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The role of regulatory mechanisms for control of plant diseases and food security - case studies from potato production in Britain.

Running title: Role of regulatory mechanisms for control of plant diseases

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Abstract

Being aware of the potentially devastating impacts of plant diseases on food security, governments have designed and employ plant health legislation to prevent or inhibit the worst impacts. The development of such policies in Britain, and latterly in Europe, can be closely linked to disease events that have occurred in the potato sector. We analyse early and current examples of policies governing potato diseases in Britain to identify the decision processes leading to the implementation of such phytosanitary polices and how they have evolved over time and in response to different disease threats. Reasons for developing and implementing phytosanitary policies include the desire to prevent pathogens being introduced (entering and establishing in a new area), the protection of export markets, and the lack of effective control measures. Circumstances in which regulatory policies would not be appropriate could include situations where a disease is already widely distributed, unacceptable costs, lack of exclusion measures, or difficulties of disease diagnosis.

We conclude that in general, government policies have worked well in protecting British potato growing over the last one hundred years, despite of the failures of some of the policies discussed here. They have also contributed much to the development of plant health policies for other crops. Voluntary grower initiatives are a new mechanism complementing existing formal policies with an additional level of

security that allows individual growers to take on additional responsibility rather than relying entirely on government legislation.

Keywords: quarantine, potato disease, plant health, policy development, regulation

1. Introduction

Plant pathogens have been the subject of biosecurity policies at a national and international scale for decades and in some cases for centuries (MacLeod et al. 2010). Increasing trade and globalization as well as climate change are among the most important factors contributing to the growing threat from the introduction of plant pests, which includes pathogens, underlining the importance of such policies and the need to keep policies up to date and relevant (Brasier 2008, Pautasso et al. in press, Perrings et al. 2005, Waage and Mumford 2008). The effects of plant diseases for global food supplies are potentially devastating and there is therefore the need to acknowledge this threat at the political level and to devote adequate resources to their control (Strange and Scott 2005).

In Europe, the development of plant protection policies has been closely linked to potatoes (Ebbels 2003) due to the economic importance of the crop and the wide range of pests that affect them. In the 19th century the Irish potato famine, caused by *Phytophthora infestans,* set a telling example of the devastating effects and far reaching consequences a plant disease could have (Bourke 1964). It also demonstrated the vulnerability of crop production to the introduction of new diseases by global trade. Due to their vegetative propagation, potatoes are particularly susceptible to the accumulation of diseases. Pathogens multiply within a growing season in seed potatoes, multiple infections can occur both within and over successive seasons and pathogens are carried from one area to another through trade. Even today with our understanding of disease epidemiology and management techniques, potato diseases are still causing considerable losses in one of the world's most important staple foods. Oerke and Dehne (2004) estimated that between 1996 and 1998, pathogens and viruses were responsible for the loss of approximately 30% of global potato production. In England and Wales the mean annual crop losses due to established diseases may account for up to 15% in ware and seed crops, equivalent to around £95million (Bradshaw et al. 2000). In a scenario analysis conducted to estimate the potential impacts of different options to revise EU pesticide legislation, the most restrictive scenario where under current management practice nearly all fungicides used to control potato fungal diseases would be withdrawn, potato production in Britain was forecast to fall by 45% (Clarke et al. 2008). Therefore preventing the introduction of further diseases, as well as preventing spread of emerging or established diseases, through implementation of policy measures, are important instruments and features for crop protection. The development of new policies should be informed by the success or failure of previous policies (Simberloff et al. 2005). Reviewing potato diseases and the long history of their regulation therefore offers an opportunity to understand better why some policies have been successful and others not. Here we use the example of potato diseases in Britain to demonstrate different policy responses and how they have evolved over time and to different disease epidemics.

2. Potato cultivation in Britain and the introduction of diseases

Potatoes were introduced into Europe around 1570 and reached Britain at the end of the 16th century (Salaman 1949). From then, potato cultivation slowly progressed from being a component of the kitchen garden to being cultivated in the open field. It is estimated that the area under potato cultivation in England and Wales increased from 20,000 ha in 1775 to more than 200,000 ha by the end of the 19th century (Salaman 1949). From the beginning of the 20th century there was a steady decline in the area of potatoes grown in Great Britain, except for the period during the Second World War, 1939-1945. As area declined there was a commensurate increase in yield from around 15 t/ha up to the 1920s to more than 40 t/ha in the 2000s (Figure 1).

The first reports of serious impacts of potato diseases in Britain date back to the 1760s when a condition termed 'the Curl' was reported to threaten potato cultivation in Lancashire (Glendinning 1983). Descriptions of the symptoms suggests that severe virus infections were the main cause, probably mostly *Potato leaf roll virus* and to a lesser extent mosaic type viruses (Glendinning 1983). It was soon realised that the disease did not occur in northern areas or at higher altitudes and as a consequence the practice of using seed potatoes from these disease free areas, mainly in Scotland, developed. However, a correlation between the absence of disease and the absence of aphid vectors was not realised at the time. The main disease 'event' in the 19th century was the arrival of blight (*Phytophthora infestans*) in the 1840s with the resulting severe famine in Ireland. The last of the three "limiting factors" which Salaman (1949) considered as threatening the British potato crop with almost complete destruction was wart disease, caused by the fungal pathogen *Synchytrium endobioticum*, probably present in Britain by 1876.

