- Functionality and implementation of the food web model and its pressures were discussed in a personal interview with Vincent van de Pol (programmer) and Peter van Dranen (project leader) of Atlantis Games.

- The original Ecopath food web model parameterization (June 2013), provided by Deltares, which as a simplification of the original Mackinson and Daskalov North Sea model provided the foundation for values in the ecology-ecology matrix in the MSP challenge 2050.
- The October 2015 version of the source code of the MSP Challenge 2050 was consulted when needed, and was used to run and test the MSP Challenge 2050 game.
- An email from Bas van Nuland to Xander Keijser dated 27 February 2015 explains key choices and assumptions made when designing the game.
- An email from Wouter Gotje to Xander Keijser, dated 15 February 2015 discusses shortcomings of the food web model for addressing ecological issues.

1.3. Findings

Assessment of the food web model, and the pressures that impact it, has shown the following.

1.3.1. The current food web configuration

The foundation EwE food web model, which is a simplification of the Mackinson and Daskalov (2007), was executed in the version 6.4.4 of the Ecopath with Ecosim software. This model runs perfectly flat in Ecosim, showing that all functional groups and fishing effort are in balance. This is a good foundation for gameplay.

When executing the MSP Challenge 2050 without any anthropogenic pressures, the food web shows different trends from the foundation EwE model. Lower trophic level species (such as bivalves) show a slow but steady increase in biomass while some mid and higher trophic level species (cod, herring, seals and porpoises) show a slow but steady decline in biomass. It would have been expected that the MSP Challenge 2050 foodweb model would replicate the trends in the EwE food web model if all pressures are kept at initial level. The different trends can be attributed to differences in parameter values between the EwE model and the MSP food web model; the MSP food web model parameters were deliberately tweaked to make the food web more stable for game play.

When executing the MSP Challenge 2050, the food web model responds visibly to introduction to human stressors. When slightly perturbed, the food web model is measurably impacted but no species crash.

The ecology-ecology matrix and ecology computations show that the MSP food web model uses fixed predation ratios, which do not vary with changes in predator and prey abundances. This makes the food web rigid and prone to continuing negative trends and oscillations in predator-prey biomasses. Diet rigidity does not conform to reality, where predators vary prey consumption rates in response to changes in prey abundance.

The ecology-ecology matrix and ecology computations show that the MSP food web uses fixed growth and recruitment rates which do not conform to reality, where animals may translate changes in feeding rate into changes in reproductive rather than growth rates, or they may translate changes in food availability into changes in foraging time that in turn affects predation risk (Walters et al., 2000): stressed animal populations contain smaller individuals that spawn at earlier ages, while abundant populations reserve energy for growth.

The ecology computations show that MSP food web model is only in part spatially explicit. Biomasses of different species are allocated to spatially explicit polygons that cover the MSP game area. Species interactions and anthropogenic pressures are applied to these biomasses within each polygon. However, the MSP game then reallocates the biomasses across the various polygons using a single environmental suitability index as weighting factor, without considering factors that limit species movability and species behaviour. Although species interactions and pressures are applied with spatial location in mind, species distributions and movement are not spatially explicit. During the game design phase the MSP development team decided to sacrifice food web realism for quick play feedback, but various simplifications have consequences for the ability of the food web to address spatial questions:

- Human pressures (excluding fishing) are applied to the entire biomass pool of species in the spatial polygon in which the pressure originates. This is likely to overestimate the impact of a pressure, because the pressure impacts all species in the polygon, regardless of spatial proximity of to the pressure.

- After anthropogenic pressures have been applied to ecology, and ecological food web effects have been computed, resulting biomasses are distributed across the MSP game area using a simple weighting system as described in Stolte et al. (2013). This redistribution ignores important ecological traits such as species movement rates and behavioural aspects of species interactions.

- The Ecology layers in the MSP user interface allegedly represent species biomass distributions across a grid of cells. These layers do not visually respond to biomass variations and distributions.

1.3.2. Non-fishing pressures

Human constructions lead to pressures on the ecosystem. Although pressures are entered at spatially explicit locations, their impact is applied as mortality multiplier to the entire biomass of targeted species as described in Stolte et al. (2013). Species are known to relocate away from pressures to more suitable areas with less mortality and more prey (Christensen et al., 2014), but as the current food web model is not applied with a spatial dimension, this response cannot be represented in the current version of the MSP Challenge software.

In addition, human pressures may cause other changes in marine species populations aside from a higher mortality, such as changes in behavioural or feeding parameters. These changes are not considered in the current version of the model.

1.3.3. Fishing pressure

The MSP game offers input controls to enable or disable fishing pressure layers, but variations in these inputs does not vary the impact on the food web. Instead, fishing effort is implemented as a fixed and constant mortality term in the ecology – ecology matrix irrespective of player inputs. Fishing can therefore not be varied or disabled by the player as a game control.

Fishing does not have a spatial component as the food web that fishing operates on is non-spatial.

The fishing effort function maps that are displayed in the MSP user interface do not change in response to biomass changes in the food web. The content of these layers is static, and they communicate fishing effort distributions that do not exist since fishing has no spatial distribution.

1.3.4. Marine protection

Marine Protected Areas (MPAs) are established – at least in part – to protect marine habitats for conservation considerations. In ecological models MPAs are typically placed only to limit local fishing efforts. The MSP Challenge 2050 adds an extra dimension to prevent construction in MPA areas thus protecting marine habitat. However, the current structure of the MSP software is unable to enforce fishing limitatations within MPAs, because fishing is implemented as a fixed mortality rate in the ecology – ecology calculations, and this fixed mortality rate is unaffected by the enabled/disabled state of MPAs.

In addition, the effects of protecting habitat are not realistically captured. The MSP software does not connect local species biomasses to local habitats and local protection measures, while marine protection measures can only be computationally represented if all three factors are considered at local scales (Walters et al., 1999).

1.3.5. Validation

The MSP food web model is deeply integrated within the MSP Challenge 2050 software, and cannot be validated independently from the MSP software against the foundation EwE model. This makes it hard to test and validate the behaviour of the MSP food web.

