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Potential for longevity of novel genetically modified herbicide-tolerant traits in the Irish landscape

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Abstract

With the renewed interest in GM crop technology in Ireland, some concern has been raised in relation to the potential impact on biodiversity in the Irish agri-environment. This concern can focus on the potential for a transgenic trait to cross to wild relatives. A novel trait will be judged to have persisted in a wild population via the successful production of seeds, such that these seeds are viable and result in the establishment of a self-sustaining population. In the case of a herbicide tolerant (HT) trait, feral and volunteer populations can only remain viable if managed with applications of the herbicide that the trait is designed to resist. This surviving population of HT plants would then need to compete successfully with other wild plants in order to prevail in the landscape and persist over time. There are few agricultural crops that can manage this combination, but as oilseed rape plants are often noted along roadsides and hedgerows in Ireland, it is correct to assume that this crop has the ability to be a successful feral survivor. This paper presents the results of a thought experiment, derived exclusively using the academic literature, on the issue of longevity. This is done by taking four hypothetical case scenarios and examining the potential for a combination of events to take place for oilseed rape (*Brassica napus*); this is selected here because it has a high potential for 'escaping' via pollen- and/or seed-mediated gene flow. A lack of quantitative data on Irish farmland biodiversity hinders solid conclusions, but when management pressure is eased biodiversity stress is lessened.

Key words: GM crops, oilseed rape, biodiversity, scenarios, landscape impact

Introduction

The management of the landscape is in continual flux and future land use patterns are unknown (Angus *et al.*, 2009; Burgess and Morris, 2009; Ewert *et al.*, 2005; Levidow and Boschert, 2008; Rounsevell *et al.*, 2006). This gives rise to concern over the future impact of agricultural activities on the environment, especially on landscape biodiversity. One issue relates to the potential impact on biodiversity, in agri-environmental landscapes, of cultivating genetically modified (GM) crops suited to the Irish tillage sector. Since the lifting of the EU moratorium on growing GM crops Ireland has not adopted GM cropping regimes, though there have been selected trials in the past (with sugar beet) and currently an environmental study is underway with blight-resistant potatoes as

part of the EU-funded project, AMIGA (<http://www.amigaproject.eu>). However, as new data and new crops become available and as global uptake of the technology expands, it is important to consider that Irish farmers could be afforded the choice of certain GM varieties tailored to Irish agri-environmental conditions sometime in the future.

Globally, GM crop hectareage has been increasing annually since their first commercial introduction (James, 2011) and while there are numerous new traits under development (Lheureux *et al.*, 2003; Stein and Rodriguez-Cerezo, 2009) herbicide tolerance (HT) is a trait that would be applicable to Irish tillage systems, with particular relevance to oilseed rape (*Brassica napus*) (O'Brien and Mullins, 2009). However, issues have been raised in regards to the potential ecological impact of GMHT crops within the agri-environment and across the wider landscape. This is particularly relevant with respect to crop volunteers (seeds that persist and thrive within the field after harvesting) and feral crops (which survive outside field conditions). In order to ascertain the potential impact of a HT crop on the biodiversity of the Irish landscape it is necessary to examine all aspects of the production of the crop. Alterations and innovations in crop management schemes that are associated with the management of GM crops have the potential for reducing the impact on the wider landscape (Mullins *et al.*, 2009). This paper takes *B. napus* as a case example. First we will look at the status of oilseed rape in Ireland and continue with a presentation of four hypothetical but realistic scenarios, wherein a potential release of the HT trait could occur under normal farming practises. The paper concludes with a discussion on the wider issues of biodiversity in the Irish landscape and a summary of potential effects.

Oilseed rape (*B. napus*) is a recent arrival into the Irish agri-environment but has been readily adopted and will no doubt increase with the push towards the provision of biofuels throughout the EU (see table 1). Like wheat and barley, oilseed rape can survive outside agronomic zones, in some cases for up to five years (Lutman, 1993) and possibly up to nine (Lutman *et al.*, 2005). Case studies of now obsolete varieties of oilseed rape have shown them to persist as feral populations (Wilkinson *et al.*, 1995), which supports observational records of feral *Brassicaceae* along roadsides, hedges, gardens and railway embankments in the Irish countryside (Aalen *et al.*, 1997; Preston *et al.*, 2002). *B. napus* can successfully hybridise with a neophyte wild relative *Brassica rapa* (wild turnip) and studies on the fitness of the resulting hybrid are numerous, but the likelihood of this being successful in Ireland is low, though our knowledge of the status of *B. rapa* in Ireland is poor (Collier and Mullins, 2012). Allainguillaume, et al. (2006) show that the fitness of F₁ hybrids is low, and when added to data from multiple sampling surveys in the UK there is the likelihood of a decline in “transgene abundance” within the F₁ population (p. 1182). Still, the ability of transgenic

oilseed rape to remain viable over time is unknown (Senior and Dale, 2002), though D'Hertefeldt, et al. (2008) recorded GMHT traits in a small number of volunteers in a field that held a GMHT crop ten years previously. However, this study did not account for any nearby GMHT oilseed rape crops that were grown in the meantime and thus it is unclear if the volunteers in question relate to the original GMHT crop. Indeed, Lutman et al. (2005) concluded that feral GMHT oilseed rape plants were not more likely to become persistent than non-GM oilseed plants, though they stressed that extended timescales and after-harvest management can be limiting factors and thus need to be carefully monitored. Others have shown that feral survival is generally low but that some GMHT volunteers do persist after two (and possibly three) years (Daniels *et al.*, 2005). In an extensive review by Warwick et al. (2009) it was shown that there are few data available with which to establish the pervasiveness of these populations.

Table 1. Current and predicted status of oilseed rape (in '000ha) (CSO, 2010). Projections to 2015 and the projected percentage change from 2004 to 2015 (Teagasc, 2008).

