USING A SPATIALMICROSIMULATIONMODEL TO ESTIMATE THE POTENTIAL ECONOMIC IMPACT ON AGRICULTURE OF POSSIBLE FRESHWATER PEARL MUSSEL PROTECTION STRATEGIES

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"The spatial dimension in analysing the linkages between agriculture, rural development and the environment"

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1. INTRODUCTION

The protection of water resources is an important topic on the agenda of many policy-makers around the world and in the EU Member States in particular. The need to protect water bodies was originally driven by the odour and visual pollution which had become apparent and barely tolerable (Novotny, 2003). As a result of research and increased social awareness of these issues, demand for protection of water bodies across Europe developed. Protection not only involves a physical cleaning of the water in the rivers and streams but also a more holistic approach to water body management, where the water, flora, fauna and morphological structure are all treated as being of a high value and importance. One result of this new understanding is an introduction of new policies such as the Water Framework Directive (WFD) (Directive 2000/60/EC). This directive recognises the need for an integrated holistic approach to water protection and demands cooperation at the EU level in order to achieve the targeted improvements in water quality. It also prohibits any further deterioration of the water bodies and sets penalties for non-compliance (Directive 2000/60/EC).

A number of studies have sought to estimate the cost of the WFD implementation internationally. Most of this research focuses on non-point pollution sources and on agricultural activities in particular; however some research is of a general nature, like Del Saz-Salazar et al. (2009), who estimated costs and benefits of restoring water quality. In the UK Fezzi et al. (2010) conducted an econometric analysis to estimate the cost of nitrate reduction measures. In Belgium, Cools et al. (2011) coupled a hydrological and economic optimisation model to create a framework to evaluate the cost-effectiveness of nitrogen emission reduction measures. Gómez-limón and Martin-Ortega (2013) conducted an economic analysis of the WFD implementation in Spain and outlined the weaknesses in the existing economic methods used to estimate the economic costs. Lescot et al. (2013) conducted a spatially-distributed cost-effectiveness analysis framework comparing various agro-environmental measures to control pesticide pollution in surface waters in France. In an Irish context, a number of studies have investigated the costs of the possible WFD measures that would potentially reduce pollution from agricultural activities (Doody et al., 2012, Lally et al., 2009). This paper builds on the model developed by Chyzheuskaya et al. (2014) and the spatial microsimulation model described by O'Donoghue et al. (2014a), O'Donoghue et al. (2014b), O'Donoghue et al. (2014c) and estimates the cost of the proposed measures to protect specific species of the fresh water pearl mussel (FWPM). Microsimulation models present an invaluable alternative where conducting a real-life data collection is time or cost-prohibitive. Furthermore, spatial microsimulation models contain geographically referenced information that links micro-data to specific location (O'Donoghue et al., 2012).

FWPM are protected under the Habitats Directive (Council Directive 92/43/EEC), the Wildlife Acts (Wildlife Act No 39 of 1976) and the Water Framework Directive (Directive 2000/60/EC). These species have very complicated reproduction cycles and require very high water quality for successful reproduction, particularly for the survival of juvenile mussels (Bauer, 1987, DEHLG, 2010). The presence of these pearl mussels in their natural habitat of fresh water rivers has been used as an indicator of water quality and the declining numbers of once abundant FWPM indicates declining water quality and the need for habitat protection policy in Ireland. This mollusc is not only a very sensitive organism that signals the presence of water pollution problems but is also a unique and endangered species that has to be preserved for future generations in its own right.

Ireland has 46 percent of the individual EU FWPM (DEHLG, 2010). This species is currently in decline throughout Ireland and the rest of Europe. Sedimentation, turbidity and nutrient enrichment from a variety of anthropogenic activities have contributed significantly to this decline (Cooksley et al., 2012, Österling et al., 2010, Ostrovsky and Popov, 2011). Under the Water Framework Directive (WFD), water quality requirements within FWPM special areas of conservation must be met by 2015. In order to meet the requirements of the Habitats Directive (Council Directive 92/43/EEC) and the WFD (Directive 2000/60/EC) associated with the FWPM, Sub-Basin Management Plans (SBMPs) have been established for each of the FWPM sites. These plans deal with impacts on FWPM arising from all land uses and activities in the FWPM catchments and discussed in more detail in a later section.

Agriculture has been identified in the literature as one of the many sources of non-point pollution (Buckley and Carney, 2013, Buckley et al., 2012, O'Donoghue et al., 2010, Schulte et al., 2006) and the SBMPs also cite agriculture as a sector putting environmental pressure on the catchments' ecology (DEHLG, 2010). Irrespective of the size of this possible contribution from agricultural activities, farmers are required to participate in efforts to reduce environmental pressure on FWPM, along with other sectors. The measures that are needed to protect the pearl mussel species will impact on the agricultural sector since research indicates that the FWPM is sensitive to nutrient enrichment and sediment pollution which are known to originate from agricultural activities (DEHLG, 2010, Merrington et al., 2003, Novotny, 2003, Novotny et al., 2005, Ritter and Shirmohammadi, 2000).

There are other human influences that contribute significantly to environmental pressures on FWPM – such as the use of septic tanks and sewage on site treatment plants (Cooksley et al., 2012, Ni Chathain, 2009). However these non-agricultural influences are not considered in this paper notwithstanding the fact that they may significantly impact the ecology of water streams.