2. The four questions

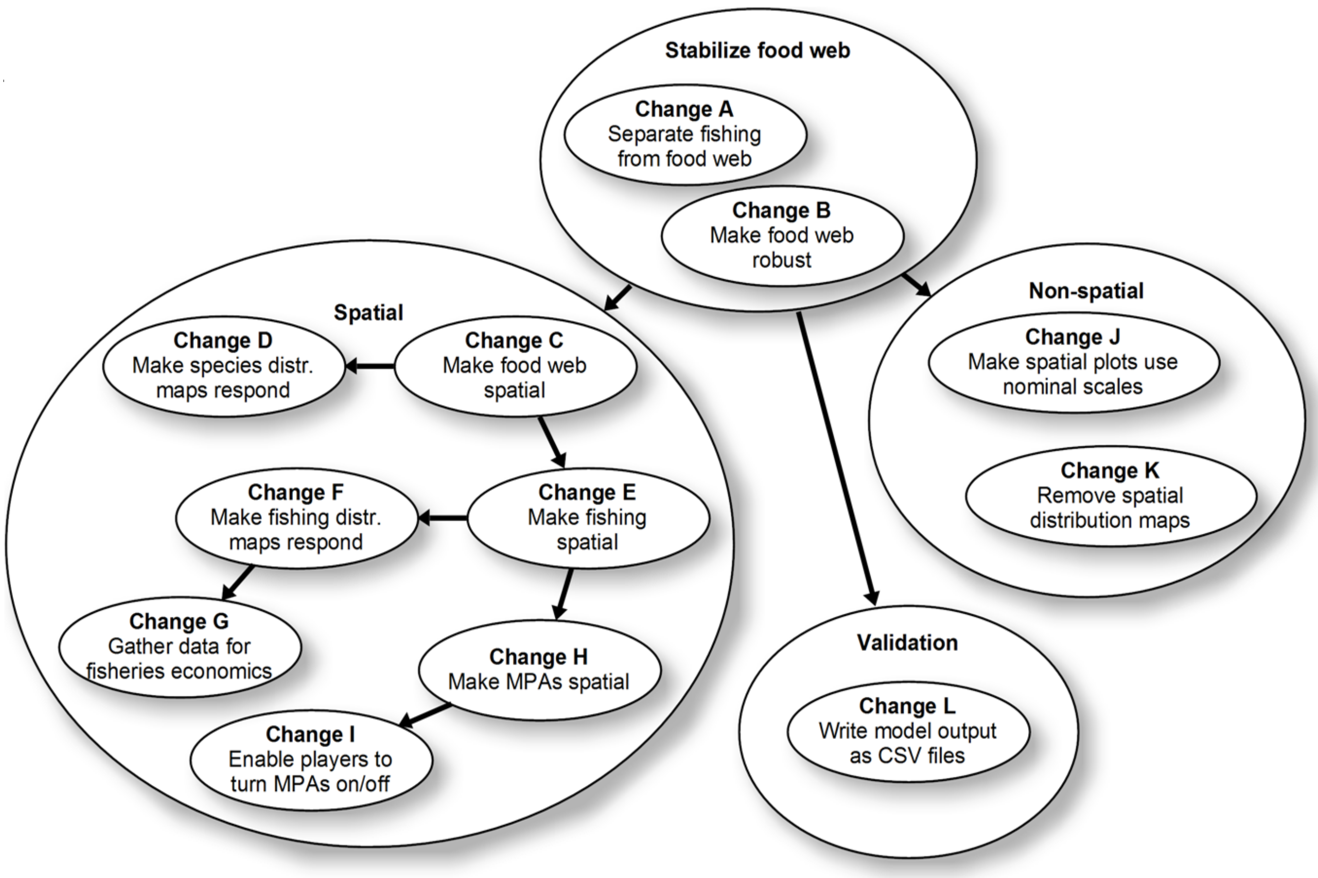
1. What are the advantages and disadvantages of the current food web model in the MSP Challenge 2050?

2. Is it correct that once the ecosystem in the food web model starts displaying a dropping trend, it is difficult to counter this trend? What could be done to fix this?

3. What type of (spatial) measures could enable players to benefit the ecosystem?

4. Other suggestions.

Developments suggested in this section are presented in figure Figure.



1.1. Advantages and disadvantages

1.1.1. Advantages

The food web is responsive to increasing and decreasing pressures, and does not crash when lightly perturbed. Since food web effects and pressures are applied to the food web as a whole regardless of spatial location, impacts are felt immediately throughout the MSP area, which benefits quick and simple gameplay.

The current implementation of the food web shows is a powerful prototype that has successfully demonstrated that the MSP Challenge 2050 approach is feasible, and that a dynamic food web can actually be integrated into a complex multi-player management. The MSP serious game can be expected to attract great interest among the scientific community, policy makers, and the general public.

1.1.2. Disadvantages

One major disadvantage of the food web in its current form is the rigidity in diet assumptions, where predation patterns do not vary in response to variations in predator and prey abundances. This makes the food web prone to unstoppable negative trends and runaway predator–prey biomass oscillations that are unrealistic and hard to counter. Unlike Ecosim, the temporal module of EwE (Ahrens et al., 2012; Christensen and Walters, 2004), the food web model implemented in the MSP software assumes linear predation relationships between present predator and available prey, which disregards crucial species behaviour and produces results that are too unrealistic even for the simplified game play purposes of the MSP Challenge 2050. This should be addressed to make the food web more robust and realistic (and its results more credible) even for simple game play purposes.