Crop	2004-6	2006	2007	2008	2015	% change
Oilseed rape	3.7	5.1	8.2	6.7	20	441

Herbicide tolerant varieties of oilseed rape generated through mutagenic treatment as opposed to GM also exist, and it is predicted that one such crop, imidazolinone-tolerant (IMI) oilseed rape will be commercialised for use from 2013 (Coghlan, 2009) and may be grown in Ireland soon after that. Derived using non-GM technology the issues of gene transfer, pollen flow, introgression to wild relatives and persistence remain and apply to this new variety of oilseed rape as much as they do with a GM-derived HT oilseed rape variety. Yet, as IMI oilseed rape was not developed using GM technology it is exempt from the EU regulations (Council Directive 2001/18/EC) that govern the release of GM crops as well as related Directives that relate to GM labelling and transport. IMI oilseed rape is also not covered by EU-wide coexistence strategies for GM crops, implying that the management regime for this crop is likely to be similar to that of crops currently on the market in Ireland. As this oilseed rape variety has the same management advantage as the GMHT oilseed rape it is likely to be popular with Irish farmers for the same reason that GMHT varieties will be. However, the herbicide imidazolinone has a higher toxicity than either glyphosate and glufosinate (Coghlan, 2009).

Methods

This paper reports on a thought experiment that considered four realistically viable scenarios wherein there was an accidental release of GM crops into the Irish rural landscape. It is not unusual for perusing scenario testing in cases such as the co-existence of GM crops with non-GM crops (e.g. Bock *et al.*, 2002; Gaugitsch, 2002; Reuter *et al.*, 2011), since it is difficult to model risk when

considering the totality of activities in the rural landscape. Envisioning research is common when dealing with stakeholder concerns over land use change (e.g. Soliva *et al.*, 2008; Tress and Tress, 2003), and in order to devise parameters for research it is necessary to hypothesise scenarios in the form of notional case studies, which in this case will serve to illustrate how the HT crops are grown and what the avenues for, and consequences of, gene flow may be. There exist many models of potential impact of GMHT *B. napus* (e.g. Colbach *et al.*, 2001a; 2001b), but modelling may not always capture the nuances of practical management of a cultural landscape, such as Ireland. The following case studies use the academic literature to examine hypothetical (yet realistic) ‘worst-case scenarios’ and the potential impact of a GMHT oilseed rape crop ‘escaping’ into the Irish landscape. Because there are multiple variables that need to be considered in any agri-environmental scenario, it is necessary to establish some parameters from the outset. Therefore, the following scenarios cover a ten year timeframe. This is in line with the maximum timeframe used in the research findings that were drawn-upon for this study. These scenarios are also based on current management regimes and available technology though this could be altered with the advent of novel-trait crops. Figure 1 is an aerial photograph of a fictitious part of the Irish landscape where the following four scenarios may have an impact.

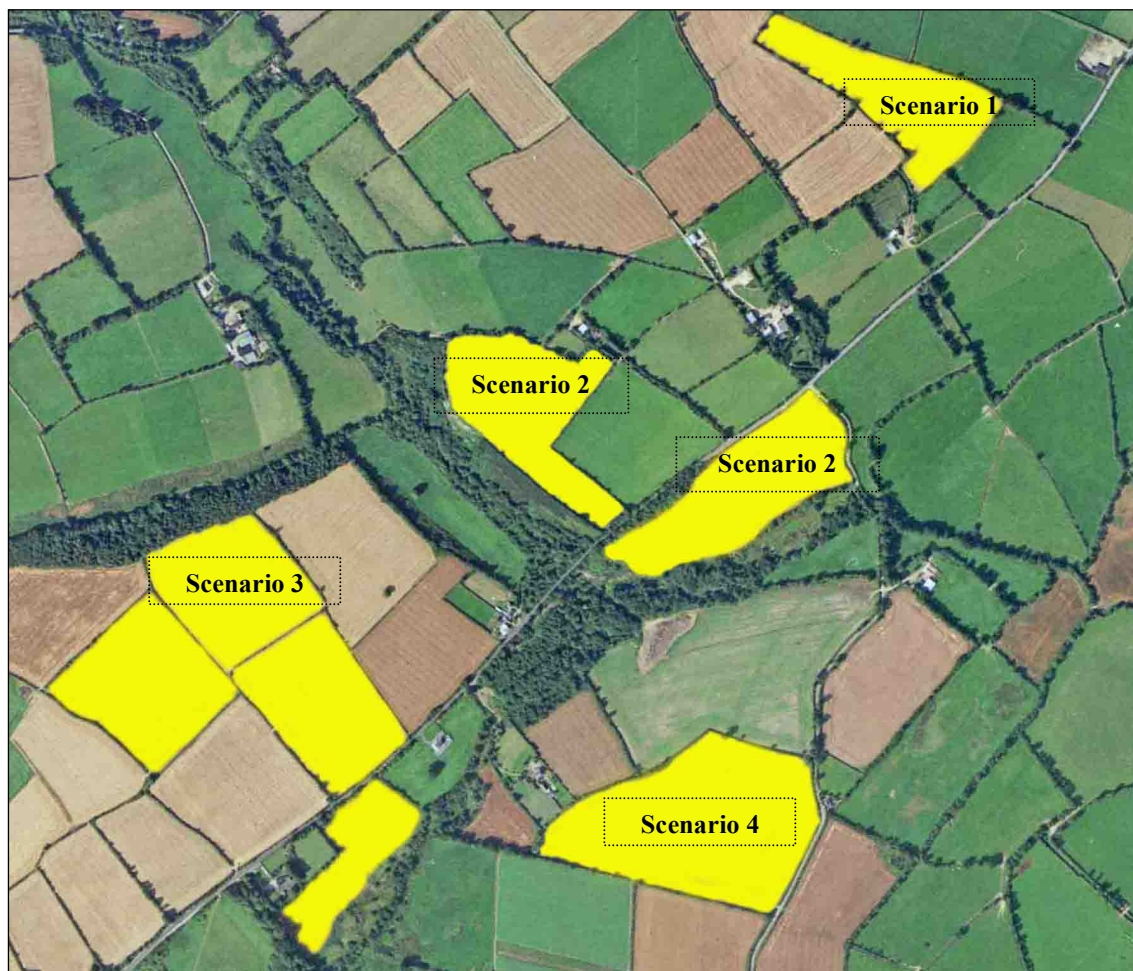


Figure 1. A notional aerial photograph where each scenario takes place (image: ©, 2013, Google).