This paper builds on the model developed by Chyzheuskaya et al. (2014) and the spatial microsimulation model described by O'Donoghue et al. (2014a), O'Donoghue et al. (2014b), O'Donoghue et al. (2014c) and estimates the cost of the proposed measures to protect specific species of the fresh water pearl mussel (FWPM). Microsimulation models present an invaluable alternative where conducting a real-life data collection is time or cost-prohibitive. Furthermore, spatial microsimulation models contain geographically referenced information that links micro-data to specific location (O'Donoghue et al., 2012).

In this paper the cost of introducing the measures to protect the Irish populations of the FWPM is estimated in a spatial microsimulation framework. In face of more and more limited economic resources there is a need for efficient resources allocation and, thus, the cost of each project needs to be known before the allocation decisions can be made. The costs of protecting FWPM are likely to be localised in character and confined to the areas where these organisms are present. The use of spatial microsimulation models in different research areas is well documented and these models can be used to generate data as well as providing a framework for spatial policy impact analysis. O'Donoghue et al. (2012) conducted a comprehensive review of these models and their applications. These models have been originally applied to evaluate taxation systems in the US in 1960s (O'Donoghue, 2001). Later spatial microsimulation models found their way into the areas such as healthcare (Edwards and Clarke, 2009, Procter et al., 2008, Smith et al., 2006), transport (Bradley and Bowman, 2006, De Palma and Marchal, 2002, Liu et al., 1995), housing and labour markets' (Clarke, 1996, Hooimeijer and Oskamp, 2000), and finally in environmental and climate change analysis (Hynes et al., 2009b, Kruseman et al., 2008a, Kruseman et al., 2008b, Svoray and Benenson, 2009).

There is still a gap in the literature regarding the costs of protecting FWPM despite the fact that there is a comprehensive literature on its biology and ecology. The focus is on agricultural activities because existing policy responses to protect the FWPM will impact heavily on the farms located in the FWPM catchments. In Ireland, many farmers are motivated by a desire to preserve the culture and tradition of farming in addition to profit motives, reflected in the relatively high proportion of farming that is loss-making. Thus, regulations that impact on the agricultural sector may further erode the position of farming leading to welfare implications for farming communities. Another consideration which must be borne in mind when determining optimal policy responses to endangerment of FWPM is the necessity of increasing food production in light of the projected increases in the population of Earth. This projected increase in the population will lead to an increase in demand for agricultural outputs. Food Harvest 2020 agenda includes increase in the value of agricultural output by of 33 percent by 2020 (Department of Agriculture, 2014). In light of the implications that many FWPM measures are anticipated to have for agricultural production, this paper explores the effects of these protective measures on the income of farmers in the catchments where the populations of FWPM are present. Moreover, unlike the air pollution, the water pollution impacts are often localised, thus, the measures to mitigate such pollution and as a result the economic impacts will also be localised. Thus, spatial microsimulation models need to be utilised in the assessment of the FWPM protection measures that will be localised to the catchments where these organisms are present.

Following the recommendations put forward in the Sub-Basin Management Plans (SBMPs), five measures that would reduce farming activities in the FWPM catchments are considered: 1) the reduction of fertiliser by 10 percent; 2) the reduction of livestock units (LU) to achieve 170kg of organic N per hectare; 3) a 20 percent LU reduction; 4) switching from tillage to beef production and 5) the fencing off of water body banks by 10m, 25m and 50m. The economic impacts of each measure are modelled using the microsimulation approaches described in detail by (Chyzheuskaya et al., 2014). The microsimulation model produces a farm-level estimate of the economic impact for farms contained in the National Farm Survey (NFS). In order to simulate the effect that these measures have on farm gross margin for all farms in Ireland a spatial microsimulation model, the Simulation Model of the Irish Local Economy (SMILE) as described by O'Donoghue et al. (2012) is also used. This further allows one to isolate the economic effects of the measures on farms located in the FWPM catchments. Costs are compared on the basis of cost in Euro per unit of Nitrogen abated per hectare or CPUA.

2. Ecology of the Freshwater pearl mussel and environmental issues associated with it.

The measures that have been proposed in the literature to protect the FWPMs are based on the ecology of these species. The FWPM (MM and MD) is a type of mollusc that is known to be present in a small number of places in the world. MM has reportedly been found in Austria, Belgium, Czech Republic (critically endangered), Denmark, Estonia, France, Germany, Lithuania and Poland (believed to be extinct), Portugal, Spain, Scandinavia, Canada, USA, UK and Russia. Ireland is known to have 46 percent of all populations of MM in Europe (DEHLG, 2010, IUCN, 2009, Makhrov, 2011). MD is a unique type of freshwater pearl mussel that can be found only in the Nore catchment in Ireland. Thus, Ireland is an important region for efforts to preserve FWPM.

Experts now estimate that over 90 percent of all Margaritifera individuals died out during the 20th century and that there are now only small ageing populations left across the EU and other parts of the world (DEHLG, 2010). The declining numbers of FWPM species are attributed to ecological and environmental factors that make reproduction and survival of this mollusc more and more difficult.

In Ireland, Magaritifera is a protected species under the 1976 Wildlife Act and it is also listed in the Habitats Directive (Council Directive 92/43/EEC). It is also protected by the International Union of Conservation of Nature (IUCN) red data book as endangered worldwide (Baillie, 1996, IUCN, 2009, WFD Ireland, 2005). FWPMs are valuable to the environment due to their ability to filter water from pollutants that naturally occur in the environment. One Margaritifera can filter up to 50 litres of water a day (Ziuganov and Nezlin, 1988). However, pearl mussels are sensitive to man-made pollutants and require very high quality of water with low levels of nutrients/sediment and clean river beds for survival and for sustainable reproduction. It is believed that the condition of the water in the river needs to be very close to its natural state (unimpacted by human activities) to allow FWPM reproduction and survival (DEHLG, 2010).