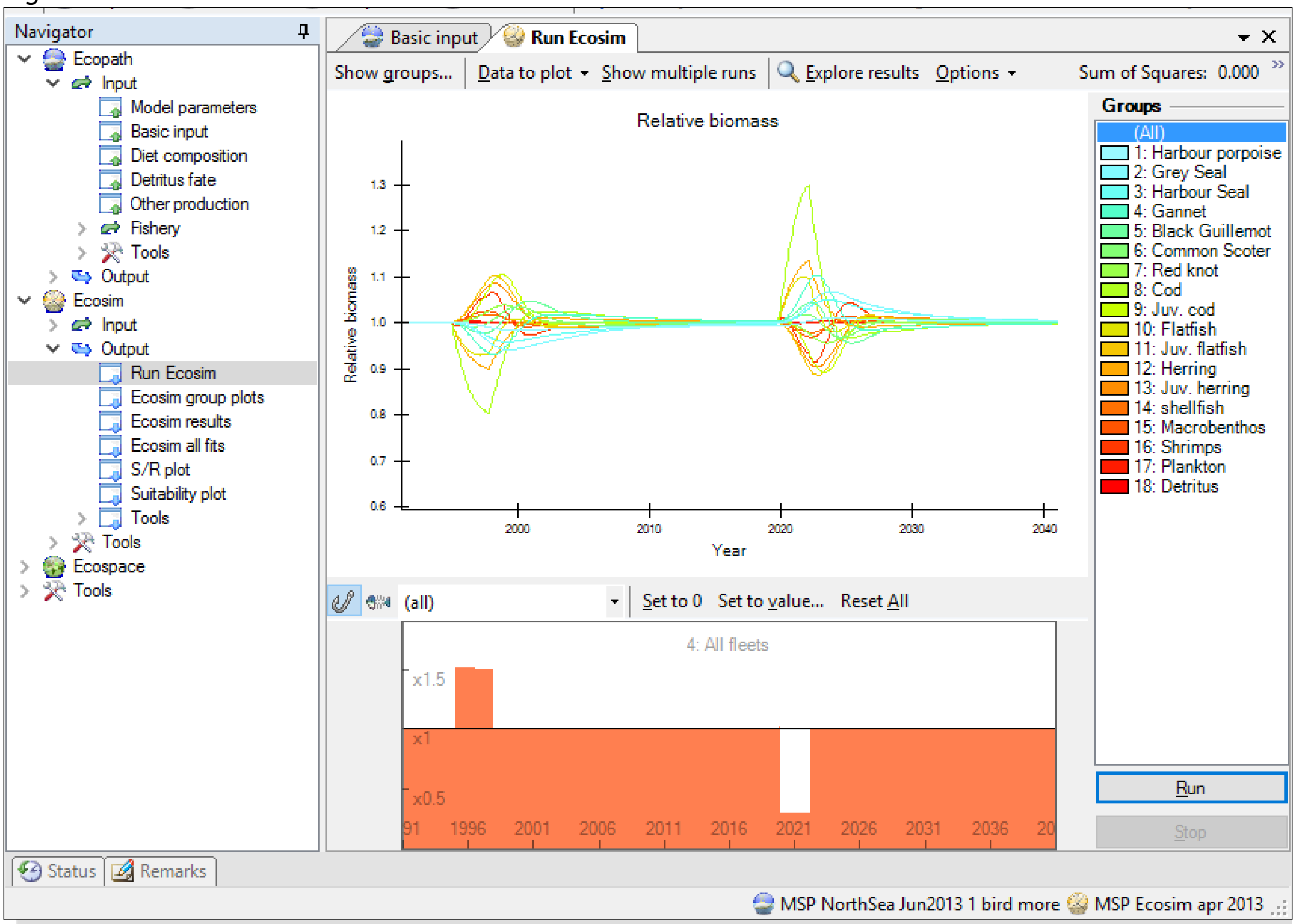
Secondly, the model does not include density-dependent responses in species populations, which stunts growth and recruitment (reproduction) more than needed. This may make the food web recover more slowly from perturbation as is witnessed in reality.

Third, fishing mortality is tightly integrated within the food web calculations, players do not have the ability to exert control over fishing. This eliminates players to use the most direct control measure when trying to restore fish populations.

The fourth disadvantage is that current food web model cannot be reliably used to address spatial questions. The model does have a spatial dimension, considering food web effects and affecting pressures in regional contexts, but does not consider species-specific movements, behaviours and environmental preferences when distributing species biomasses across the game area. Although this simplification results in quick cause-and-effect feedback in the game view, it does not provide realistic ecological responses to spatial measures, and makes the current implementation of the food web model unsuitable for policy advise.

1.2. Negative trends in the ecosystem

Figure



2: The foundation EwE model as executed in Ecosim, the temporal module of EwE, showing stabile

The EwE model that was developed for the MSP Challenge 2050 as a simplification of Mackinson and Daskalov (2007) runs perfectly flat in the EwE software; with constant fishing effort the Ecosim module shows a food web model that is in perfect balance. When perturbed through brief periods of increased or decreased fishing, the food web model stabilizes itself within a few years (Figure).

Scrutinizing the MSP implementation of this food web model shows that it is prone to negative trends that can be difficult to counter by player measures. The negative trends can be attributed to three main causes: (i) fishing mortality is fixed and cannot be disabled by the player to alleviate the ecosystem; (ii) the food web is structurally unstable due to (a) diet rigidity in the food web diet matrix that makes the food web structurally prone to extinctions, and (b) missing density-dependent responses make the food web less able to recover from perturbations; and (iii) all anthropogenic pressures increase species mortality, while in reality species are likely to move away from pressures and/or change behaviour.

The MSP Challenge 2050 software needs structural modifications to address these issues.

Change A) Separating fishing from the food web in order to enable players to control fishing should be relatively easy to address. Players can already show and hide the statistical maps where fishing occurs (#14 to 18), but players do not have the means to allow or stop fishing of a specific fishing gear type to allow the ecosystem to recover.

This would require an extra input which adds to the complexity of playing the game. If the fixed fishing mortality ratios in the ecology-ecology matrix are turned into conditional mortality ratio (conditional to whether specific fishing effort is enabled or disabled), players will notice immediate impacts of their fishing decisions onto the food-web.

Change B) In order to make the food web more robust to perturbations two sub-changes are needed.

i. Introducing resilience in the diet relations in response to varying predator and prey biomasses the MSP software will have to be extended to estimate predator – prey diet ratios each time prior to calculating the ecology – ecology impact matrix. A solution could be based on the implementation of Ecosim, the temporal model of the EwE approach (Christensen and Walters, 2004), which also includes the foraging arena[1] (Ahrens et al., 2012) that enables to take into account behavioural parameters to limit predator mortality on preys (otherwise linearly based on the biomass of predators and prey).

ii. Introducing density-dependent behaviour will enable species in the food web to respond to changing abundance by investing energy in either growth or recruitment. This behaviour should replace the fixed growth and recruitment factors in the MSP food web ecology matrix. Food web models that fail to represent this feature tend to produce unrealistic results (Walters et al., 2000).

Change C) Giving species the opportunity to move away from pressures instead of increasing mortality and moving to more suitable areas where is more prey will be a major undertaking, but will greatly enhance the credibility of the MSP Challenge 2050 software. For this, the MSP food web will need to become spatially explicit: species will have to be distributed across a

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1. The foraging arena theory argues that predation interactions between predator and prey are not a linear function of biomasses of predator and prey, but are severely restricted by species behaviour that limits the amount of prey that is availabile to predators.

grid of cells, where species movement is directed towards better living conditions (better eating, less predation, and less pressure) and will be limited by species dispersal rates and other behavioural parameters. Each cell contains unique biomasses of the food web species, and food web dynamics will play out within each cell in addition to species movement to capture local variation. For the methodology to distribute species MSP programmers are advised to borrow ideas from species niche modelling and food web dynamics of the habitat capacity modelling approach in Ecospace (e.g., Christensen et al., 2014).