Scenario 1. Inefficient seed control post-harvest (oilseed rape)

Oilseed rape is a prolific seed producer, with varieties generating up to 130,000 seeds/m² (Fray *et al.*, 1996). In this scenario farmer ‘A’ is transporting GMHT seed to a nearby silo after the harvesting of a GMHT oilseed rape crop. Because the trailer was not adequately sealed prior to leaving the GMHT field, seed has spilt out of the trailer within the field, and scattered along hedgerows and the open road. In addition to this, upon arriving at the silo the GMHT seed is sent by rail/road to the processing plant, with similar consequences due to inadequately covered trailers. As it can be expected that a percentage of lost seed will germinate and survive through to the following season, the issue in this scenario is that the GMHT oilseed rape seeds will populate and thrive in the semi-natural zones and even act as secondary sources of GM traits for neighbouring non-GM oilseed rape crops, i.e. acting as a ‘genetic bridge’ (Flannery *et al.*, 2005). The concern here is that residual GMHT *B. napus* seeds accidentally ‘escape’ into semi-natural habitats where they survive and maybe even act as secondary sources of GM traits.

Outcome

Field. Several management techniques will minimise the impact of seed loss within the field environment. These include delaying ploughing for several weeks after harvest (Devos *et al.*, 2004) to induce germination and decrease the potential for secondary dormancy induction (Lutman *et al.*, 2004). Applying a herbicide 4 weeks post-harvest followed by an additional time lag of 4 weeks will ensure that lost seed has the maximum chance to germinate, upon which the second volunteer flush can be destroyed through the ploughing of the field.

Railway. While Canadian prairie studies have shown transgenic *B. napus* may be found along rail lines (Yoshimura *et al.*, 2006), feral *B. napus* is unlikely to thrive in an Irish setting as it would be growing in a harsher medium (i.e. diverse substrates and/or gravel) than that for which it is designed (i.e. richer soils), though some *Brassicae* wild relatives and / or feral volunteers have been noted in these locations. However, railway track management is carried out regularly and the use herbicides that are not glyphosate- or glufosinate-based is typical. This management regime will prevent the GMHT trait from gaining any selective advantage and ensure that feral oilseed rape populations do not expand in population size.

Roadside. Oilseed ferals will populate roadsides (Norris and Sweet, 2002) but these individuals are susceptible to competition from grasses and other perennial plants. On recently completed roads, or roadsides where works were carried out, ‘escaped’ oilseed rape may grow and survive due to the short-term lack of competition, but in time successional colonisation will result in these plants being

out-competed by the more persistent species (Crawley and Brown, 1995). In the absence of management by herbicide, 'escaped' GMHT oilseed rape will have no enhanced ecological advantages and unless the roadside is continually disturbed feral populations will not prevail (Devos *et al.*, 2004).

Semi-natural habitats. Field margins are rarely managed with herbicides as they can be prohibitively expensive for the size of land and such a practise will damage the entire hedgerow system and the ecological services they provide. The high level of shading and vegetation competition in a hedgerow will not permit any 'escapes' to prevail, especially in the absence of a herbicide for which the GM trait was originally designed to resist (Crawley *et al.*, 1993). Any volunteer populations of GMHT oilseed rape will only have an advantage if in the management of the landscape the farmer uses any of the herbicides to which the plant is resistant. So without any advantage being conferred, the volunteer GMHT oilseed rape plants will be subject to the dynamics of normal competition and thus may be no more likely to persist than 'escaped' non-GM cultivars which are currently found in the landscape (Norris *et al.*, 1999).

Scenario 2. Pollen-mediated gene flow from GMHT oilseed rape to *B. rapa*

In this scenario it is assumed that successful pollen flow has occurred from a GMHT oilseed rape crop to some wild *B. rapa* growing within the crop field and/or in a nearby marginal habitat (such as in a hedgerow or along a roadside). The following planting season farmer 'B' decides to spray off field weeds as part of the preparation for the next crop in the rotation, which in this scenario is wheat. During this spraying there is some accidental drift into a nearby hedgerow. At the same time the local authority in the area also decides to spray along the roadside. Both sprays are glyphosate-based, which is the subject of the trait that has been introgressed into the wild *B. rapa* and as a result small populations of hybrid *B. rapa* exist with physiological resistance to glyphosate. Therefore, the concern is that pollen from GMHT oilseed rape will give rise to successful hybrid populations and thus confer a selective advantage on these populations in the landscape.

Outcome

Field. Growing within the wheat farmer 'B' notices both volunteer oilseed rape from the previous year and what appears to be some *B. rapa*. As the wheat is not herbicide tolerant farmer 'B' now uses a different herbicide (e.g. metsulfuron) to remove the *Brassica* weeds. Using this management approach, all GMHT crop volunteers and any hybrids within the field will be removed. Thus, the in-field population of hybrid *B. rapa* and any GMHT *B. napus* volunteers would be destroyed.

Semi-natural habitats. The issue is different in the semi-natural areas. After being treated with glyphosate by the local authority, the bulk of the roadside vegetation dies with the exception of the

B. rapa x GMHT *B. napus* hybrids. The hybrid *Brassicae* are now free to grow to seed and to self-perpetuate with little competition. Similarly, the area where glyphosate that farmer 'B' was using has accidentally drifted into the hedgerow base and the vegetation is desiccated, with the exception of the hybrid and feral GMHT *Brassicae*, both of which are able to mature without competition. In such a situation, the question arises: what is the likelihood of these hybrid populations persisting? While the probability of interspecific gene flow is quite low, it is not zero (Ellstrand *et al.*, 1999; Raybould and Gray, 1993). Using *B. napus* and *B. rapa*, Warwick *et al.* (2003) were the first to demonstrate the movement of modified genes from a crop to a near relative in natural, non-confined conditions, but it was not shown if these genes were fully introgressed. Later, Warwick *et al.* (2008) demonstrated that GMHT oilseed rape genes can persist for up to 6 years or more in *B. rapa*, but in the process there was a gradual retreat to the original *B. rapa* genes and a gradual loss of the genes of *B. napus*.