There are four main threats to the sustainability of the FWPM population in Ireland, 1) siltation; 2) nutrient enrichment; 3) acidification; 4) toxic pollution (DEHLG, 2010). These threats make reproduction, development or survival of the FWPM difficult and can have a number of origins including agricultural activities. These are also the main threats to FWPM populations around the world and not only affect the FWPM populations but can also lead to changes to the whole habitat of watercourses (Cooksley et al., 2012, Österling et al., 2010, Ostrovsky and Popov, 2011). Thus, measures taken to protect FWPM are likely to lead to improved environmental conditions for a number of other flora and fauna species.

3. MITIGATION MEASURES

In order to address the location specific issues related to FWPM in an attempt to develop favourable conditions for the sustainable reproduction of these species SBMPs, which are part of the WFD river basin programme of measures, were developed in Ireland by the Department of Environment, Heritage and Local Government (DEHLG). 27 SBMPs were developed with the aim of providing a mechanism to address the threats to the survival of FWPM on at a catchment-level scale. The SBMPs develop a strategy to implement measures that will bring the catchment, and by extension the FWPM populations, back to a favourable condition. This is done by defining a programme of measures for each sub-basin.

As part of this process, each SBMP lists potential pressures on the FWPM populations and suggests both general and specific measures to reduce these pressures. These measures are grouped into two broad categories: measures to reduce pressure at the source and measures to remediate pressure along the pathway (DEHLG, 2010). Table 1 lists these measures.

Table 1 List of measures to reduce pressure on the ecology of FWPM.

Measures to remediate pressures at the source:	Measures to remediate pressures along the pathway:
Reductions/cessation of fertiliser use	Establishment of an appropriate, site-specific buffer zones of native woodland or semi-natural
Reductions/cessation of slurry application	Vegetation around drains, streams, rivers and lakes
Implementation of nutrient management plans	Floodplain restoration
Reductions/cessation of ploughing	Wetland restoration
Reductions/cessation of drainage and drainage maintenance	Creation of artificial wetlands or filter beds
Reductions in grazing intensity/livestock units	Installation of appropriately-sized sediment traps
Other reductions in land use intensity, e.g. conversion to native woodland	Other measures to increase infiltration or slow/divert surface run-off, or flow in drains.
No liming of land in sensitive areas	Reducing or eliminating extraction within the identified catchment.
Fencing off drains, streams or rivers where there is significant bed or bank erosion.	

In addition to the measures listed in Table 1, emergency measures may be employed in “highly sensitive” areas. However, the definition of highly sensitive areas is unclear and the “emergency” measures are not currently specified in the SBMPs. It is proposed that agri-environmental schemes are to be developed to reward/compensate the farmers that operate in a more environmentally friendly fashion. This scheme would insure that farms within the 27 catchments would have on-farm plans that may include any of the measures listed if they are deemed necessary after an on-farm survey and assessment has been conducted (DEHLG, 2010).

To achieve the mitigation objectives, and the associated reduction in pressures on FWPM streams, would require either reductions in the level of agricultural production or increases in farms' production efficiency or some combination of both.

This paper estimates the costs associated with five mitigation measures cited in the SBMPs that have the potential to reduce the pressure on FWPM at source since they may mitigate problems associated with nutrient enrichment, siltation, toxic pollution etc. However, the cost of the measures needs to be known to fully inform the decision-makers. The five mitigation measures are:

- the reduction of inorganic fertiliser by 10 percent;
- the reduction of LU to achieve 170 kg of organic N per hectare[i1;]
- the reduction of LU by 20 percent;
- switching from tillage to beef production and
- the fencing off of adjacent streams (and an associated de-intensification of production).

4. DATA

Since the impact of the measures, if introduced, would be localised, the estimated costs should apply only to the impacted areas. To isolate the affected farms, spatially referenced farm level data is required which is representative at the local level. Since such rich data is not available, instead farm level data is utilised to estimate costs and

[1] As defined by SI 378 of 2006 the maximum allowable production of organic N on the farms is 170 kg of N per hectare. Farmers at the moment can apply for derogation up to 250 kg N per hectare – this scenario assumes that the limit of 170 kg of N per hectare becomes binding. http://www.environ.ie/en/Legislation/Environment/Water/FileDownLoad,1573,en.doc

then a spatial micro-simulation approach is used to determine the costs at a local level. Data from the Teagasc NFS data is used to estimate the effect of each of the five FWPM protection measures on farm gross output and direct costs. In order to estimate the effects of each measure on all farms located in the FWPM catchment, a spatial microsimulated dataset – produced using the Spatial Microsimulation of the Irish Local Economy (SMILE) model (described later in this paper) was used to isolate farms in the catchment area (O'Donoghue et al., 2013). Information on the catchments is taken from the SBMP reports (DEHLG, 2010).

NFS Data and the Catchments' Statistics

The NFS data is collected by surveying a sample of farms in Ireland. The survey has been conducted by Teagasc on an annual basis since 1972. It contains detailed socio-economic information about approximately 1,200 farms each year that represent over 100,000 farms in Ireland (Connolly et al., 2010). On the basis of statistical information from the Census of Agriculture which is reported by the Central Statistics Office (CSO), Teagasc develops national and regional weights every four years to ensure the representativeness of results obtained using the NFS.