The first review of potato diseases in Britain was published in 1914, listing 9 diseases (Horne 1914). In 1917, the Food Production Department of the Board of Agriculture and Fisheries formed a committee advising on questions related to plant diseases and insect pests (Board of Agriculture and Fisheries 1918). This committee received monthly reports from their 30 ‘Honorary Correspondents’ located in different districts in England and Wales. The reports were summarised and published in annual reports by the Board and later by the Ministry of Agriculture and Fisheries up until 1946, and from 1957 – 1968. The first report for 1917 counts 13 diseases and three disorders, then assumed to be caused by growing conditions (Board of Agriculture and Fisheries 1918) but with two of them later recognised as virus diseases. The report for 1921 lists 21 potato diseases and physiological disorders occurring, out of 391 plant diseases in crop plants described for England and Wales at that time (Cotton 1922). Today, more than 30 bacterial, fungal and viral diseases are known to affect British potatoes with 16 mentioned in the 1996-2000 analysis of potato diseases of higher importance (Bradshaw et al. 2000). This increase in the number of diseases reflects both progress in the identification and description of diseases as well as the arrival of additional diseases over this period (Figure 2). An analysis of disease introductions by Jones and Baker (2007) found that four new potato diseases entered Britain between 1970 and 2004: dry rot/gangrene (*Fusarium trichothecioides*) in 1982, *P. infestans* A2 mating type in 1983, brown rot (*Ralstonia solanacearum*) in 1992 and ring rot (*Clavibacter michiganensis* subsp. *sepedonicus*) in 2003 and 2004. Ring rot was subsequently eradicated and it is no longer present (see section 4.2 below). A fifth disease, caused by *Erwinia chysanthemi* (now known as *Dickeya dianthicola*), not included in Jones & Baker (2007), was already present in Britain on ornamentals but was first found on ware potatoes, grown from seed potatoes from the Netherlands, in 1990. More recently a new strain of *Dickeya* spp. has been detected on potatoes in England with the proposed name *D. solani* (Elphinestone 2009).

3. Policies

The early policies in Britain can broadly be divided into those dealing with the prevention of the introduction of diseases from outside Britain, the prevention of establishment of diseases after their arrival as well as policies to control common and widely distributed diseases (Fryer 1939). To achieve this – based on the powers given in the “Destructive Insects Act, 1877” and the subsequent “Destructive Insects and Pests Act” in 1907 - the foundations and basic principles of a plant health system in Britain were set, including, for example, the inspection and notification system, the listing of quarantine species and the powers to destroy infested crops (Ebbels 2003). Under the Act a series of Orders affecting potatoes were issued dealing more specifically with the control of certain diseases (e.g. Wart Disease of Potato Orders), the prevention of introduction of new diseases (Importation of Plants Order, 1933) and the control of widely distributed diseases by ensuring a healthy planting stock (Seed Potatoes Order, 1918; Sale of Diseased Plants Order, 1927). Three of our examples (wart disease, powdery scab and blackleg) are selected to illustrate the variety of early policies used and how they have developed over time.

The main elements of these policies form the foundation of the current policy framework governing the protection of potatoes from plant diseases in Britain. Policies have been developed that operate at a variety of spatial scales. Some deal with specific diseases whilst others are more general and protect crops from a range of diseases. These are implemented at the international, national, and regional level. Whereas national and regional policies aim to prevent the introduction and spread of pathogens into and within a country, thereby protecting national potato industries including their export activities, international policies are designed to prevent the distribution of pathogens between all countries. Figure 3 illustrates the current disease protection for potato production in the UK which is governed by a European Commission Directive, 2000/29/EC (Anonymous 2000) known as the Plant Health Directive, and 2002/56/EC On the Marketing of Seed Potatoes (Anonymous 2002), as well as more specific 'control' Directives dealing with particular quarantine diseases, for example, ring rot or brown rot. These EU Directives are implemented at a national and regional level in regulations such as the Plant Health (England) Order 2005 or the Seed Potatoes (Scotland) Regulation 2000. In addition, national standards may contain further regulations to guarantee higher plant health standards. For example, the Scottish and English Seed Potato Classification Schemes require rotational periods of four, five or seven years depending on the level of classification. Many of the early policies are now integrated in this system. We use the example of ring rot to illustrate current policies for quarantine diseases.

The mechanisms for change in policies are normally via national or EU regulations and are instigated by grower, trade or the official plant health service seeking to develop proposals in anticipation of, or in response to, new concerns or outbreaks of new or increasingly important organisms. Governments increasingly value the input and views of stakeholders in developing policy (MacLeod et al. 2010) and can engage with stakeholders through direct correspondence and with the broader public through publishing information on official websites, where feedback is invited (for example see http://www.fera.defra.gov.uk/plants/plantHealth/pestsDiseases/praTableNew.cfm). National certification schemes can be changed by the relevant EU member state in conjunction with interested parties provided there are no detrimental implications for other member states. However, the concern is that due to the single market, there needs to be free marketing of seed potatoes throughout the EU. Changes in EU policies and organisms listed for 'quarantine' regulation must be agreed at the EU level, usually following an assessment of pest risk and discussion at the Standing Committee for Plant Health. Removal of listed organisms or amendments of the conditions for control follow the same procedures. There are many economic and practical reasons to be considered and opinions between member states can vary widely. Changes to the EU Marketing Directive for Seed Potatoes, which is applicable to all EU member states, have a similar procedure.

In the following section we present four case studies: the first two (wart disease, ring rot) are chosen to show historical and current applications of quarantine policies, the third example (blackleg) illustrates the use of certification schemes, and the last how national schemes have been used (powdery scab). Our examples also show that often a combination of policies is used over time or if dealing with different aspects of diseases, making it difficult to place diseases into single policy categories.