Glyphosate and glufosinate are systemic, decay rapidly and become inert upon contact with the soil. Thus, in all sprayed locations in this scenario there will be a definite re-growth of 'natural' vegetation within a few months of the initial spray treatment. This can be one of the negative agricultural consequences of using these 'milder' forms of herbicide, in that vegetation often returns more rapidly. Depending on the time of initial herbicide application this vegetation may either compete with the established feral HT population or its seeds the following season. There is also evidence that *B. rapa* would need to be in high abundance in the local landscape for introgression to occur to a significant level (Johannessen *et al.*, 2006), and as discussed earlier the exact distribution of *B. rapa* is not quantified in Ireland. Therefore, farmer 'B' has no need to be concerned because if there is no selection pressure then any GMHT hybrids/ferals in the marginal habitats will have no competitive advantage over adjacent flora populations (Beckie *et al.*, 2001; Norris and Sweet, 2002; Norris *et al.*, 2004; 1999; Simpson *et al.*, 1999). On the contrary, if selection pressure is applied via glyphosate applications then there is an increased likelihood of hybrid and/or feral plants in the landscape. Critically, the fitness of these populations will diminish outside agronomic management regimes as the new hybrid and/or feral plants will also possess genes bred into oilseed rape to ensure maximal performance under the managed environment of the field but which will actually reduce plant fitness outside the field (Warwick *et al.*, 2008).

Scenario 3. Increased use of GMHT oilseed rape in the Irish landscape

In this scenario, a GM clustering arrangement is in place in a particular county in the south east of Ireland, of which farmer 'C' is a participant (for a detailed explanation of GM clustering see Mullins *et al.* (2009). All *B. napus* in this cluster is GMHT (e.g. for glyphosate) and the cluster has

been producing for ten years. The management regimes that are used in this system are now more dependant upon the use of glyphosate than other areas. One concern is that the concentration of GMHT oilseed rape will provide a continual supply of HT pollen, which will ensure some HT *B. rapa* populations, as well as volunteer GMHT oilseed rape populations, are maintained through continuous selection. As with scenario 2 there is also an elevated level of seed scatter resulting in increased feral populations of GMHT oilseed rape in marginal habitats. This may result in high levels of sub-populations of feral *B. napus* as well as hybrid *B. napus* x *B. rapa*. If more than one GMHT variety is prevalent (such as glyphosate and glufosinate) this may give rise to populations with stacked genes (i.e. with a resistance to both herbicides). In combination, these populations may act as ‘genetic bridges’ and gradually prevail in marginal habitats outside the cluster zone. A second concern may be that the increased presence of glyphosate and glufosinate would force other species to evolve resistance (known as ‘weed shifts’ – emerging unrelated plant species with a tolerance to those herbicides). The first concern is that a combination of feral crop and hybrid *Brassicae* may now act as ‘genetic bridges’ and slowly spread along marginal corridor habitats outside the cluster zone. A second concern is that the increased presence of glyphosate and glufosinate would force other species to adapt to a herbicide tolerant phenotype.

Outcome

Guidelines have been established for the management of GM crops in the Irish landscape (McGill *et al.*, 2005). One recommendation includes the establishment of clusters of GM-licensed farmers within a region or agricultural zone, to simplify the key EU requirement of monitoring GM cropping sites post-cultivation (EC, 2001). This monitoring is composed of a general surveillance phase and a more focussed case specific analysis. The general survey is the responsibility of the network of GM farmers within the cluster along with the GM crop company representatives. The case specific survey offers the opportunity to monitor the persistence of feral populations and test for phenomenon such as ‘gene stacking’. As with the earlier scenarios, the response may entail an application of different herbicides or to manage these habitats by non-chemical means. Furthermore, as with earlier scenarios, ecological processes will apply in these semi-natural habitats and vegetation competition (which all crops do not tolerate) will mitigate population expansion. Yet, in a clustering situation, monitoring will only take place in semi-natural habitats and fields in the vicinity, and as there is the possibility for ‘genetic bridging’; semi-natural areas that are beyond the GM cluster zone are unlikely to be monitored on a regular basis. Conversely, such areas outside the GM cluster are also unlikely to be managed using these herbicides, and thus the absence of selection pressure will also impede feral/hybrid persistence over time. Separately, the case-specific monitoring must survey for the propensity for non-*Brassicae* weeds to spontaneously mutate and

develop herbicide tolerance. These ‘weed shifts’ are suspected to have occurred already, though weed species diversity is not known to have declined as a consequence (Beckie *et al.*, 2006). Beckie *et al.* (2006) also suspect that increased reliance on herbicides will lead to an increased potential for selection pressure to occur, but this is based on a ten year assessment on Canadian farms where the entire landscape was subjected to repeated herbicide applications as normal practice. This is unlikely under current Irish management regimes, which typically avoid applying herbicides in those areas where *Brassicae* hybrids and volunteers may be located. While some studies note some potential concerns (Campbell *et al.*, 2006) there is no evidence directly linking oilseed rape production and possible weed evolution (Ellstrand *et al.*, 1999).