The SBMPs report the length of the rivers in catchments where populations of the FWPM are present (DEHLG, 2010). Out of the 27 catchments in Ireland where FWPM can be found only nine are considered to be under ecological pressure from agricultural activities: Munster Blackwater, Nore and Leannan, Dereen, Mountain Aughnabrisky, Ballymurphy, Clodlagh, Bandon and Caha and finally Cloon.

5. METHODOLOGY

A cost-benefit analysis would be required to fully inform the stakeholders of the economic implications of the various mitigation measures. Such analyses very often demand detailed spatial data on all the costs and benefits (both tangible and intangible) of the proposed measures. In this paper only the costs associated with mitigation measures are explored, as the anticipated benefits of the measures (in terms of increases in the FWPM populations) have not been quantified in the relevant scientific literature. A number of different approaches were used for cost estimation. The costs for each mitigation measure were calculated in the following manner.

Fertiliser and Livestock reduction scenarios

The economic impacts of the 20 percent fertiliser reduction scenario and of the reductions in the number of livestock units were estimated using microsimulation methods similar to those described by Chyzheuskaya et al. (2014). Such microsimulation techniques are useful in conducting counterfactual analyses such as the outcome of different policy scenarios at a household, firm/farm or other micro-unit levels. Microsimulation approaches have been used extensively to evaluate taxation and pension systems (Merz, 1993, Mitton et al., 2000, Spadaro, 2007) and are increasingly being applied in other contexts (O'Donoghue et al., 2012). The application of simulation approaches within an environmental context is growing. For instance, Hennessy et al. (2005) use a linear programming approach to simulate the effects of complying with a limit of 170 kg of organic N per hectare on farm income.

In this paper an econometric technique (described in detail by (Chyzheuskaya et al., 2014) is used to simulate the impact of the five alternative policy measures on individual farm profits (π_i). While the model in described by them is applied only to dairy farms in

Ireland; the current paper applies the model to all farm systems represented in the NFS data. Farms in Ireland are generally engaged in multiple enterprises. Chyzheuskaya et al. (2014) considered only 3 enterprises, while in the current context four - dairy, beef, sheep and crops enterprises – are considered.

Farm profit (π_i) is defined as the value of gross output (GO_i) less direct costs (DC_i) and fixed costs (FC_i) (equation 1), where *i* denotes an individual farm. However, since FC are not affected by the changes in GO and DC that are simulated within the model, changes in π_i are driven by changes in only GO_i and DC_i i.e. by changes in Gross Margin (GM_i=GO_i- DC_i) (equation 2). In Ireland many farms engage in more than one farm enterprise so to reflect this this model operates at the farm enterprise level (dairy, sheep, beef and crops enterprises) rather than at farm level. Thus, eight functions are estimated in this paper. Each enterprise provides different gross margins per unit of output. Individual enterprises also have different gross output and direct cost functions. Thus, GO and DC are simulated for each enterprise separately (equations 3 and 4) and the results are then aggregated together to give a farm level total for GO and DC. A subscript *j*, is used to denote a particular enterprise.

Thus, the micro simulation model can be represented by:

$$\pi_i = GO_i - DC_i - FC_i \tag{1}$$

$$GM_i = GO_i - DC_i \tag{2}$$

$$GO_{ij} = (X_{ij}\beta_j, \varepsilon_{ij}^{GO}) \tag{3}$$

$$DC_{ij} = (X_{ij}\gamma_j, \varepsilon_{ij}^{DC}) \tag{4}$$

Where X_{ij} is a vector of explanatory variables; e.g. - livestock units, farm size, fertiliser usage and concentrates[2]. X_{ij} determine the level of each enterprise GO_j and DC_j, where j denotes dairy, cattle, sheep or crop enterprise on the farm.

The simulation procedure is carried out by holding the regression coefficients (β, γ) and the error terms (ε_{ij}^{GO}, ε_{ij}^{GO},) constant and changing the explanatory variables (X°) to reflect the introduction of a particular measure. This involves changes in the amount of fertiliser used or the number of livestock units in the model. When the parameters of the model are estimated the new production and costs are simulated (denoted as GO° and DC° in equations 5 and 6).

$$GO_{ij}^{\circ} = (X_{ij}^{\circ}\beta_j, \varepsilon_{ij}^{GO}) \qquad (5)$$

$$DC_{ij}^{\circ} = (X_{ij}^{\circ}\gamma_j, \varepsilon_{ij}^{Dc}) \qquad (6)$$

The simulated impact of the measure is the difference between farm profit before (π) and after the change (π°) (equations 7 and 8).

$$\pi^{\circ}_{ij} = GO^{\circ}_{ij} - DC^{\circ}_{ij} \qquad (7)$$

$$\Delta\pi_{ij} = \pi^{\circ}_{ij} - \pi_{ij} \qquad (8)$$

This is the approach taken for the first three measures considered in this paper: 1) the reduction of fertiliser by 10 percent; 2) the reduction of livestock units (LU) to achieve 170 kg of organic N per hectare; 3) a 20 percent LU reduction. For each measure the livestock numbers or fertiliser usage were adjusted according to the scenario considered and the change in profits was simulated.

Switching from Tillage to Beef production

[2] The models are estimated using a log-polynomial functional form using ordinary least squares (OLS) regression.

It was assumed that if farmers were not allowed to plough in the FWPM catchments they would switch from tillage to beef production. The farms are divided into three groups: 1. the farms that do not engage in the crop production; 2. the farms that have crop enterprises and have at least 20 percent of land designated to beef production; 3. crop farms that do not have beef enterprise. The first type of farms is unaffected by the measure.