4. Examples

4.1 Using quarantine legislation to develop successful plant health policy on a specific potato disease: Wart disease (*Synchytrium endobioticum*)

The example of wart disease shows how policies have been able to control and repress a disease that was considered to be one of the three worst potato diseases affecting Britain at the beginning of the 20th century (Salaman 1949). The pathogen causes the development of galls on tubers and stolons that can replace the whole tuber if the infection occurs early in the season under favourable soil conditions. The fungus produces resting spores that are able to survive in the soil for more than 40 years (Wale et al. 2008). Crop losses of up to 100% are possible in badly infested soils

(Hampson 1993). *S. endobioticum* arrived in Britain from South America probably with new potato varieties that were introduced in the aftermath of the 1840s blight epidemic whilst growers were searching for more resistant varieties (Hampson 1993). The disease was probably present in Britain by 1876 (Salaman 1949) from where it subsequently spread to other European countries, North America, Africa and New Zealand (Hampson 1993). This resulted in a ban of potato imports from Britain to the USA and Canada in 1912 causing a reduction of British exports of 20% and a loss of £1 million (Pratt 1979). In contrast, the actual crop losses at that time seem to have been small in relation to the total crop in Britain (although losses may have been locally severe). The annual report of the Intelligence Division of the Board of Agriculture and Fisheries in 1913 stated that there were 'probably scarcely five hundred acres in all England which are under cultivation for potatoes as field crop which are liable to be affected while even in these the proportion of diseased tubers is generally trifling' (cited in Horne 1914). The spread of the disease, however, continued and the ministerial annual disease occurrence reports continuously reported new outbreaks in previously unaffected areas cumulating in a total of 22,222 reported outbreaks in England by 1919 (Hampson 1993) (Figure 4). It had also been realised that the pathogen was spread with infected seed potatoes or seed contaminated with infested soil and that some varieties were immune to the disease. However, the naming of potato varieties was beset by confusion over synonyms and lack of purity making the purchase of known immune varieties very difficult for the grower. Based on this knowledge, the first policy measures were introduced in 1907 under the Destructive Insects and Pests Act, making the disease notifiable and, in 1910, giving local authorities and inspectors the power to control outbreaks (Pratt 1979). In 1912 the first Wart Disease of Potatoes Order was issued, followed by the first Seed

Potatoes Order in 1918. Several updates of the Wart Disease Order followed and a Seeds Act of 1920 made the certification of seed potatoes almost compulsory (Ebbels 2003). The aim of these policies was to prevent further spread by containing the disease in declared ‘Infected Areas’ in which planting of non-immune varieties was prohibited through the Wart Disease Order and to make sure that growers could get immune varieties in the seed potato market. However, continued spread of the disease showed that these policies were not sufficient and therefore, in 1923, a more stringent Wart Disease of Potato Order (1923) came into force. The most important feature of the new policy was the prohibition of the planting of seed potatoes in England and Wales that had not been certified as immune varieties, or grown on land free from the disease, or been certified as disease free by an inspector (Pethybridge 1926). Furthermore, any movement of potatoes out of an infected area was prohibited, with the exception of ware potatoes of immune varieties for consumption. Finally, in 1941 the success of these policies could be seen and the Order was relaxed. Although the disease still had to be notified and certain measures had to be taken on infected land it was no longer considered necessary to maintain a system of ‘infected areas’ or ‘clean land certificates’ (Moore 1944). Whereas in 1917 nearly 5,000 new outbreaks were reported this figure fell to less than one hundred at the beginning of the 1940s. This success was also attributed to the efforts of plant breeders to produce more disease resistant varieties and it was estimated that by 1944 around two thirds of potatoes grown were of resistant varieties (Moore 1944). In the 1950s, levels of new confirmed outbreaks, mainly in allotments and gardens, were down to ‘a dozen or so’ each year (Baker 1972). The last outbreaks on commercial farms in England and Wales occurred in 1985 when three were detected; since then there have only been a few in private gardens or allotments, with the last in 2008 (figure 4). No outbreaks have occurred in Scotland since 1979 or in Northern Ireland since the 1950s. However, 700 ha in England and Wales and about 8,000 ha in Scotland remain classified as ‘scheduled land’ under restrictions (Reed 2004) although much of this is no longer farmland.

Present national legislation governed by EC legislation implemented in national law is based on the same principles that were successfully applied to control wart disease in Britain in the first half of the 20th century by identifying infected areas and safeguarding the supply of immune varieties. Land found to be infected is ‘scheduled’ under statutory notice and no potatoes are allowed to be grown in the field and only ‘immune’ varieties in a surrounding safety zone. These restrictions have no time limit and under EC legislation can only be removed if the pathogen is “no longer found to be present” (Anonymous 1969). The European and Mediterranean Plant Protection Organization (EPPO) produced a procedure for ‘de-scheduling’ infested land including a period of no infestation of 20 years since the last positive testing, cultivation of the land in that period (no grassland) and certain testing and other requirements (EPPO/OEPP 1999). If soil testing shows no infestation by viable spores is present, all restrictions on the land can be lifted. The UK Government Department for Environment, Food and Rural Affairs (Defra) has successfully completed de-scheduling of four fields covering 11.4 ha to date, but sampling and testing are laborious and expensive. However, the long term outlook for eradication is good. If fields where it is more than 50 years since the last outbreak are automatically de-scheduled (as is being proposed for the next revision) then only a few fields would need to be tested and found free of the pathogen, to declare England and Wales to be free of the disease, assuming no more outbreaks occur.

Nevertheless, the disease is still regarded as a substantial threat to potato production in the UK and worldwide. New pathotypes have been found in continental Europe in recent years where it is more difficult to find resistant potato varieties (Baayen et al. 2006). For these reasons, EU and UK legislation continues to require controls on seed potatoes for potato wart disease (Figure 3), in particular to prevent the introduction of new pathovars into and within EU Member States.