Scenario 4. Increased use of IMI oilseed rape in the Irish landscape

It is ten years since the uptake of IMI oilseed rape and many farmers nationwide, including farmer ‘D’, now grow this variety in the absence of any regulation as it was not developed through GM technology. There is no restriction on its use and no assessments of introgression into wild relatives in any of the marginal semi-natural habitats as was the case in the above scenarios. The key concern is that un-monitored and un-clustered farming of IMI oilseed rape may give rise to large populations of imidazolinone-resistant volunteers and hybrid *Brassicae* in semi-natural habitats. In this scenario a hypothetical survey of ruderal habitats within oilseed rape farmland landscapes is carried out as part of a landscape impact research project. This survey reveals multiple populations of feral *B. napus* and hybrid *B. napus* x *B. rapa*, all with imidazolinone tolerance. The concerns here are the same as previous scenarios, but with a non-GM variety of oilseed rape, which is un-regulated, similar to current conventional and organic crops. An additional concern is that IMI tolerance will increase the levels of toxic exposure in the landscape.

Outcome

As IMI is not used to manage semi-natural habitats there will therefore not be any selection pressure applied and thus the situation in marginal habitats will be the same as the previous scenarios. If there are any accidental applications of imidazolinone the same outcomes as scenario 2 would arise. If all oilseed farmers are using the IMI variety and there are the same number of oilseed farmers as currently, hybrid and volunteer *Brassicae* ought to be the same as current levels in the absence of any advantage being conferred to these populations. However, the hypothetical landscape impact research study in this scenario has hypothesised that populations of hybrids or volunteer in semi-natural habitats may be increasing. Having discovered this, the farmer can manage the ‘problem’ using alternative herbicides or using non-chemical management. Finally, as farmers become reliant on regularly using this herbicide (imidazolinone), levels will build up in the

landscape and as with scenario 3 there may also be weed shifts. None of these issues point towards IMI oilseed rape being different from GMHT oilseed rape in that regard.

One key difference here is that because there are no regulatory mechanisms for the (mandatory) monitoring of IMI crops it is highly unlikely that any surveys will take place, and thus issues regarding persistence will go un-noticed. Critically, in the absence of selection pressure they will have the same lack of advantage as current *Brassicae* feral and/or hybrid populations. If on the other hand, IMI oilseed rape is grown in proximity to GMHT oilseed rape, then there is the possibility of stacked tolerant genes being located in feral or hybrid *Brassicae*. There are some reports of multiple-trait oilseed rape in Canada (Beckie *et al.*, 2006; Downey, 1999; Hall *et al.*, 2000), in France (Champolivier *et al.*, 1999; Méssean, 1997) and the United Kingdom (Simpson *et al.*, 1999). While these populations can be controlled through alternative management regimes, their prevalence erodes existing strategies and increases the risk of these gene-stacked populations persisting and expanding.

Discussion

There are many descriptions of the biological diversity of the Earth; comparatively fewer describe the biodiversity of cultural landscapes. This has been addressed to some extent with the AgBiota project (Purvis *et al.*, 2009), which examined non-tillage landscapes. Very few long-term research projects have examined the landscape impacts of agriculture or the potential influence that agricultural activities can have on biodiversity (Paoletti, 1995), even though it is recognised that agriculture would not be possible without the ecosystem services that habitat and species diversity provides (Butler *et al.*, 2007; Costanza *et al.*, 2007; Jackson *et al.*, 2007). Still, biodiversity must be given perspective. Biodiversity is not quantified, nor is it universally agreed of what it constitutes and how it is to be regarded or measured and thus is open to diverse interpretations. Rather, it is a notional representation of all life forms and their interaction with human processes. It is therefore a highly useful term for broad representations of ecological processes especially when it comes to discussing the agri-environment and it is often studied using indicators. In addition to this, unwanted weed or invasive species may have the potential of influencing some basic ecosystem services (van Andel and Aronson, 2006). Any new crop or land usage may give rise, in time, to an alteration of the biodiversity on an area. In some instances this may include a species (native or alien) that is later adjudged to be 'invasive', i.e. one that is negatively impacting on the wider diversity to the detriment of rare, threatened or endangered species and/or habitats. This is a complex and understudied area despite the relevance to landscape impact assessment and land use change.

With a growing demand for food security there may be an intensification of farming in Ireland. This may mean that the impact on biodiversity (from the removal of hedgerows, for example) may follow those impacts seen in the UK and continental Europe after the Second World War. Any future adoption of GM crops in Ireland could see a higher demand for land, and thus the incorporation of marginal land into farming. However, reduced chemical spraying and lower management activity could have a greater beneficial impact on species and habitats (Collier and Mullins, 2010). The GM coexistence issue illustrates that land management is key to biodiversity impact and that a successful coexistence strategy would ensure a higher standard of management. It is also suggested that a clustering arrangement with a collaborative methodology is an optimal mechanism for ensuring efficient coexistence and a minimal impact on neighbouring lands.

Conclusions

The lack of a working understanding of agri-environmental biodiversity, co-existence strategies and basic data on species prevalence in Ireland make a strong case for the use of scenario testing, such as presented here. The four scenarios above were specifically designed to hypothesise a worst-case situation, which could viably occur with the cultivation of GMHT oilseed rape crops. Scenarios are conceivable whereby the GMHT / IMI traits may persist in feral/volunteer populations of *B. napus* populations and/or be successfully introgressed into wild populations of *B. rapa*. While hybridisation is not the exception; it is the rule in natural systems. It is the consequence of the gene flow events, which is critical; for without selection pressure through the application of herbicides, these plants are no more likely to persist than current conventional oilseed rape-derived populations.

Furthermore, if HT *B. napus* x *B. rapa* hybrids or HT *B. napus* volunteers are identified, they can be eradicated using alternative agricultural herbicides. If populations of GMHT / IMI *B. rapa* do arise and are subjected to selection pressure (i.e. spraying), they will have an opportunity to increase their numbers in the short term before the rest of the vegetation returns. In the long term, typical ecological process will prevail (e.g. successional growth) and competition (e.g. for light, nutrients, water, etc.) will impact on the HT populations as with all plants. The limiting factor in all scenarios is the management regimes of either the crop and/or the semi-natural areas, which was shown elsewhere (Collier and Mullins, 2010). The requisite monitoring of GMHT oilseed rape ought to reveal any persistence issues in the short term. This monitoring or control is not legally required for IMI crops, or for any other crops in the Irish landscape, and thus any issues regarding persistence may not be noticed until some time has passed. By following current best practices in farm

management, coupled with the established guidelines for the coexistence of GM and non-GM crops in Ireland, the risk of either GMHT crop becoming any more prominent in the landscape than existing non-GM crops is minimal.