It is further assumed that after switching from tillage to beef production the second type of farms will derive the same gross output per hectare and will incur the same direct costs per hectare as their existing beef enterprise. It is assumed that the third type of farms will derive the same gross output per hectare and will incur the same direct costs per hectare as an average beef enterprise in the same region. The effect of the measure is the change in the farm profit (equation 8). This measure does not take into consideration the initial investment that may be required for extending the beef enterprise (e.g. buying more cattle, investing in buildings etc.).

Spatial Microsimulation

Although the NFS dataset is nationally representative, it cannot be used to estimate aggregate effects at a local level since it is not spatially representative, nor would the sample size permit detailed local analysis even if it were spatially representative (See Green and O'Donoghue (2013)). In order to estimate the effects of each measure on all farms located in the FWPM catchment, a spatially representative dataset is required. One potential source is to simulate the data utilising a spatial microsimulation approach (O’Donoghue et al., 2014b). Hynes et al. (2006) outline three main benefits of using synthetic data: the ability to create micro data from aggregated macro data at different spatial resolution; the ability to retain a number of characteristics of micro-units within the data and facilitate a multivariate analysis and the ability to assess the impact of different policies on particular groups within the population within spatial unit.

The SMILE, farm model (O'Donoghue et al., 2012) simulates spatially representative households and farms at an electoral district (ED) level using a number of data sets: the NFS, the Census of Population and the Census of Agriculture (COA) amongst others (O'Donoghue et al., 2012). The data simulation process involves the sampling of farms from the micro dataset containing detailed farm level data from the Teagasc NFS to make it consistent with the COA. The constraint variables used include, farm size, farm system, soil type and stocking rate; variables that are strongly associated with farm level outcomes in Ireland.

SMILE was developed as a policy simulation tool to evaluate and provide evidence in relation to the impact of public policies that have a spatial dimension, particularly in relation to policies that affect rural populations. The model comprises two linked components: a household model and a farm enterprise model. The household model contains a database of households in each of the 3400+ electoral districts of the country with detailed data on individuals within households and their respective demographic characteristics, labour market, income and expenditures. The farm level model that is linked to the farm households in the household model contains 140k farms each located within their district and containing all of the land use, output, subsidy, direct cost and indirect cost variables at the individual enterprise level, amounting to 1,500 variables per farm. The objective of the model is to assess how the types of policies introduced by the government may affect households and farm enterprises within the spatial locations of where they live and work and to be able to perform disaggregated analyses by the characteristics of these units such as age, income category, employment status, farm type etc. (O'Donoghue et al., 2012).

The SMILE-FARM model was developed by Hynes et al. (2008a), Hynes et al. (2009a), Hynes et al. (2006), Hynes et al. (2009b) who used a Simulated Annealing (SA) method to enhance the household SMILE model with a view to examining the impact of EU Common Agricultural Policy in Ireland. They used NFS data for the year 2008 and the COA for the year 2000 to develop a data set that would represent the population of farms in Ireland. Although their methods proved to be robust, its limitation was that SA took weeks or even months to run. There were also some challenges in relation to the spatial representativeness of stocking rates, which is very important given the importance of animal based agricultural systems in Ireland. O'Donoghue et al. (2014a), O'Donoghue et al. (2014b) have further improved the methodology of SMILE-FARM by trying 16 different methods of simulation on NFS 2010 and COA 2010 and data validation. They utilised a new method for data generation, known as Quota Sampling (QS) which was found to be the most efficient approach to simulate the data with a minor loss of convergence but large gains in time-efficiency, which took only hours to run (for further discussion see O'Donoghue et al., 2014b, 2014c).

SA and QS methods are very similar, they select observations at random and consider whether these observations are suitable for selection for a given spatial unit based on conformance with aggregate totals for this spatial unit. Unlike SA, QS only assigns units (in this case farms) that conform to aggregate constraint totals and once a unit is selected, it is not replaced; which is the main reason for computational improvement (Hynes et al., 2006, O'Donoghue et al., 2014).

The spatial unit aggregate totals for each constraining variable are required as to determine ‘quotas’, or running totals for each constrained variable, which are recalculated once a unit is admitted to a small area population. The method randomly sorts the population of farms and allocates one unit at a time, subject to a number of constraints. If the unit sum of each constraining characteristic (e.g. a Dairy Specialist Farm) is less than or equal to each small area total (e.g. 10 Dairy Specialist Farms in the small area), the unit is assigned to the small area population. Once a unit is selected for a given small area, quota counts are amended, reduced by the sum of the characteristics of the assigned unit(s). This procedure continues until the total number of simulated units is equal to the small area population aggregates (i.e. all quotas have been filled) (O'Donoghue et al., 2014).

This mechanism of sampling without replacement avoids the repeated sampling procedure of SA and is fundamental to the efficiency gains of the quota sampling procedure relative to other methods. However, this method of improving efficiency does present a number of convergence issues. Disparities in population distributions between census and survey totals may create a number of problems for unit-based microsimulation procedures. This is because survey micro-data are representative at the national level, whereas small area census data are representative at the district level. This poses little difficulty in simulating small areas that have a population distribution similar to that of the national distribution, but areas that differ from the national distribution may lead to some demographic groups consistently being underrepresented in a given district. These differences may cause some districts to consistently fail in reaching adequate convergence (O'Donoghue et al., 2014).