4.2 Current EU quarantine legislation: Ring rot *(Clavibacter michiganensi*s subsp. s*epedonicus*)

Ring rot is one of the most regulated potato diseases and is included as a quarantine disease in international, regional and national regulations. Such legislation reflects the view that it is regarded as the world's most important disease of seed potatoes. It occurs mostly in cool temperate regions. Long latent periods and the general absence of symptoms in some cultivars complicate detection and control (Stead 1999). In the EU, Council Directive 93/85/EEC on the control of potato ring rot aims to "(a) locate it and determine its distribution; (b) prevent its occurrence and spread; and (c) if found, to prevent its spread and to control it with the aim of eradication" (Anonymous 1993). Member states are therefore obliged to conduct regular surveys to detect possible outbreaks and confirm the national status of the disease. In addition, the national seed potato certification schemes set up under the Council Directive 2002/56/EC on the marketing of seed potatoes do not allow any tolerances of ring rot (Anonymous 2002). As figure 3 shows, any potatoes entering the UK need to be accompanied by official statements confirming disease free status of the exporting country (if the exporting country is not an EU member state) or in the case of EU member states the producer has to be a registered grower free from ring rot. The first ring rot outbreak in the UK in 2003, originating from seed stock derived from the Netherlands, was contained and establishment of the pathogen prevented by following the control measures of the policy (DEFRA 2004) . Since then there have only been two other outbreaks, one at a farm in Lincolnshire and another at a farm in Herefordshire, both outbreaks were in 2004 and both farms had sourced seed potatoes from the same Dutch source. Both outbreaks were successfully eradicated. The complex policies controlling ring rot disease and the impacts they have on the potato trade have been analysed using bio-economic models comparing prevention policies versus a 'no-policies' approach leaving control to individual farmers (Waage et al. 2005). In the scenario analysed, an outbreak of ring rot in the UK is imagined and no eradication is attempted. As a result the disease establishes and the costs of production rise. A proportion of export markets for affected products is permanently lost, and yield losses (despite control) increase. Waage et al. (2005) conclude from their model that the UK potato industry is expected to benefit from the exclusion of ring rot by around £0.6 million per year, mainly by not loosing valuable potato export markets. An earlier cost-benefit analysis of UK plant health quarantine measures in 2000 related to ring rot estimated the potential cost of establishment of the disease in Britain at £10.68 million (within a range from £3.46 to £14.46 million) per year arising mainly from losses in the seed potato sector, whereas the costs for the phytosanitary measures to keep the disease out were £222,000 per year (Temple et al. 2000). It is not entirely clear why there are differences of this magnitude in these figures but one interpretation may be that different approaches were used (stochastic modelling versus cost-benefit analysis), as well as a number of factors that were not taken into account in the model by Waage et al. (2005) but which were included in the cost-benefit analysis of Temple et al (2000), such as the costs for additional land required to grow the same amount of potatoes should the disease reduce yields. This also demonstrates some of the difficulties policy makers face when taking into account such analyses in their decision making process. Nevertheless, among British potato farmers the level of protection provided by these policies was not perceived as high enough and in response to the 2003 outbreak the 'Safe Haven Certification Scheme' was initiated by the British Potato Council and set up in 2005 (Potato Council 2009). Starting from fully tested nuclear stock and using rigorous hygiene procedures in the seed supply chain, prohibition of entry of other stocks and guarantied traceability of seed stock origin, the scheme aims to prevent the disease entering the British potato market. The scheme operates on a voluntary basis and although many seed producers have signed up to it, this effort could be undermined if the disease was introduced by any of the non-affiliated seed producers of imported seeds causing the loss of disease-free status of the UK for the whole industry.

4.3 Using seed marketing legislation and industry self regulation: Blackleg *(Erwinia carotovora* var. *atroseptica)*

The following example of the bacterial disease blackleg shows how policies can change and adapt once the initial aim of controlling and possibly eradicating a disease is not met. Blackleg was of sporadic occurrence in the beginning of the 20th century in Britain (Horne 1914). Knowing that the disease spread with infected tubers, blackleg policies were designed to ensure healthy planting material. Therefore, the first policy measure was to list blackleg together with wart disease in the first 'Sale of Diseased Plants Order, 1921' which prohibited the sale of plants or any parts of plants infected with any of the diseases or pests listed in the Order. However, in the second edition of this order published in 1927 it was no longer included. This may have been because the disease was then so widespread that it was presumed control through the Order was no longer practical. The annual ministerial reports for this time give some evidence of the fairly common distribution of the disease, for example mentioning it causing "ravages second only to Blight" in the northern parts of England in 1929 (Pethybridge 1929). Other reasons may have been that the infection could not be identified in tubers easily, with the symptoms emerging only later in storage or in growing plants if seed potatoes were sold. There were also some doubts about the epidemiology of the disease and suggestions it may frequently be transmitted in soil water and not always in seeds alone (Moore 1944) or even as aerosols in the air. Nevertheless, the idea of controlling the disease using legislation was not abandoned. When the seed potato certification schemes incorporated plant health aspects (previously only certifying trueness to varietal type) in Scotland in 1936 and in England in 1940 (Ebbels 1979), blackleg was not specifically included. However, levels of virus infections became regulated. Nevertheless, blackleg management benefited through the general health requirements of the schemes. Today the EU Council Directive 2002/56/EC on the marketing of seed potatoes (Anonymous 2002), prescribes maximum allowed levels for growing plants being affected by blackleg of 2% for the 'basic' seed potatoes category and 4% for the 'certified' category, although these levels can be stricter in national certification schemes. For example, the English and Scottish Seed Potato Certification Schemes have maximum tolerances of 0.25 – 2.00% in growing plants depending on the classification class and category.

Since blackleg was first included in the Sale of Diseased Plants Order in 1921, the control of blackleg relies primarily on the production of healthy seed tubers governed by regulating policies. One reason for this is that no chemical control measures or resistant cultivars seem to be available (Pérombelon 2000). Over time blackleg has become less of a problem which may be seen as the result of a policy working well. However, the improvement has undoubtedly also benefitted from improvements in crop husbandry, especially seed storage and reduction in tuber damage (Pérombelon 1992).

4.4 Using national non statutory schemes: Powdery scab (*Spongospora subterranea*)

The following example shows that official regulation may not always provide an optimal solution to dealing with plant disease when the risk to exports is high yet the threat to food security is perceived as low and as a consequence policies are not enforced.