Yet, given the principal of precaution in these matters, might there be the potential for the management of *Brassicae* (GM and non-GM) to impact detrimentally on farm landscape biodiversity? Even if, under the rare likelihood of a population of HT hybrids or crop volunteers persisting locally, there is no evidence that these may become invasive or in any way impact detrimentally on Irish species and/or habitats or ecosystem services. There are no data to show that *Brassicae* have invaded or are otherwise occupying an ecological niche of a native species. The prevalence and persistence of escaped *Brassicae* have not been shown to have impacted upon Irish flora in a negative manner that would pose a problem for landscape biodiversity. In addition, these flowering plants may provide additional support for nectar feeders in the rural landscape, something that has long been suspected (Free and Nuttall, 1968). Beside the lack of information upon which to base concrete conclusions, this study also reveals a double-standard in scientific thinking (Ammann, 2012). It can be seen that while GM crops have engendered a significant volume of impact-related research over the last few decades, this is not counterpointed by similar research for non-GM or conventional crops which also have the potential for impacting on agri-environmental biodiversity via the same mechanisms and pathways. Until this area of research has begun to show clear insights into the morphology of landscape biodiversity, scenario and literature-based research may be the best way to assess potential impacts of land use change.

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References

- Aalen, F. H. A., Whelan, K., Stout, M., 1997, Atlas of the Irish Rural Landscape, Cork University Press, Cork.
- Allainguillaume, J., Alexander, M., Bullock, J. M., Saunders, M., Allender, C. J., King, G., Ford, C. S., Wilkinson, M. J., 2006. Fitness of hybrids between rapeseed (*Brassica napus*) and wild Brassica rapa in natural habitats. *Molecular Ecology*, 15 (4), 1175-1184.
- Ammann, K., 2012. Genomic misconception, an old and important mistake in the regulation of GM crops. *New Biotechnology*, 29, Supplement (0), S24.

- Angus, A., Burgess, P. J., Morris, J., Lingard, J., 2009. Agriculture and land use: demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. *Land Use Policy*, 26 (Supplement 1), S230-S242.
- Beckie, H. J., Hall, L. M., Warwick, S. I., 2001, Impact of herbicide-resistant crops as weeds in Canada, in: *Proceedings of British Crop Protection Conference: Weeds*, pp. 135-142.
- Beckie, H. J., Harker, K. N., Hall, L. M., Warwick, S. I., Legere, A., Sikkema, P. H., Clayton, G. W., Thomas, A. G., Leeson, J. Y., Seguin-Swartz, G., Simard, M. J., 2006. A decade of herbicide-resistant crops in Canada. *Canadian Journal of Plant Science*, 86 (4), 1243-1264.
- Bock, A. K., Lheureux, K., Libeau-Dulos, M., Nilsagard, H., Rodriguez-Cerezo, E., 2002, Scenarios for co-existence of genetically-modified, conventional and organic crops in European agriculture, Institute for Prospective Technological Studies (IPTS) / JRC / European Commission, pp. 1-133.
- Burgess, P. J., Morris, J., 2009. Agricultural technology and land use futures: the UK case. *Land Use Policy*, 26 (Supplement 1), S222-S229.
- Butler, S. J., Vickery, J. A., Norris, K., 2007. Farmland biodiversity and the footprint of agriculture. *Science*, 315 (5810), 381-384.
- Campbell, L. G., Snow, A. A., Ridley, C. E., 2006. Weed evolution after crop gene introgression: greater survival and fecundity of hybrids in a new environment. *Ecology Letters*, 9, 1198-1209.
- Champolivier, J., Gasquez, J., Méssean, A., Richard-Molard, M., 1999, Management of transgenic crops within the cropping system, in: *Gene flow and Agriculture: Relevance for Transgenic Crops* (P. Lutman, ed.), British Crop Protection Council, Keele, UK, pp. 233-240.
- Coghlan, A., 2009. Conventional crop breeding may be more harmful than GM. *New Scientist*, (2694), 10.
- Colbach, N., Clermont-Dauphin, C., Meynard, J.-M., 2001a. GeneSys: a model of the influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape volunteers. I. Temporal evolution of a population of rapeseed volunteers in a field. *Agriculture, Ecosystems and Environment*, 83, 235-253.
- Colbach, N., Clermont-Dauphin, C., Meynard, J. M., 2001b. GeneSys: a model of the influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape volunteers: II. Genetic exchanges among volunteer and cropped populations in a small region. *Agriculture, Ecosystems & Environment*, 83 (3), 255-270.
- Collier, M. J., Mullins, E., 2010. The CINMa Index: assessing the potential impact of GM crop management across a heterogeneous landscape. *Environmental Biosafety Research*, 9 (3), 135-145.
- Collier, M. J., Mullins, E., 2012. Assessing the potential for introgression of GM *Brassica napus* to wild relatives in Ireland. *Biology & Environment: Proceedings of the Royal Irish Academy*, 112B (3), 257-266.
- Costanza, R., Fisher, B., Mulder, K., Liu, S., Christopher, T., 2007. Biodiversity and ecosystem services: a multi-scale empirical study of the relationship between species richness and net primary production. *Ecological Economics*, 61 (2-3), 478-491.