Change D) Species distribution maps that are now static and disconnected from the functioning of the game will be connected to the new spatially explicit food web, and will display realistic biomass distributions as computed by the game. Through realistic biomass distribution maps, MSP players can for instance identify biodiversity hotspots that are candidates for marine protection measures.

1.3. (Spatial) player measures to benefit the ecosystem

A few measures to benefit the ecosystem are suggested. Spatial measures cannot be implemented unless change C – a spatially explicit food web – is realized. With a spatially explicit food web, local measures such as marine protection and spatially distributed fishing can offer greater player control onto a food web that responds with greater realism.

1.3.1. Spatial fishing

With a spatial food web in place fishing must follow suit to provide more credible model output. However, it is also imperative that fishing changes from a static input to a relatively simple rule-based model output that tries effort to fish where the fish are, where fishing is allowed, and where fishing is more profitable.

Making fishing spatially explicit requires the following changes:

Change E) Remove Fishing effort as a fixed mortality factor in the ecology – ecology computations. Instead, fishing effort becomes a factor per cell, per fishing function, per target species that is distributed by a fishing gravity model that will need developing. This fishing gravity model considers cost factors such as distance from port and fishing limitations (shipping, obstructions, regulations) and benefit factors such as biomass of targeted species). This distribution then leads to a unique amount of fishing effort per fishing function per cell, which then is used to calculate the local fishing mortality per cell.

Change F) The fishing effort maps currently displayed in the interface reflect historical fishing effort to help players make educated decisions regarding marine protection. However, these maps are static and do not change to reflect newly computed fishing effort in the game. The player thus does not know if and how fishing effort distributions are changing in response to game dynamics. The fishing effort maps should be updated to reflect the actual distribution and intensity of effort, per grid cell, per time step to provide continuous useful information to the player.

Change G) The amounts of biomass caught per cell, per fishing function, and per country is summarized as a foundation for future socio-economic analysis.

1.3.2. Marine protection

When Change D is implemented, only then can marine protection functions be made to behave as would be expected:

Change H) With changes C (a spatial food web) and E (a spatially explicit fishing model) in place, Marine protected areas will have to be allocated to the same grid of cells, imposing fishing limitations to specific fishing functions and fished species for every cell that an MPA overlaps with. This will give targeted species a reprieve of fishing pressure in these cells, and players will see species biomasses recover. If Change D (accurate feedback of species biomass distributions) is implemented players will be able to locate biological hotspots for protecting fished species.

Change I) Players can already turn marine protected functions layers on or off, which currently do not impact fishing and thus do not have an effect on the food web. The MSP code needs adjusting to create this connection: enabling a protection function layer imposes fishing limitations in protected areas drawn for that function layer; disabling the function layer lifts those fishing limitations.

1.4. Other recommendations

1.4.1. Ambiguity in the user interface

If the current structure of the food web model is to be retained, e.g. if changes C – I are not going to be made, it is recommend that the spatial outputs of the game are simplified to reduce inaccuracy. These outputs currently reflect absolute numbers that are based on the too simplified methodology of the food web model, and can confuse game players interested in addressing ecological questions:

Change J) The ‘biomass in EEZ’ graphs reflect spatial assumptions that the game is unable to realistically produce. These plots could be changed to show values on nominal scales (less to more, or low to high) instead of displaying absolute numbers to communicate a measure of change without conveying inaccurate details, but the plots could also be removed from the game.

Change K) Maps that imply distributions of fishing effort and species biomasses should be removed from the game since the game does not use these data as input, and cannot produce these data as output.

1.4.2. Validation

If Change B – adding robustness to the food web – is implemented, the model should be respond more realistically to changing pressures. However, the MSP food web is deeply integrated within the MSP software, and food web assumptions cannot be validated outside the MSP software. It is recommended that the MSP server is slightly modified to deliver this validation data:

Change L) It should be possible to validate the behaviour of the food web model and compare its outputs to other models such as Ecosim, independently of the MSP software and its complex interactions. One suggestion would be to make the MSP game server write CSV files of biomass per species over time as the game progresses, which is a relatively simple change to make to the MSP source code.

1.4.3. Habitat degradation and restoration

Anthropological activities can disturb the seabed, changing living conditions favourably to some, and unfavourable to others. Habitat restoration is a well-used measure for trying to restore declining fish populations (e.g., Limburg and Waldman, 2009; Seaman, 2007)

If a spatial food web is implemented (Change C), the MSP Challenge 2050 system could be extended with a dynamic habitat preferences model or *niche model* (Christensen et al., 2014). Niche modeling requires habitats and species preferences of different types of habitats to introduce variability in living conditions across a modelled area. Spatial variability of living conditions will produce more realistic species distributions. With a niche model in place, players could be given the possibility to degrade or restore habitats to affect the marine food web.

Change M) To introduce habitats, species responses to habitats, and the means to vary habitat, the MSP Challenge software needs to be extended with the following:

i. Add spatial layers of habitat types (e.g., sand, rocks, mud, seagrass, etc), each describing what ratio [0, 1] of a cell contains a given habitat type per cell. These habitat layers must also be displayed in the interface. A statistical map of substrate already exists in the MSP game as a polygon data layer, and its content will need to become available as a raster layer per habitat type to the spatial model..

ii. Add response preferences of individual species to each type of habitat. In ecological modelling, such preferences are often implemented via so-called functional response curves, which describes using a mathematical curve to describe the lower, optimum and upper tolerance of a type of habitat by a given species (Christensen et al., 2014). Extensive laboratory experiments, field work and statistical analysis yielded freely accessible libraries of functional response curves (such as Aquamaps, http://aquamaps.org) that could be used to drive an MSP niche model.

iii. Add a mechanism that performs a per-cell, per-species evaluation of the total suitability of a cell, which is the product of the responses of species to individual habitat types. This suitability can be made to affect the ability of species to feed in a cell, where optimal suitability represents optimal feeding conditions. Changing conditions will triggering species starvation and/or movement to better conditions.

iv. Add player input controls to change the habitat composition of cells. One could for instance think of placing rocks in a cell, planting seagrass, or even changing the depth of an area. In addition, fishing activities such as trawling could be made to erode certain types of habitats.

With habitat suitability modelled, players can now obtain the possibility to restore habitats within the EEZ of their country. For inspiration about habitat suitability modelling, MSP developers could refer to the implementation of the Habitat Foraging Capacity Model in Ecospace (Christensen et al., 2014).

1.4.4. Climate change

If the MSP challenge is to be applied to management advise it should be able to capture the effects of climate change on species distributions (Beniston et al., 2007). The plaice box provides a clear example of this need: in order to protect juvenile plaice an MPA was established in shallow waters to ban fishing, but changing temperatures moved the juvenile plaice to deeper waters out of the protected area and into fishing nets (e.g., Rijnsdorp et al., 2009).