Powdery scab was first found in Britain in 1846 (Harrison et al. 1997) and then called 'Corky Scab'. The disease causes warts and pustules containing a dusty spore mass in infected potato tubers (Jeger et al. 1996). The impact of the disease in Britain in the beginning of the 20th century was not regarded as very serious although considerable crop losses reported from Ireland and the quarantine measures imposed on foreign potatoes in the USA because of the disease were of some concern (Horne 1914). Nevertheless, a 'Potato Corky Scab Order' was adopted in 1914, working in a very similar way to the wart disease order making corky scab a notifiable disease, declaring any land where it had been found as "infected premises" and giving local authorities the power to impose measures to prevent further spread. Documents in the National Archive (MAF 133/45) from the Ministry of Agriculture related to this Order produce some interesting insights into the reasons why the Order was implemented and later suspended and revoked in 1957. It becomes clear that the main reason for the order was the import ban in the USA for potatoes from Britain and the request from the US Government to demonstrate that the exporting areas were free from the disease before the ban could be lifted. In May 1914, the Secretary of the Vice President of the Department of Agriculture in Dublin informed the Board that his Department did not see any reason for a similar order in Ireland because it was considered to be a harmless disease in Ireland as well as in England, not affecting market value or yield and extremely impractical to enforce. This was due to the difficulty in identification of the mostly very slight manifestation of the disease and the problem of confusion with common scab. This statement appears to contradict scientific data cited in Horne (1914) detailing the negative impacts of the disease in Ireland and probably reflects the perception that the proposed policy may be impractical to operate. Indeed, in England and Wales the Order was soon found impractical and it was suspended in 1918. However, two years later, in 1920 severe outbreaks of corky scab led to calls for a revision of the Order. It was decided not to do so for the following reasons: (1) the widespread distribution of *S. subterranea* in the country and the fact that there were no large areas of land free from the disease; (2) the dependence of the disease on weather and local soil conditions, and (3) the difficulty of identification of the disease which would make it necessary to employ more inspectors and involve extra expense (Anonymous 1921). Corky scab was later regulated by inclusion in the Sale of Diseased Plants Orders of 1922, 1927 and 1936 under which tubers substantially affected by the disease could not be sold for planting. *S. subterranea* continued to spread and in 1947 a ministerial memo concluded that it was doubtful that there remained any potato land in England and Wales to which the disease had not been introduced with Scottish seed potatoes. Another internal memo by the Ministry of Agriculture in 1957 stated that it had not been possible to trace a single notification of the disease under this Order. The American market had remained closed for British imports but new export markets had emerged making the main reason for the Order obsolete. Furthermore, it was thought to be damaging to have an Order in place which was not enforced when at the same time strict adherence to the Wart Disease of Potato Order was expected. Therefore, the Order was finally revoked in 1957.

Today, rotational periods in seed certification schemes are the only policy measure remaining to control corky scab. The importance of the disease has increased in recent years due to higher quality demands and the rejection of infected seed potato tubers as well as the increased planting of highly susceptible cultivars (Jeger et al. 1996, Wale et al. 2008). The soil-borne pathogen is also important as a vector for the transmission of *Potato mop-top virus* (PMTV) (Jones and Harrison 1969).

5. Discussion and conclusions

The examples of plant health policies for potato diseases analysed here show how over the last one hundred years a complex plant health policy framework has developed to protect potato crops in Britain. From these examples Table 1 summarises some of the reasons that have been put forward for and against the implementation of phytosanitary policies. Among the reasons for having phytosanitary policies, the most straightforward is the prevention of the introduction and establishment of new diseases. Another is the protection of global export markets, one of the main reasons for policy measures against potato wart disease and ring rot today. The protection of export markets was also a historical driver when British exports to the USA were threatened. In the case of powdery scab it seems to have been the only reason for a policy that was never enforced and perhaps only served the purpose of demonstrating control activity to the outside world. A very recent example for the importance of policies for the protection of export markets is the Scottish

Government consultation on the emerging new pathogenic strain *Dickeya solani* (Anonymous 2009) conducted in late 2009/early 2010 and which came into force in March 2010. *D. solani* has caused considerable losses in the Dutch seed potato industry in recent years and was found in England and Wales in 2007 for the first time (Elphinestone 2009). Scottish seed potatoes have so far not been affected. However, *D. solani* was prior to this not included in any certification policies. The amendment of the Scottish seed potato certification policies sets a zero tolerance level for the disease giving Scottish seed potatoes the official recognition of the disease free status and thus potentially a national and international marketing advantage. Stakeholders consulted about this were presented with the pros and cons of this option as well as the option of doing nothing (Anonymous 2009). Introducing this amendment could result in a continued market advantage for Scottish seed potatoes but also bears the risk that if the disease were to become established some growers may suffer economic losses because of failure of their seed stocks which have to be destroyed under the new policy. Then, if further spread in Scotland occurred, and the tolerance levels were relaxed, this could harm the reputation of Scottish seed potatoes, suggesting that they are no longer safe, and could cause a loss in confidence in export markets. This consultation is a good example of a more inclusive decision making process which goes beyond the traditional interactions between scientists and policy advisors to include stakeholders and the general public (MacLeod et al. 2010). Another reason why policies are implemented for certain pathogens is the difficulty of controlling them by other means. This is illustrated by the example of blackleg policies. Similar policies are common, for example for virus diseases that cannot be controlled by chemical measures or crop cultivation techniques. Here seed potato certification policies are used to ensure certain maximum tolerance levels are not exceeded and thus maintain a reasonable marketable quality. Such certification schemes are not trying to eradicate or claim complete freedom from diseases they aim to control. Seed certification schemes can also ensure certain standards of cultivation techniques such as the length of rotational periods to control soil-borne diseases. Policies for widespread diseases may become increasingly important for diseases previously easily controlled by pesticides due to changes in pesticides legislation and the withdrawal of some previously approved substances.