Also, the use of sampling without replacement in quota sampling results in quota counts becoming increasingly more restrictive as the simulation progresses. As quota counts reach their target, the search space is continuously refined in accordance with concurrent quotas, whereby all units no longer eligible given updated quota totals are removed from the subset and the procedure is repeated. When each constraint allocation reaches its target quota, all individuals of that characteristic are removed from the candidate search space. These mechanisms cumulate to offer a continuously diminishing search space and may prohibit convergence, whereby no unit is able to satisfy all concurrent quota counts (O'Donoghue et al., 2014).

The SMILE has been applied in a number of contexts including for rural healthcare services evaluation, (Morrissey et al., 2008), travel cost modelling (Cullinan, 2011, Cullinan et al., 2008) and proved to be a very useful tool in evaluating agricultural policy analysis. For example, (Hynes et al., 2009b) used SMILE-FARM to evaluate methane emissions on Irish farms. In another study by (Hynes et al., 2008b) this model was used to estimate the probability of Irish farmers to participate in REPS.

The SMILE model is used in this paper to create a spatial microsimulation model and enhance the micro-simulation model described by Chyzheuskaya et al. (2014). There are a number of advantages in using spatial microsimulation models over the traditional macro-models that include the potential to link different data sets that contain just one attribute in common with flexibility in spatial resolution of the study that can vary in scale. Moreover, such models store data more efficiently and can be updated with new information becoming available (Hynes et al., 2006). The disadvantages include the difficulty in results validation (Hynes et al., 2006) and the cost of updating the models (O'Donoghue et al., 2012).

As a result of merging the two models the final model allowed the aggregation of the simulated results for the farms contained within the FWPM catchment to obtain a total cost of implementing a particular measure in the catchment area and, thus, to assess the impacts of the mitigation measures at a catchment scale.

Fencing Off Streams

The cost of the fencing off measure cannot be estimated in the same manner as the other five measures due to data limitations. Since the NFS does not contain spatial information it is not possible to say which farms would have streams passing through them. There are two costs associated with introducing this measure – 1) the cost of erecting the fence on both sides of the streams in the pearl mussel catchments and 2) the opportunity cost of the agricultural land taken out of production in the buffer zone fenced off. The cost of erecting the fence is calculated on the basis of €0.9 per meter of the fence (equation 9),

$$C_{fence} = m \times 0.9 \times 2 \tag{9}$$

where m is the total length of streams in the pearl mussel catchments. The opportunity cost of the land fenced off is calculated by multiplying the average farm gross margin per hectare ($GM_{av/ha}$) in the FWPM catchment by the total area of agricultural land fenced off in the catchment (n_{ha}) (equation 10).

$$GM_{lost} = n_{ha} \times GM_{av/ha} \tag{10}$$

The cost per unit of Nitrogen

In order to make the economic costs of the three simulated (livestock and fertiliser reduction) measures comparable, a cost per unit of Nitrogen abated due to the measures is calculated. To do so first, the total amount of organic and chemical N per hectare that is produced on the farms in the status quo scenario is calculated , then, assuming one of the three policy measures is introduced the new level of N is calculated. The level of organic N used in enterprise *j* is calculated by multiplying the number of LU of type *k* on a farm by the annual N excretion rate of that LU type (E_k) and summing across the *k* types of LU, which is then added to the level of Inorganic N for enterprise type to give a total N for each enterprise type.[3] The total N for farm *i* is obtained by summing over each of the enterprises (equation 11).

$$N_i = \sum_j^J \left(\sum_k^K \left(E_k NLU_{kj} \right) + Inorganic\ N_j \right) \tag{11}$$

The change in N is then calculated for each of the measures. The cost per unit of N abated (CPUA) is then calculated by dividing the total cost by the change in N to give a cost per unit of N abated (equation 12).

$$CPUA = \Delta\pi_i / \Delta N_i \tag{12}$$

6. RESULTS

The results of the analysis are presented and discussed in this section. Table 2 presents summary statistics on the catchments. These statistics show that the catchments under consideration not only differ in size but in the average GM per hectare that farmers earn in different catchments. While in Blackwater, Brandan and Caha and average GM/ha is

[3] The annual N excretion rates for each type of LU were taken from Table 6 on page 36 of http://www.environ.ie/en/Legislation/Environment/Water/FileDownLoad,1573,en.doc

about €1000, in Nore it is about €850. Blackwater catchment falls into dairying agricultural area, Nore falls into livestock and arable regions.

Table 2 Catchments' summary statistics.

FWPM Catchment Statistics					
Catchment Name	Size (ha)	Length of river (km)	Proportion of catchment under agri use	Land in agri production (ha)	Average GM** € per ha
Blackwater	233,300	2240	0.81	189,155	1,003
Nore	105,890	970	0.80	84,985	853
Leannan	23,765	460	0.70	16,752	872
Derreen	20,118	253	0.78	15,714	947
Mount Aughnabrisky*	10,316	130	0.78	8,058	975
Ballymurphy*	3,242	41	0.78	2,532	975
Clodiagh*	12,303	154	0.78	9,610	975
Bandan & Caha*	15,821	199	0.78	12,358	1,003
Cloon*	5,900	74	0.78	4,608	891

*Only the total length of the streams for these catchments was available, the length was calculated as a proportion of the catchment size. ** GM (farm gross margin is calculated as a difference between gross output and direct costs)

The Blackwater and Nore are the two largest catchments with significant agricultural activities. The NFS survey for 2008 was used to calculate the average gross margins (GMs) reported in Table 2. The Gross Margin figures for each catchment were calculated based on the average farm Gross Margin in the relevant NUTSIII region weighted to represent the full population of farms at a NUTSIII level[4].