Change N) Relying on the changes proposed in Change M), the MSP Challenge 2050, could be extended with climatology and species' responses to climatological variability:

i. Add spatial distribution layers of relevant climatological drivers such as sea surface temperature, bottom temperature, etc,

ii. Add a functional response curve to each driver for each species that is affected by a driver.

iii. Include the driver layers and response functions into the habitat suitability considerations as suggested in Change M).

iv. Add the ability to vary the content of climatological data layers from external data series, obtained from climatological prediction models.

With this system in place, the climatological data layers can be made time-varying to simulate the effects of climate change on species distributions, fisheries, and the ecosystem services derived from the sea. Several data repositories offer projects of climatological parameters such as EMIS (JRC, 2011).

1.4.5. Nutrients

Variation in available nutrients are projected to greatly impact the state of the future North Sea ecosystem (Beniston et al., 2007), and many climate studies are devoted to predict possible future nutrient distribution patterns (e.g., JRC, 2011). It may be interesting for management purposes if the MSP software were able to integrate these predictions.

Change O) The MSP food web already contains the functional group 'Plankton' that represents the influx of nutrients into the web. Overwriting the content of this plankton layer with climatological predictions requires, beside a spatially explicit food web (Change C), addition of the following:

i. Creation of libraries of primary productivity maps, obtained from climatological models such as EMIS (JRC, 2011), in a format that can be easily read by the MSP challenge food web code.

ii. A system that reads a primary productivity map for a given MSP game time step, and overwrites the content of the 'Plankton' layer in the MSP food web.

1.4.6. Improved fisheries management

The MSP Challenge 2050 could be improved to address policy issues such as implemented under the Common Fisheries Policy Reform of the European Union (European Commission, 2015).

Change P) Adding more detailed fisheries management could be implemented with several levels of complexity:

i. Allow MSP players to enable and disable specific marine protected areas instead of all marine protected areas at once

ii. Allow MSP players to enable control which months of the year specific MPAs are closed for fishing

iii. Allow MSP players to set fishing quotas

iv. Allow fishing quotas to be driven by national or European policy decisions

These options will add realism useful for addressing policy, but will make the MSP Challenge 2050 significantly harder to play.

For inspiration how policy could be implemented, MSP developers are advised to refer to Marine Protection and the EwE Management Strategy Evaluation (MSE) routines implementations in the Ecopath with Ecosim software.

1.4.7. Fish restocking

Players could be given the means to inject fish biomass in specific locations as a restoration measure. This suggestion is not translated to code changes at this point.

1.4.8. Pollution

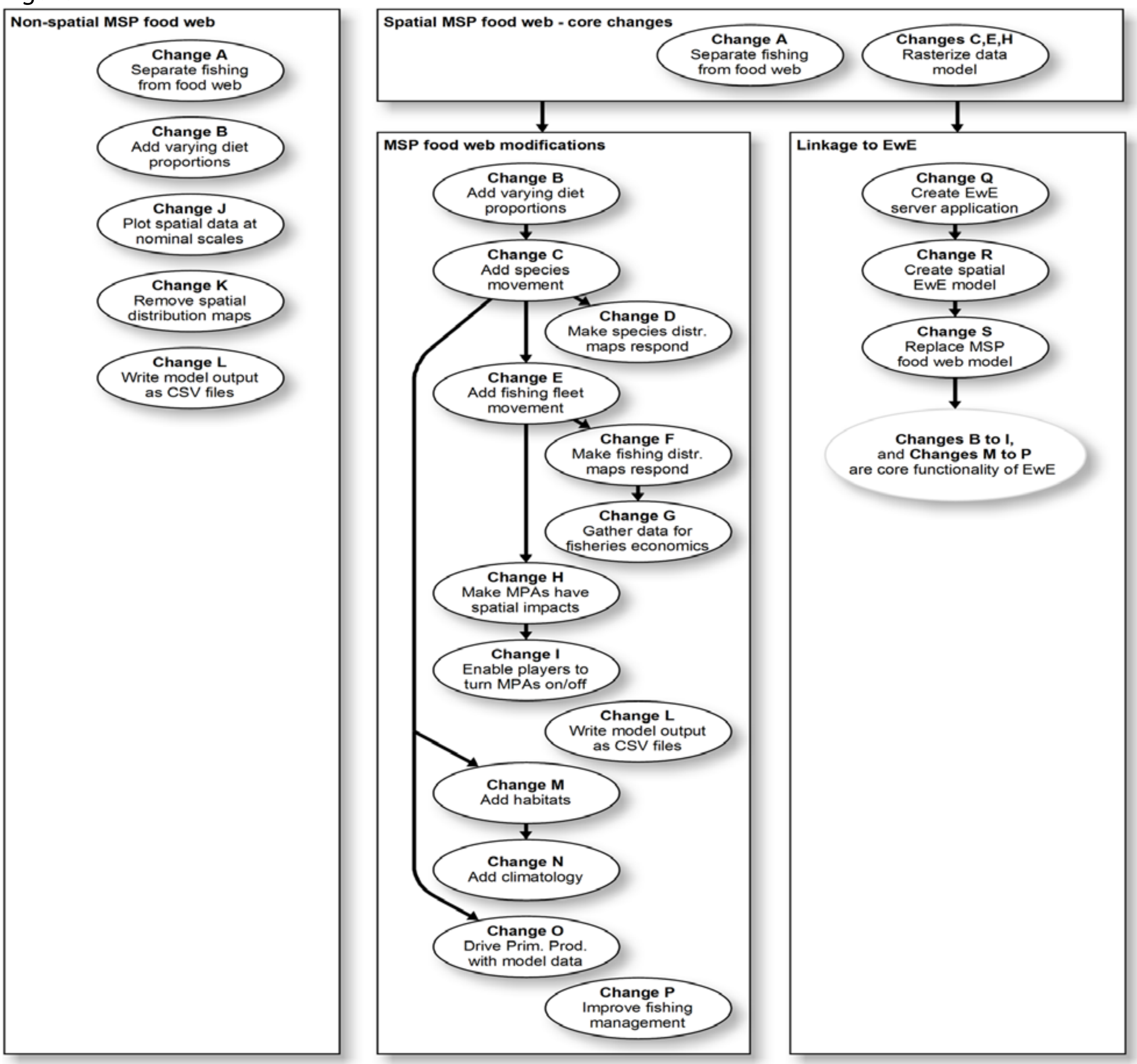
An extra effect that could be added to the MSP Challenge 2050 would be function-created pollution, which through species mortality and habitat degradation adds another level of realism (and complexity) to the game. The MSP challenge software already contains a 'Contaimants' layer that could be made time varying and could be made to impact the food web model. Pollution could increase via user-added polluters, and a simple dispersal model could distribute pollution cross the North Sea based on currents and tide movements. Last, the pollution needs to be made to impact the food web.