Historically there has been little publically available information showing decision-making processes which lead governments to introduce legislation or leave industry to voluntarily control a disease problem. The examples provided, e.g. powdery scab, give some reasons that are still valid today. The policy discussions following the most recent pathogen introduction of the A2 type of *P. infestans* - possibly from Mexico in a quarantine-breaking shipment following a drought in Europe in 1977, resulting in potato shortages (Hardwick 2006) - further illustrate some of these reasons. For the A2 type of *P. infestans* it soon became apparent that there was no practical way of controlling it by legislation or certification, because it cannot be distinguished visually from the endemic strain, and the geographic distribution of the new type was unknown. Also, because it is caused by an airborne organism, blight cannot realistically be controlled by isolation, roguing or other recognised certification scheme procedures. Instead it can only be limited by setting tolerances in harvested tubers. Currently a tolerance maximum of 0.5% tubers can be infected for all basic and certified categories in the English scheme. Control and management of most established and widespread diseases are therefore left to individual farmers or incorporated into seed certification schemes which are only partly effective. Wart disease remains a rare example of how a statutory policy has succeeded in containing a disease that was already well established in large parts of the country. Costs of policies have also been an early criterion for the decision process that is now becoming increasingly important and underlined by cost-benefit analyses and economic modelling (MacLeod 2007). The example of ring rot shows that the quarantine measures set at the European level are economically benefitting the UK potato industry, with potential losses from lost exports having the biggest impact (Temple et al. 2000; Waage et al. 2005). Economic analyses and modelling are also used to assess trade-offs between prevention, control strategies and potential eradication (Touza et al. 2007). For brown rot in the Netherlands, Breukers et al. (2007) used bio-economic modelling and scenario analysis to show that the cost-effectiveness of brown rot (*Ralstonia solanacearum*) control is determined, to a large extent, by a small number of governmental policies and efforts within the potato sector supply chain to minimise infections .They found that governmental policies dealing with the sampling strategy to detect infected sites could be set at reduced levels if at the same time the sector maximises efforts to reduce infections through improved farm hygiene and reduction in illegal use of surface water for irrigation, which were identified as the most important sector factors in the model. This would result in governmental savings in control costs of 2 million Euros annually and in a reduction of disease incidence by 75% .

Carrasco et al. (2010) developed an economic model to determine concurrent optimal exclusion, detection and control of multiple plant pests and diseases, including ring rot. Our examples show how policies are an integral part of the disease protection system for potato growing. In particular the development of the policies against wart disease has provided evidence of successful principles of plant health and quarantine that are now widely used for the control of other diseases. The use of infected and non-infected areas, standards controlling the naming of potato varieties as well as seed potato certification schemes have all been developed in the fight against wart disease and it is not surprising that in 1951 the National Agricultural Advisory Service concluded “it may fairly be suggested that to this extent the disease has proved a blessing in disguise” (Owen 1951). Compared to other arable crop plants, potatoes, at least in Europe, seem to be very well protected by phytosanitary policies underlining their particular vulnerability but also their importance for the global provision of food. The question remains how flexible the current system is to adapt to new emerging diseases resulting from climate change, the increasing globalisation of trade and transport and agricultural change (Anderson et al. 2004). The general import prohibition of seed potatoes from outside the EU as well as restrictions on the introduction of other plants of the family Solanaceae seem to be a prevention strategy that few other crop plants or sectors have, with the exception of *Citrus* and to a certain extent other fruit tree species. Nevertheless the emergence of new diseases like *D. solani* and new strains of existing diseases show that plant health and food security is about managing the pest risks associated with the movements of plants and plant products and can never be totally secure (MacLeod et al. 2010). Non-governmental voluntary initiatives such as the British Potato Council Safe Haven scheme (Potato Council 2009) add a new level of flexibility to adapt to new diseases quickly, leaving the decision to act to individual farmers joining the scheme rather than to governments. Based on the principle to propagate only from British pre-basic seed potatoes in a closed system, the Safe Haven Scheme delivers a high level of protection which may be difficult to achieve by non-voluntary policies due to the market restrictions on the origin of new propagation material that this would impose. The Safe Haven Scheme has already proved this flexibility. Originally set up to increase the protection against ring rot it is now perceived as the only already existing protection mechanism against *D. solani,* although the voluntary nature of the scheme does allow for extra conditions to be used above those required in the statutory certification scheme. We conclude that in general policies have worked well in protecting British potato growing over the last hundred years, despite of the failures of some of the policies discussed here. New pathogens or wart pathotypes have not spread widely over the last few decades or so, which is also the result of more thorough inspection controls and monitoring, and improved diagnosis as well as faster communication. Potato policies have also contributed much to the development of plant health policies for other crops. Voluntary grower initiatives are a new mechanism complementing existing formal policies with an additional level of security that allows individual growers to take on additional responsibility rather than relying entirely on government legislation.

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Table 1: Reasons for and against implementing quarantine policies for the control of plant diseases

Figure 1: Area of potatoes grown (bars) and yield (line) in Britain from 1917 to 2006. Data sources: (DEFRA 2008, Ministry of Agriculture Fisheries and Food and Department of Agriculture and Fisheries for Scotland 1968) (Data for the years 1967 to 1972 not available).

Figure 2: Introduction of potato diseases into Britain. The dates correspond to the first year of description.

Figure 3: Potato disease protection in the UK: CMS – *Clavibacter michiganensis* subsp. *sepedonicus* (ring rot), SE - *Synchytrium endobioticum* (wart disease), PSTVd – Potato spindle tuber viroid, PSM - Potato stolbur mycoplasma, RS – *Ralstonia solanacearum* (brown rot)

Figure 4: Outbreaks of wart disease in England and Wales from 1917 till 2008 and timeline of policy measures against the disease.