- Crawley, M. J., Brown, S. L., 1995. Seed limitation and the dynamics of feral oilseed rape on the M25 motorway. *Proceedings: Biological Sciences*, 259 (1354), 49-54.
- Crawley, M. J., Hails, R. S., Rees, M., Kohn, D., Buxton, J., 1993. Ecology of transgenic oilseed rape in natural habitats. *Nature*, 363 (6430), 620-623.
- CSO (Central Statistics Office), 2010, Area, Yield and Production of Crops, Central Statistics Office, Dublin.
- D'Hertefeldt, T., Jørgensen, R. B., Pettersson, L. B., 2008. Long-term persistence of GM oilseed rape in the seedbank. *Biology Letters*, 4 (3), 314-317.
- Daniels, R., Boffey, C., Mogg, R., Bond, J., Clarke, R., 2005, The Potential for Dispersal of Herbicide Tolerance Genes from Genetically Modified, Herbicide-tolerant Oilseed Rape Crops to Wild Relatives. UK DEFRA contract ref EPG 1/5/151, in: *Trends in Ecology and Evolution*, Centre for Ecology and Hydrology, Dorchester, pp. 23.
- Devos, Y., Reheul, D., Schrijver, A. D. E., Cors, F., Moens, W., 2004. Management of herbicide-tolerant oilseed rape in Europe: a case study on minimizing vertical gene flow. *Environmental Biosafety Research*, 3 (3), 135-148.
- Downey, R. K., 1999, Gene flow and rape - the Canadian experience, in: *Gene flow and Agriculture: Relevance for Transgenic Crops* (P. Lutman, ed.), British Crop Protection Council Symposium Proceedings No.72, Keele, UK, pp. 109-116.
- Council Directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC.
- Ellstrand, N. C., Prentice, H. C., Hancock, J. F., 1999. Gene flow and introgression from domesticated plants into their wild relatives. *Annual Review of Ecology and Systematics*, 30, 539-563.
- Ewert, F., Rounsevell, M. D. A., Reginster, I., Metzger, M. J., Leemans, R., 2005. Future scenarios of European agricultural land use: 1. estimating changes in crop productivity. *Agriculture, Ecosystems and Environment*, 107 (2-3), 101-116.
- Flannery, M. L., Mead, C., Mullins, E., 2005. Employing a composite gene-flow index to numerically quantify a crop's potential for gene flow: an Irish perspective. *Environmental Biosafety Research*, 4 (1), 29-43.
- Fray, M. J., Evans, E. J., Lydiate, D. J., Arthur, A. E., 1996. Physiological assessment of apetalous flowers and erectophile pods in oilseed rape (*Brassica napus*). *Journal of Agricultural Science*, 127, 193-200.
- Free, J. B., Nuttall, P. M., 1968. The pollination of oilseed rape (*Brassica napus*) and the behaviour of bees on the crop. *The Journal of Agricultural Science*, 71, 91-94.
- Gaugitsch, H., 2002. Experience with environmental issues in GM crop production and the likely future scenarios. *Toxicology Letters*, 127, 351-357.
- Hall, L., Topinka, K., Huffman, J., Davis, L., Good, A., 2000. Pollen flow between herbicide-resistant *Brassica napus* is the cause of multiple-resistant *B. napus* volunteers. *Weed Science*, 48 (6), 688-694.

- Jackson, L. E., Pascual, U., Hodgkin, T., 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems and Environment*, 121 (3), 196-210.
- James, C., 2011, Global Status of Commercialized Biotech/GM Crops: 2011. ISAAA Brief 43, International Service for the Acquisition of Agri-biotech Applications (ISAAA), Ithaca.
- Johannessen, M., Damgaard, C., Andersen, B., Jørgensen, R., 2006. Competition affects the production of first backcross offspring on F1-hybrids, *Brassica napus* X *B. rapa*. *Euphytica*, 150 (1), 17-25.
- Levidow, L., Boschert, K., 2008. Coexistence or contradiction? GM crops versus alternative agricultures in Europe. *Geoforum*, 39 (1), 174-190.
- Lheureux, K., Libeau-Dulos, M., Nilsgard, H., Rodriguez Cerezo, E., Vorgrimler, D., 2003, Review of GMOs under Research and Development and in the Pipeline in Europe, European Science and Technology Observatory / Joint Research Centre, European Commission / Institute for Prospective Technological Studies, pp. 127.
- Lutman, P. J. W., 1993. The occurrence and persistence of volunteer oilseed rape (*Brassica napus*). *Aspects of Applied Biology*, 35, 29-36.
- Lutman, P. J. W., Berry, K., Payne, R. W., Simpson, E., Sweet, J. B., Champion, G. T., May, M. J., Wightman, P., Walker, K., Lainsbury, M., 2005. Persistence of seeds from crops of conventional and herbicide tolerant oilseed rape (*Brassica napus*). *Proceedings of the Royal Society B: Biological Sciences*, 272 (1575), 1909-1915.
- Lutman, P. J. W., Freeman, S. E., Pekrun, C., 2004. The long-term persistence of seeds of oilseed rape (*Brassica napus*) in arable fields. *The Journal of Agricultural Science*, 141 (02), 231-240.
- McGill, N. P., Armstrong, K., Dardis, J., Downey, J., Gaule, S., Lohan, G., Macken, F., O'Reilly, B., Thorp, C., Devlin, R., Leech, B., McLoughlin, T., Mullins, E., 2005, Coexistence of GM and non-GM Crops in Ireland: Report of the Working Group, Department of Agriculture, Fisheries and Food, Dublin.
- Méssean, A., 1997, Management of herbicide tolerant crops in Europe, in: *Proceedings of Brighton Crop Protection Conference - Weeds*, BCPC, Brighton, UK, pp. 947-954.
- Mullins, E., Collier, M., O'Brien, M., Meade, C., Spillane, C., 2009, Predicting the Impact of Coexistence-Guided, Genetically Modified Cropping on Irish Biodiversity: STRIVE Report 39, Environmental Protection Agency, Wexford, pp. 64.
- Norris, C., Sweet, J., 2002, Monitoring large scale releases of genetically modified crops (EPG 1/5/84). Incorporating report on project EPG 1/5/30: Monitoring releases of genetically modified crop plants, The National Institute of Agricultural Botany, Cambridge, UK, pp. 119.
- Norris, C., Sweet, J. B., Parker, J., Law, J., 2004. Implications for hybridization and introgression between oilseed rape (*Brassica napus*) and wild turnip (*B. rapa*) from an agricultural perspective. in: (H. C. M. den Nijs, D. Bartsch, J. Sweet, eds.) *Introgression from genetically modified plants into wild relatives*. Wallingford: CABI Publishing pp. 107-138.
- Norris, C. E., Simpson, E. C., Sweet, J. B., Thomas, J. E., 1999, Monitoring weediness and persistence of genetically modified oilseed rape (*Brassica napus*) in the UK, in: *Gene Flow and Agriculture: Relevance for Transgenic Crops*, BCPC Symposium Proceedings No. 72 (P. J. W.