At this point this suggestion is not translated into code changes.

2. Development options

The food web currently embedded in the MSP software has successfully demonstrated that an actual food web model can be integrated into a multi-player game. This can be consideres a significant feat

Figure



3: Proposed changes for the three code paths: a non-spatial MSP, a spatial MSP with embedded food web model, and a spatial MSP linked to the EwE software

that offers prospects for management advice, generating public awareness, etc.

However, as indicated above, the MSP food web model is not stable enough for game play purposes. Depending on intended use, three development paths can be foreseen to remedy shortcomings as depicted in Figure.

2.1. A stable food web without explicit spatial capabilities

If the MSP challenge 2050 is meant to serve as a public awareness tool, where quick game feedback is required and spatial realism is not a priority, then changes B, J, K and L should be implemented to provide player interaction with a stable food web, with simple fishing control, and (spatial) outputs that cannot be misinterpreted.

2.2. A stable food web with explicit spatial capabilities

If the MSP challenge 2050 is meant to serve as a policy awareness tool with a food web model that responds intuitively to spatial measures by providing spatially explicit outputs, then changes A to I, and L should be implemented. This provides players with intuitive spatial responses to measures that may not be scientifically accurate, but provide some measure as to how the ecosystem and fishing may respond. Atlantis Games has provided a rough estimate for the implementation of this path (Appendix A).

2.3. A stable spatial food web, validated by the scientific community

If the MSP challenge 2050 is meant to serve as a scientifically robust tool with a spatial food web model that is validated by the scientific community, it probably makes most sense that the MSP food web is replaced by a bi-directional link to Ecospace, the spatial-temporal module of the EwE food web model (Christensen et al., 2014; Walters et al., 1999).

In order to implement this path, change A will need to be implemented, and the part of changes C, E and H that concerns rasterizing the data model for the MSP food web, fishing and marine protection. Besides the MSP changes estimated by Atlantis Games (Appendix A), developments that need to take place at the EwE model end are:

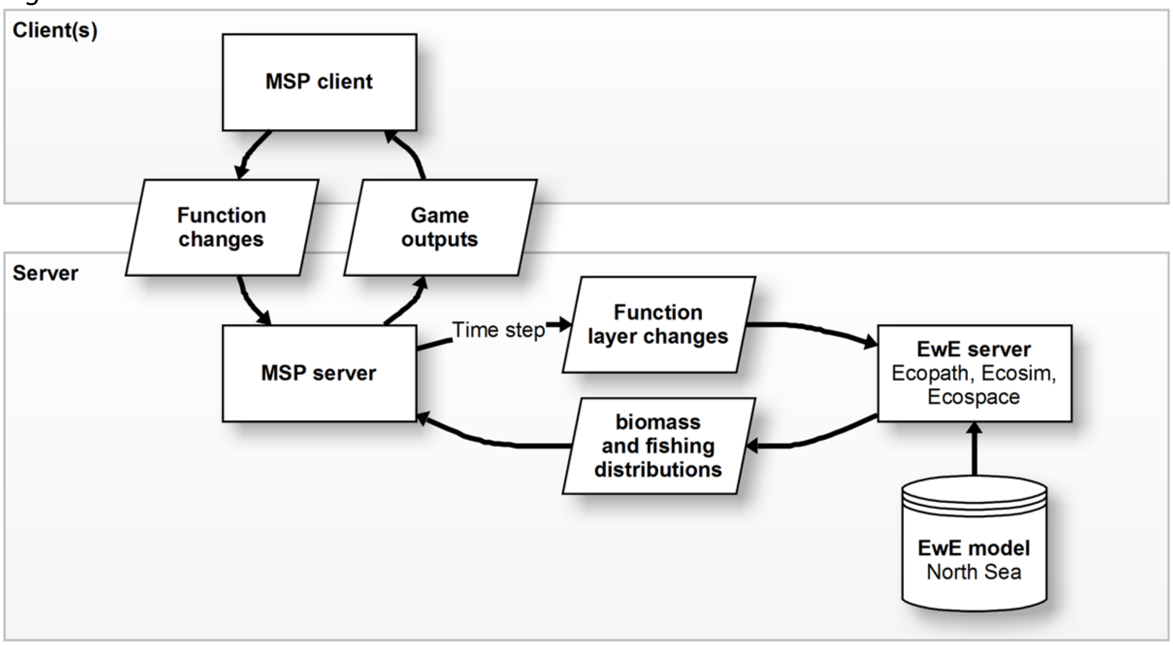
Change Q) Write a server application that hosts the EwE model on the MSP game server, and make this application communicate with the MSP game server via sockets. The EwE server application hosts the EwE model, receives function layers from the MSP game, runs an Ecospace time step when the MSP game requests this, and communicates Ecospace estimates back to the MSP server

Change R) The MSP game must use an explicitly spatial EwE model. With a linkage to the EwE software, this model could very well be the newest instalment of the North Sea model that has been validated by the scientific community, and has been accepted as a key run by ICES (the International Council for the Exploration of the Seas). MSP function layers will need to be added to the EwE model, and species responses to these function layers will need to be defined.

Change S) The existing food web model in the MSP software needs to be replaced with the link to the EwE server.

The linkage between the MSP client, MSP game server, and the EwE software is shown in Figure.

Figure



4: A schematic overview of the linkage between the MSP client(s), MSP server and the

2.3.1. Feasibility

The Ecospace model is scientifically compatible with the MSP game. The MSP food web is based on a EwE model, and Ecospace can directly represent the impact of MSP function layers via its Habitat Foraging Capacity model (Christensen et al., 2014) and on fishing effort. In turn, Ecospace can provide distributions of fishing effort and species biomasses back to the MSP game.

The Ecospace model is technically compatible with the MSP game. The MSP game is written in Python, which can directly communicate with the EwE software that is written in Microsoft.NET. Atlantis Games and the EwE development team both have experience connecting these two programming languages (Steenbeek et al., 2015).

The Ecospace model executes fast enough for uninterrupted game play. With a fully populated Habitat Capacity Model, the Ecospace model will need less than a second to compute a single time step. Time steps in Ecospace are typically months, which can provide the MSP food web with faster response to player measures than the current annual food web evaluations in the MSP game.