Table 1

Reasons for policies	**Example disease**	**Example of policy**
Prevent introduction	ring rot,brown rot, wart disease (other pathotypes not present in UK)	EU Plant Health Directive 2000/29/EC as implemented by Plant Health Order 2005
Prevent establishment	ring rot, brown rot, wart disease (other pathotypes not present in UK)	EU Plant Health Directive 2000/29/EC as implemented by Plant Health Order 2005
Disease control	blackleg, virus diseases, wart disease	Sale of Diseased Plants Order 1927, Seed Potato Certification Schemes. Wart Control Directive as implemented by Plant Health Order 2005
Potential loss of export market	wart disease, ring rot, brown rot, powdery scab	Wart disease orders (see text for details) Plant Health Order 2005
Reasons for not having policies		
Pathogen very common	powdery scab	
Pathogen controlled by other means		
Too expensive	powdery scab	
No policies available that would control the disease	*P. infestans*	
Identification	A2 *P. infestans* mating type	Pathogen difficult to separate and identify from 'normal strain'

Figure 1

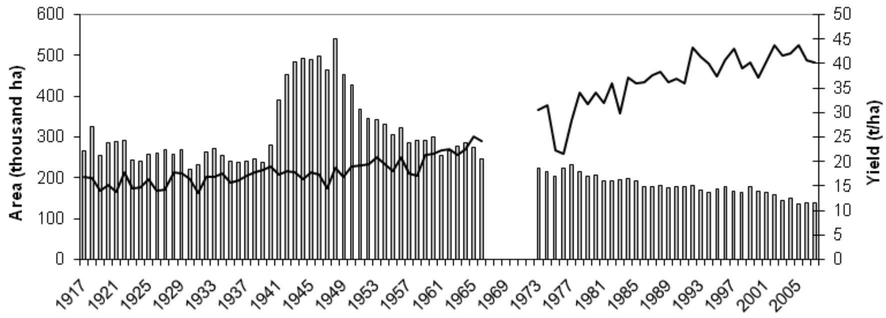


Figure 2

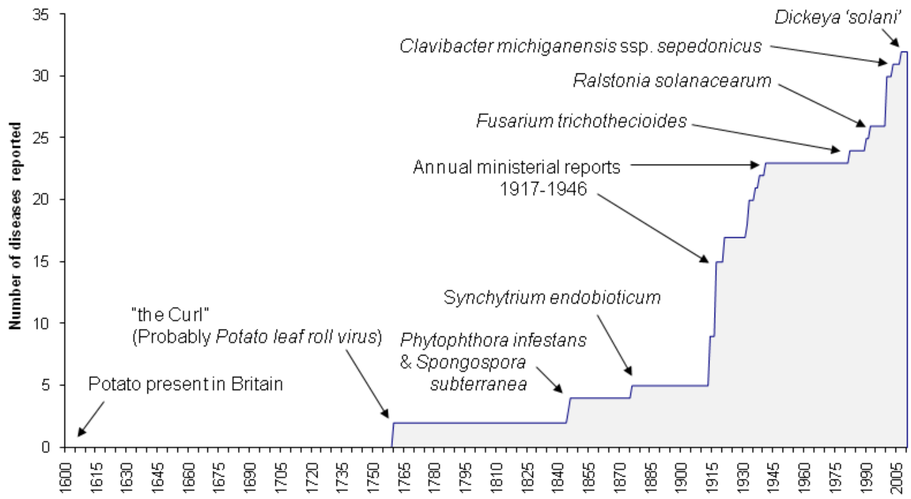
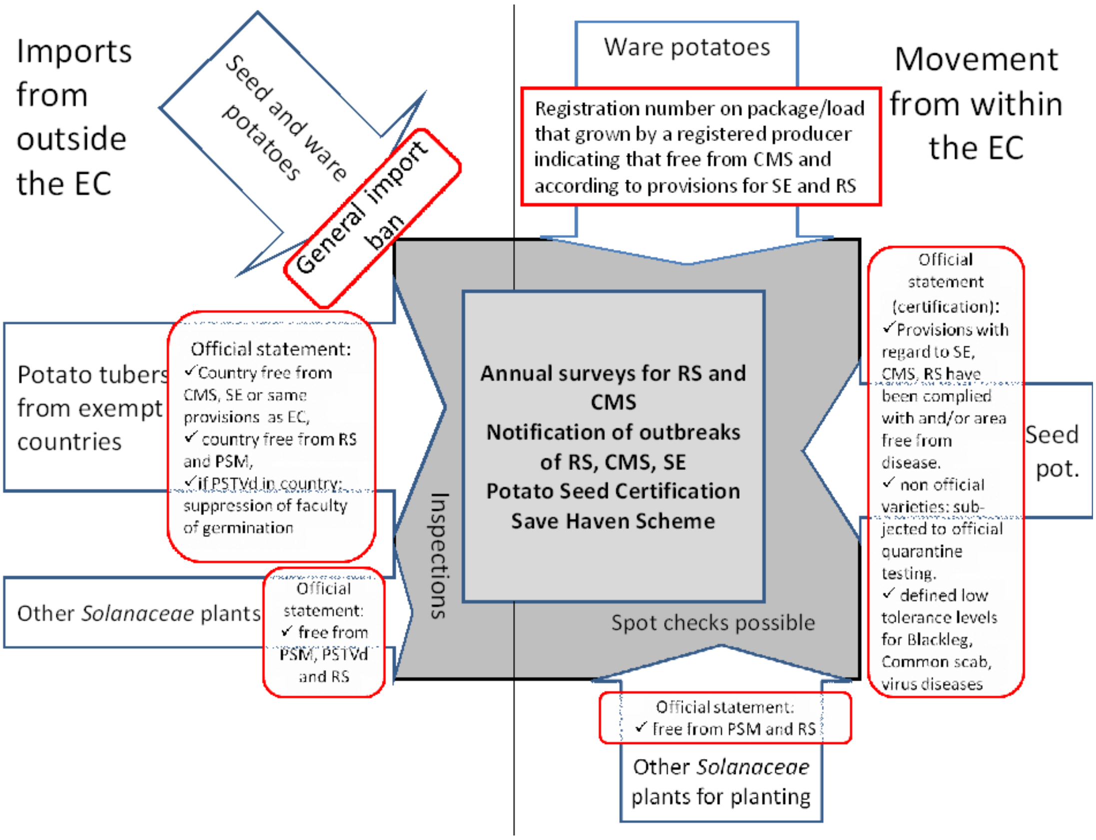
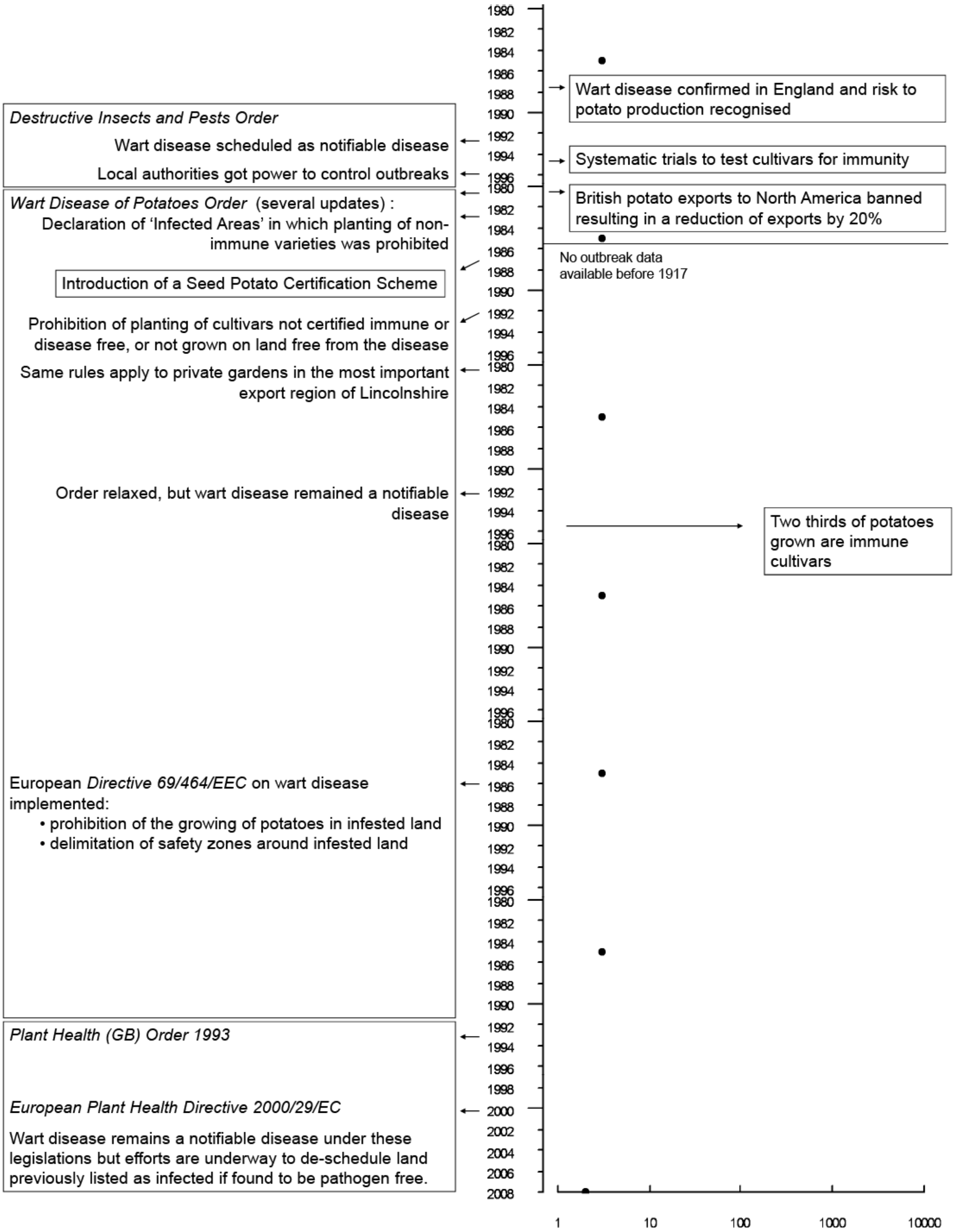