The results of the analysis confirm that measures proposed in the SBMPs to reduce pressure on the freshwater pearl mussel ecology would lead to a significant reduction in agricultural production and a loss of income for farmers in the affected catchments.

The cost of fertiliser and livestock reduction

The total impact of each measure and the percentage change in GM are reported in Table 3. The measure that leads to the largest negative impact in absolute terms would be a

[4] The Nomenclature of Territorial Units for Statistics (NUTS) classification has three levels: NUTSI covers the whole Ireland; NUTSII divides Ireland into Boarder Midlands, Eastern Region (BMW) and Southern, Eastern (SE) region; NUTSIII divides Ireland into eight regions: West, Boarder, Midlands, Mid-East, Dublin, Mid-West, South-East, and South- West IRO. 2014. *The Irish Regions Office* [Online]. Available: http://www.iro.ie/irish_regions.html..

livestock reduction by 20 percent measure. This measure would result in the loss of estimated €48 million per year for farmers located in the FWPM catchments. This represents a decrease in the total GM for all farms in the catchments of over 12 percent. A reduction in fertiliser application of 20 percent would lead to a total estimated loss of over €5 million per year.

Table 3 Total Impact of the Fertiliser and Livestock Unit Reduction Measures.

Measure	Total impact, € '000	Total Impact, percent GM lost
Fertiliser reduction by 20 percent	-5,252	-1.32
LU reduction down to 170gk N/ha	-2,690	-0.68
LU reduction by 20 percent	-48,000	-12.07

The total costs of the measures differ for these measures. This is due to the difference in the impact that individual measures would have on individual farms and on farming in the pearl mussel catchments. If all the farms in the FWPM catchments were to comply with the organic N limit of 170 kg of organic N per hectare they would incur an estimated total cost of €2,690K per year. This represents a total loss of GM of approximately 0.68 percent per year. The reason for the lower cost for this measure is that this measure would affect only 7 percent of the farms in the FWPM catchments – 6.5 percent would experience a loss of beef enterprise gross margin and 0.5 percent would benefit from the measure since they currently have cattle that attract a negative gross margin and the assumption is that these cattle would not be maintained under the measure.

The cost of switching from Tillage to Beef production.

The analysis shows that if the farmers in the FWPM catchments were to transfer the land that they are using for tillage production to beef production, there would be a total loss of €1,738K per year for all affected farms. This amount does not include the initial investment that may be required to switch from one system to another which may be considerable. The loss for predominantly-tillage farms would be €198K per year while for farms with some crop production that have over 20 percent of their land designated to beef production the loss would be €273K and on farms that have less than 20 percent of land designated to beef production the loss is estimated to be €1,471K per year for all affected farms.

The Cost of Fencing Off Streams

The cost of the fencing off measure will be comprised of (a) the costs of erecting the fence around the streams and (b) the costs associated with the agricultural land in the buffer zone taken out of production. The cost of fencing is assumed to be 0.9 Euros per meter. The total cost of fencing all riverbanks in the catchments in this study comes to €8,136K. If the fence is assumed to last approximately 5 years and maintenance costs are not included, the annual cost of erecting fencing is €1,627K.

The introduction of buffer strips between the fence and waterway is often a necessary measure. A 10m buffer strip is normally sufficient where the slope of the land does not exceed 10 percent and where no major polluting activities take place. However wider buffers may be needed where the slope is steeper than 10 percent and where there is poor soil quality. The actual buffer width would need to be decided on a case by case basis. However to give an indication of the associated costs (i.e. the GM foregone) three buffer widths (10m, 25m and 50m) are considered. Table V.4 presents the costs associated with fencing and with the buffer zones for each of the catchments.

Fencing streams off is one of the most cited measures in relation to the streams protection (Bryan and Kandulu, 2009, Collins et al., 2007, McDowell, 2008, McDowell and Nash, 2012) and the FWPM protection in particular (DEHLG, 2010). It seems to be one of the most straight-forward ways to mitigate pollution to water streams, especially from animal production. However, if introduced, this measure would not only lead to an expense in the form of erecting a fence, but to a loss of income to farms located in the areas.

The total GM lost across all catchments as a result of the fencing off of 10m buffer strips would amount to almost €7 million per year. If 25m was fenced off to further reduce the ecological pressure on FWPM populations, the gross margin loss would amount to almost €17 million per year and almost €34 million per year would be lost by farmers if 50m buffers were required. Thus the total costs of erecting fencing and creating buffer zones is between almost €8.4 and €35.6 million per year. With environmental benefits of such measure un-quantified at the moment, the large cost associated with this measure calls into question its implementation due to the disproportionally high cost. Moreover, the spatial analysis highlights the heterogeneity in the impacts that this measure would have on farms in different catchments. If the farms in Blackwater are expected to lose 2% of the GM, then in Leannan this number is double of that, thus, again stressing the need to consider spatial heterogeneity while formulating mitigation policies.

Table 4 Gross Margin lost due to fencing off land used in agriculture.