Lutman, ed.), British Crop Protection Council, University of Keele, Staffordshire, 12-14 April 1999, pp. 255-260.

O'Brien, M., Mullins, E., 2009. Relevance of genetically modified crops in light of future environmental and legislative challenges to the agri-environment. *Annals of Applied Biology*, 254 (3), 323-340.

Paoletti, M. G., 1995. Biodiversity, traditional landscapes and agroecosystem management. *Landscape and Urban Planning*, 31 (1-3), 117-128.

Preston, C. D., Pearman, D. A., Dines, T. D., 2002. *New Atlas of the British and Irish Flora*. Oxford: Oxford University Press.

Purvis, G., Anderson, A., Baars, J.-R., Bolger, T., Breen, J., Connolly, J., Curry, J., Doherty, P., Doyle, M., Finn, J., Geijzendorffer, I., Helden, A., Kelly-Quinn, M., Kennedy, T., Kirwin, L., McDonald, J., McMahon, B., Mikeshe, D., Santorum, V., Schmidt, O., Sheehan, C., Sheridan, H., 2009, Ag-Biota - Monitoring, Functional Significance and Management for the Maintenance and Economic Utilisation of Biodiversity in the Intensively farmed Landscape (2000-CD/B1-M1), Environmental Protection Agency, Wexford.

Raybould, A. F., Gray, A. J., 1993. Genetically modified crops and hybridization with wild relatives: a UK perspective. *Journal of Applied Ecology*, 30 (2), 199-219.

Reuter, H., Schmidt, G., Schröder, W., Middelhoff, U., Pehlke, H., Breckling, B., 2011. Regional distribution of genetically modified organisms (GMOs) - up-scaling the dispersal and persistence potential of herbicide resistant oilseed rape (*Brassica napus*). *Ecological Indicators*, 11 (4), 989-999.

Rounsevell, M. D. A., Reginster, I., Araújo, M. B., Carter, T. R., Dendoncker, N., Ewert, F., House, J. I., Kankaanpää, S., Leemans, R., Metzger, M. J., Schmit, C., Smith, P., Tuck, G., 2006. A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems & Environment*, 114 (1), 57-68.

Senior, I. J., Dale, P. J., 2002. Herbicide-tolerant crops in agriculture: oilseed rape as a case study. *Plant Breeding*, 121, 97-107.

Simpson, E. C., Norris, C. E., Law, J. R., Thomas, J. E., Sweet, J. B., 1999. Gene flow in genetically modified herbicide tolerant oilseed rape (*Brassica napus*) in the UK. *Gene flow and Agriculture: Relevance for Transgenic Crops*, Symposium Proceedings no.72, 75-81.

Soliva, R., Ronningen, K., Bella, I., Bezak, P., Cooper, T., Flo, B. E., Marty, P., Potter, C., 2008. Envisioning upland futures: stakeholder responses to scenarios for Europe's mountain landscapes. *Journal of Rural Studies*, 24 (1), 56-71.

Stein, A. J., Rodriguez-Cerezo, E., 2009, The Global Pipeline of New GM Crops: implications of asynchronous approval for international trade, European Commission Joint Research Centre / Institute for Prospective Technological Studies, Luxembourg, pp. 101.

Teagasc, 2008, Sectoral Road Map - Tillage and Energy Crops, Oak Park, Carlow.

Tress, B., Tress, G., 2003. Scenario visualisation for participatory landscape planning - a study from Denmark. *Landscape and Urban Planning*, 64 (3), 161-178.

van Andel, J., Aronson, J., 2006, Restoration Ecology: The New Frontier, Blackwell Publishing, Oxford, pp. 319.

Warwick, S. I., Beckie, H. J., Hall, L. M., 2009. Gene flow, invasiveness, and ecological impact of genetically modified crops. *Annals of the New York Academy of Sciences*, 1168, 72-99.

Warwick, S. I., Légère, A., Simard, M.-J., James, T., 2008. Do escaped transgenes persist in nature? The case of an herbicide resistance transgene in a weedy *Brassica rapa* population. *Molecular Ecology*, 17 (5), 1387-1395.

Warwick, S. I., Simard, M. J., Légère, A., Beckie, H. J., Braun, L., Zhu, B., Mason, P., Séguin-Swartz, G., Stewart, C. N., 2003. Hybridization between transgenic *Brassica napus* L. and its wild relatives: *Brassica rapa* L., *Raphanus raphanistrum* L., *Sinapis arvensis* L., and *Erucastrum gallicum* (Willd.) O.E. Schulz. *Theoretical and Applied Genetics*, 107 (3), 528-539.

Wilkinson, M. J., Timmons, A. M., Charters, Y., Dubbels, S., Robertson, A., Wilson, N., Scott, S., O'Brien, E., Lawson, H. M., 1995, Problems of risk assessment with genetically modified oilseed rape, in: *Proceedings of Brighton Crop Protection Conference: Weeds*, pp. 1035-1044.

Yoshimura, Y., Beckie, H., Matsuo, K., 2006. Transgenic oilseed rape along transportation routes and port of Vancouver in western Canada. *Environmental Biosafety Research*, 5, 67-75.