Figure 3



Imports from outside the EC
Seed and ware potatoes
General import ban
Ware potatoes
Registration number on package/load that grown by a registered producer indicating that free from CMS and according to provisions for SE and RS
Movement from within the EC
Potato tubers from exempt countries
Official statement:
✓Country free from CMS, SE or same provisions as EC,
✓ country free from RS and PSM,
✓if PSTVd in country: suppression of faculty of germination
Annual surveys for RS and CMS
Notification of outbreaks of RS, CMS, SE
Potato Seed Certification
Save Haven Scheme
Inspections
Official statement (certification):
✓Provisions with regard to SE, CMS, RS have been complied with and/or area free from disease.
✓ non official varieties: subjected to official quarantine testing.
✓ defined low tolerance levels for Blackleg, Common scab, virus diseases
Seed pot.
Other Solanaceae plants
Official statement:
✓ free from PSM, PSTVd and RS
Spot checks possible
Official statement:
✓ free from PSM and RS
Other Solanaceae plants for planting

Figure 4



Destructive Insects and Pests Order
Wart disease scheduled as notifiable disease
Local authorities got power to control outbreaks
Wart Disease of Potatoes Order (several updates) :
Declaration of 'Infected Areas' in which planting of non-immune varieties was prohibited
Introduction of a Seed Potato Certification Scheme
Prohibition of planting of cultivars not certified immune or disease free, or not grown on land free from the disease
Same rules apply to private gardens in the most important export region of Lincolnshire
Order relaxed, but wart disease remained a notifiable disease
European Directive 69/464/EEC on wart disease implemented:
• prohibition of the growing of potatoes in infested land
• delimitation of safety zones around infested land
Plant Health (GB) Order 1993
European Plant Health Directive 2000/29/EC
Wart disease remains a notifiable disease under these legislations but efforts are underway to de-schedule land previously listed as infected if found to be pathogen free.
Wart disease confirmed in England and risk to potato production recognised
Systematic trials to test cultivars for immunity
British potato exports to North America banned resulting in a reduction of exports by 20%
No outbreak data available before 1917
Two thirds of potatoes grown are immune cultivars
1 10 100 1000 10000