Catchment Name	Length of streams (km)	Fencing Costs	GM lost in 10m buffer		GM lost in 25m buffer		GM lost in 50m buffer	
		€ '000	€ '000	%*	€ '000	%*	€ '000	%*
Blackwater	2,240	806	3,640	2	9,099	5	18,198	10
Nore	970	349	1,324	2	3,310	5	6,619	9
Leannan	460	166	562	4	1,405	10	2,809	19
Derreen	252.6	91	374	3	933	6	1,867	13
Mount Aughnabrisky	129.5	47	197	3	492	6	985	13
Ballymurphy	40.7	15	62	3	156	6	310	13
Clodiagh	154.5	56	235	3	588	6	1,175	13
Bandan & Caha	198.6	72	311	3	777	6	1,554	13
Cloon	74.1	27	103	3	258	6	515	13
Total	4,520	1,627	6,807	2	17,017	5	34,033	10

*percentage of a total GM in each pearl mussel catchment

The CPUA results

In order to compare the relative cost of the measures, the CPUAs were calculated for measures 1-3. The results, reported in Table 5, suggest that while the cost per unit of N abated are similar for the measures reducing fertiliser application and for reducing LU to reach a level of 170kg of N per hectare, the costs associated with an across the board reduction in LU of 20 percent are prohibitive at over six times the magnitude of the preceding measures.

Table 5 CPUA results.

Measure	CPUA, €/N
Fertiliser reduction by 20 percent	0.41
LU reduction down to 170kg N/ha	0.24
LU reduction by 20 percent	4.85

The analysis revealed that switching from the tillage to beef production, a measure that aims to reduce the loss of sediment due to ploughing, leads to an increase in the application of N per hectare on 86 percent of the farms in the catchments. Thus, this measure can potentially reduce the loss of sediment in the FWPM catchments but at the expense of increasing nutrient loss from the same land. Thus, the relative risks associated with nutrient loss and sediment loss must be carefully assessed before seeking to implement this measure.

7. CONCLUSION AND DISCUSSION

Spatial heterogeneity has long been recognised as an important element in policy assessment and formulation. This fact is reflected by a large number of the spatial microsimulation models developed and applied in different areas of economic analysis. Originally formulated for assessing the impact of the taxation on the population income, it is now used a variety of analysis like healthcare, environment, transport and other areas of economic analysis (O'Donoghue et al., 2012).

In this paper the spatial microsimulation model is utilised in conducting the case study if the cost of the FWPM protection. In most countries within the EU, the FWPM is either almost extinct or exists only in small senescent populations and may become extinct before future generations arrive if a major hydro-ecological recovery in the catchments where they are present is not achieved (Araujo and Ramos, 2001; Geist, 2006; DEHLG, 2010). Thus, there is an increasing demand to reduce ecological pressures on pearl mussel habitats in order to ensure the survival and reproduction of these critically endangered species.

In line with the requirements of the Water Framework Directive (Directive 2000/60/EC), SBMPs for 27 river catchments in Ireland were developed (DEHGL, 2010). In these management plans a list of possible measures to reduce environmental pressures on the FWPM at their source and along the pathways are cited. Measures that aim to reduce the pressures at their source would lead to a reduction in agricultural output due to a reduction in stocking densities, in livestock numbers or through a reduction in fertiliser usage. In this paper the likely impact of such measures is explored using microsimulation techniques applied to the Teagasc NFS data and a synthetic spatial microsimulated population using SMILE.

The results of this analysis suggest that reducing pressures on the FWPM at their source (as specified in the SBMPs) will come at a considerable cost to the agricultural sector in these regions. Moreover, the analysis reveals that some mitigation measures may potentially lead to increasing pressure in another environmental dimension if the farmers were to switch to different systems of production in response to a policy measure. This leads to the conclusion that the current plan to mitigate the pressure on the FWPM may lead to disproportionally high costs to the farming communities with the benefits of the measure somewhat ambiguous. Finally, the analysis highlighted the heterogeneity of impact that mitigation measure would have in different catchments.

However, these results should be interpreted with caution. The analysis is static and does not take into account the possibility that farmers alter their behaviour nor is the analysis a cost-benefit analysis since it does not look at the holistic costs nor seek to quantify or value the potential benefits of the measures. The list of the measures estimated in this paper does not cover all the measures listed in the SBMPs. Future work in this area could model the economic impact of the other measures in order to provide full information for policy-makers. A full analysis is currently not possible due to data limitations. Data availability is one of the main obstacles for conducting research of this kind, especially in situations where the impacts of the measures are to be localised and spatial data is needed. Simulation models like SMILE help to overcome data limitations in some instances, however, even these types of models still do not contain all the spatial data needed for comprehensive economic-ecological assessment. Despite the limitations outlined, this paper offers the insight into the magnitude of the potential costs that agriculture may need to face in order to protect the FWPM populations in Ireland.

The overall conclusion of the paper is, thus, that protective measures as currently envisioned may lead to significant costs on the agriculture sector, while alternative measures which focus on increasing farm efficiencies possibly via the introduction of new technologies may be a superior means to protect the FWPM. Such an approach would also be consistent the objectives of Agenda 2020, which envisions an increase of agricultural output to meet food demand of growing population, while the current measures are inconsistent with this objective.

The policy recommendations as outlined in the SBMPs will lead to significant costs to the agricultural sector and the wider economy. However, there is a paucity of robust scientific literature to indicate what measures are necessary and sufficient to preserve the existing populations of the FWPM in Ireland and to reinstate a successful reproduction process. Until such information is available it is not possible to conduct a cost benefit analysis on which to base policy recommendations. Thus, further research will be dependent on the advances in the biological research on ecology of the FWPM. However, in the times of the limited economic resources, the results of this study inform about the differences that the protective measure will have and, thus, may inform policy decisions if those could be isolated to specific catchments to minimise the losses.

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[i] Source: DEHLG (2010). Note: Catchments were delineated to the lowermost mussel contained within the boundary to the Special Area of Conservation