The Ecospace model provides a host of features that are needed if the MSP Challenge 2050 software is to be used for policy advise. The computational aspects for changes B to I, and changes M to P, are already implemented in the EwE software and can be connected to the MSP software when needed.

Perhaps most relevant contribution that EwE brings to the MSP challenge 2050 is scientific credibility: the EwE approach is the most widely used food web model in the world with over 400 peer-reviewed publications, and more than 7000 users world-wide (Coll et al., 2015; Colléter et al., 2015). The North Sea model that the MSP Challenge was based on is currently being refitted in Ecosim, and made spatial in Ecospace, by Steve Mackinson for a major project that spatial management advise (Rose et al., 2009). In addition, the Ecosim North Sea model has been recently revised by the ICES WGSAM (ICES Working Group on Multispecies Assessment Methods (WGSAM, http://www.ices.dk/community/groups/Pages/WGSAM.aspx). A first key run was accepted in 2013 (Howell et al., 2013) which is now used to evaluate EU Commission proposals for multi-annual plans in the North Sea (STECF, 2015). A future version of the MSP game could run this same model – or a simplification thereof– and benefit from its wide acceptance in the international policy arena. Steve Mackinson has expressed interest in providing assistance to that process.

Last, the EwE software can deliver a suite of ecological indicators for predicting and understanding the impact of man-made and climate-driven changes in the environment (Piroddi et al., 2015) to provide information about indicators outlined in the Marine Strategy Framework Directive. Future versions of the MSP challenge 2050 software could integrate and display such indicators.

2.3.2. Estimates

In addition to the estimates provided by Atlantis Games (Appendix A), the Ecopath Research and Development Consortium will need the following time to connect an Ecospace model to the MSP software:

- Writing the EwE server application, connecting the EwE server and MSP server, and implementing the data exchange framework: 10 days
- Adjusting the North Sea model to the species resolution required for the MSP Challenge 2050, validation this model against the ICES key run, and providing general food web modelling advice (including involvement of Steve Mackinson): 15 days
- Adjusting the North Sea model to include the function layers of the MSP game, and defining species responses to these function layers in the EwE model: 10 days.

2.3.3. A note about structural negative trends in EwE

The issue was raised whether the EwE approach itself is prone to negative trends in ecosystem dynamics.

The Ecosim model of the EwE software is a robust dynamic food web model (Christensen and Walters, 2004; Walters et al., 2000). If the underlying Ecopath conditions are not changed, the Ecosim model provides stable estimates over time. This is also the case for the EwE food web model designed for the MSP Challenge 2050, which runs stable when not perturbed (Figure).

However, the EwE approach offers ecosystem modellers complete freedom to structure and parametrize their food web. If a EwE food web model runs unstable or displays negative trends, it is due to model structure and parametrization, not due to the limitations in the capabilities of the EwE approach itself.

3. Summary

The MSP Challenge 2050 serious game is a very clever – and perhaps the very first – example how a food web model can be integrated into a multi-player planning tool. This review was commissioned to assess the food web model in the MSP software and to suggest improvements.

The MSP serious game is constructed with the aim to provide maritime spatial planners the means to assess the environmental consequences of planning decisions in the marine and coastal ecosystem in space and time. The computational model of the MSP food web model is based on the Ecopath with Ecosim (EwE) food web modelling approach. For quick game play feedback, the initial game designers decided to simplify the food web model. These simplifications have made the food web model not usable for its intended purposes, because it lacks fundamental features to capture essential ecological processes and lacks resilience, and provides spatial estimates that it cannot compute, thus not fulfilling its main aim.

Model shortcomings are identified in this review, and conceptual changes are suggested in the form of three possible mitigation strategies: (i) make the food web model robust and soften explicit spatial outputs; (ii) make the integrated MSP food web model robust and function explicitly over space and time; and (iii) replace the integrated MSP food web model with a linkage to the EwE software.

Atlantis Games has provided estimates for the majority of the changes outlined in this report with regards to changing the MSP software. Additional estimates have been provided by Jeroen Steenbeek for EwE-related extra work to make the MSP software connect to the actual EwE food web model and develop a full validation of the MSP food web model comparing it against a key run of the Ecospace North Sea model validated by the scientific community.

4. References

Ahrens, R.N.M., Walters, C.J., and Christensen, V. (2012). Foraging arena theory. Fish Fish. *13*, 41–59.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., et al. (2007). Future extreme events in European climate: an exploration of regional climate model projections. Clim. Change *81*, 71–95.

Christensen, V., and Walters, C.J. (2004). Ecopath with Ecosim: methods, capabilities and limitations. Ecol. Model. *172*, 109–139.

Christensen, V., Coll, M., Steenbeek, J., Buszowski, J., Chagaris, D., and Walters, C.J. (2014). Representing variable habitat quality in a spatial food web model. Ecosystems *17*, 1397–1412.

Coll, M., Akoglu, E., Arreguín-Sánchez, F., Fulton, E.A., Gascuel, D., Heymans, J.J., Libralato, S., Mackinson, S., Palomera, I., Piroddi, C., et al. (2015). Modelling dynamic ecosystems: venturing beyond boundaries with the Ecopath approach. Rev. Fish Biol. Fish. *25*, 413–424.

Colléter, M., Valls, A., Guitton, J., Gascuel, D., Pauly, D., and Christensen, V. (2015). Global overview of the applications of the Ecopath with Ecosim modeling approach using the EcoBase models repository. Ecol. Model. *302*, 42–53.

Howell, D., Kempf, A., Mackinson, S., Rindorf, A., Belgrano, A., Filin, A., Thorpe, R., Andonegi, E., Tomczak, M., Lundy, M., et al. (2013). Interim Report of the Working Group on Multispecies Assessment Methods (WGSAM): 21-25 October 2013, Stockholm, Sweden (International Council for the Exploration of the Sea).

JRC (2011). EMIS - Environmental Marine Information System.

Limburg, K.E., and Waldman, J.R. (2009). Dramatic declines in North Atlantic diadromous fishes. BioScience *59*, 955–965.

Mackinson, S., and Daskalov, G. (2007). An ecosystem model of the North Sea to support an ecosystem approach to fisheries management: description and parameterisation. Cefas Sci. Ser. Tech. Rep. *142*, 195.

Piroddi, C., Teixeira, H., Lynam, C.P., Smith, C., Alvarez, M.C., Mazik, K., Andonegi, E., Churilova, T., Tedesco, L., Chifflet, M., et al. (2015). Using ecological models to assess ecosystem status in support of the European Marine Strategy Framework Directive. Ecol. Indic. *58*, 175–191.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Möllmann, C., and Pinnegar, J.K. (2009). Resolving the effect of climate change on fish populations. ICES J. Mar. Sci. J. Cons. fsp056.

Rose, K., Mackinson, S., Deas, B., Beveridge, D., and Casey, J. (2009). Mixed-fishery or ecosystem conundrum? Multispecies considerations inform thinking on long-term management of North Sea demersal stocks. Can. J. Fish. Aquat. Sci. *66*, 1107–1129.

Seaman, W. (2007). Artificial habitats and the restoration of degraded marine ecosystems and fisheries. In Biodiversity in Enclosed Seas and Artificial Marine Habitats, (Springer), pp. 143–155.

STECF (2015). Multiannual Management Plans (North Sea), working group 16-20th March 2015 (Ispra, Italy).

Steenbeek, J., Buszowski, J., Christensen, V., Akoglu, E., Aydin, K., Ellis, N., Felinto, D., Guitton, J., Lucey, S., Kearney, K., et al. (2015). Ecopath with Ecosim as a model-building toolbox: Source code capabilities, extensions, and variations. Ecol. Model.

Stolte, W., Keijser, X., de Kluijver, A., and Nolte, A.J. (2013). A conceptual pressure-response and a simple foodweb model for the Maritime Spatial Planning Challenge 2050 serious game.

Walters, C., Pauly, D., Christensen, V., and Kitchell, J.F. (2000). Representing Density Dependent Consequences of Life History Strategies in Aquatic Ecosystems: EcoSim II. Ecosystems *3*, 70–83.

Walters, C.J., Pauly, D., and Christensen, V. (1999). Ecospace: Prediction of Mesoscale Spatial Patterns in Trophic Relationships of Exploited Ecosystems, with Emphasis on the Impacts of Marine Protected Areas. Ecosystems *2*, 539–554.

Appendix A. Estimates Atlantis Games

Please note that the estimates presented below (in Dutch) are solely based on material that emerged in the personal interview. This interview was conducted early in the review process. As such, the estimates below do not cover many changes recommended in this review. For instance, the shortcomings leading to Change B (stabilizing the food web) had not been identified when Atlantis Games provided their estimates.

Grove schatting om MSP rekenmodel te laten lijken op Ecopath

Stappen die sowieso genomen moeten worden: (40 dagen)

Op het moment is het huidige rekenmodel onoverzichtelijk en vaak nog te onstabiel of juist weer te stabiel waarbij veranderingen soms geen feedback genereren. Dit komt vooral omdat er verschillende soorten ruimtelijke data gebruikt word. Er zijn polygonen, lijnen, punten en rasters. Deze geven uiteindelijk extreem grote verschillen tot hoeveel oppervlakte de ene laag overlapt met een andere laag. De regels zijn vervolgens daar op gebaseerd en zijn soms zo extreem (omdat een punt, maar een punt is) dat ze bij kleine aanpassingen soms gigantische effecten hebben op het rekenmodel. Om stabiliteit en flexibiliteit terug te brengen bij het verder uitbreiden van het rekenmodel moeten we naar een universeel systeem gaan. Wij kiezen hiervoor om alles naar een raster te brengen, omdat dit de berekeningen enorm versnelt en versimpelt en vervolgens makkelijker is om te overzien. Dit gaat het tekenen overigens niet beïnvloeden, er zal simpelweg een extra tussenstap zitten tussen de tekendata en de data die daadwerkelijk gebruikt wordt voor de berekeningen.

Sublagen omzetten naar individuele lagen met hun eigen regels.
extra note: Een voorbeeld van de huidige inflexibiliteit is dat sommige sublagen in bepaalde lagen niet dezelfde regels zouden moeten hebben als andere sublagen in dezelfde laag. Denk vooral aan CO_2 opslag en CO_2 extractie. Dit is op het moment een limitatie en moet dus meegenomen worden in de volgende aanpassing om de flexibiliteit voor het balanceren en verbeteren van het rekenmodel terug te brengen.

- **Rastarizeren van ruimtelijke data (polygons, lijnen, punten,) naar % oppervlakte per cell. (zonder verlies van polygons, lijnen en punten bij het tekenen)**
- **Huidige MSP visserij model los koppelen om ruimte te maken voor het dynamische model**

Alternatief 1: intern MSP food web model uitbreiden: (61 dagen)

Na het zien van Ecopath is het duidelijk dat wij ook deze kant op moeten gaan. In het geval dat wij dit zelf gaan doen, moeten wij zelf een algoritme gaan produceren dat er voor zorgt dat vissen dynamisch door de Noordzee zwemmen.

Daarnaast moet het visserij model ervoor geüpdate worden om met de nieuwe dynamische data om te gaan, door zelf ook dynamisch te worden.

Daar bovenop, om stabiliteit nog preciezer te kunnen instellen, willen we eenzelfde soort [functional response] curves systeem toevoegen zoals in Ecopath [functional responses to environmental drivers, see Ecospace habitat foraging capacity model (Christensen et al., 2014), ED], waarbij er preciezer ingesteld kan worden hoeveel bepaalde lagen invloed hebben op elkaar als de waardes van de lagen verschillen.

- **Een visserij model (waar gevist wordt) toevoegen dat fishing effort verspreidt aan de hand van locatie van vissen, afstand van havens, etc, in plaats van een statische map.**
- **Een beesten verplaatsings model toevoegen (Cellular automata algoritme) dat beesten verplaatst naar cellen met betere condities (minder sterfte en meer voedsel), waarby de bekende snelheid van de beesten in ogenschouw wordt genomen.**
- **Algoritmes aanpassen om met deze modellen te kunnen werken**
- **Toevoegen van een tweakable (half sigmoid) curve systeem om eet situaties van bepaalde vis soorten makkelijker te stabiliseren in extreme situaties.**
- **Parameterizeren van functionele responses hoe beesten reageren op (veranderende) omgevingsfactoren**

Alternatief 2: MSP food web vervangen door een link naar the EwE software: (20 dagen)

Als we gaan werken met het bestaande Ecopath systeem zorgen wij er alleen voor dat we een interface maken die met Ecopath communiceert en de data omzet van ons systeem van/naar Ecopath.

Nodig van Ecopath:

- **Het systeem heeft een algoritme om de vissen dynamisch te verplaatsen aan de hand van ‘ideale’ leef omgeving.**
- **Een visserij model komt hier organisch uit.**
- **Balancering van het systeem.**
- **Een snellere berekening per ‘gamestep’ dan het huidige rekenmodel.**