QUANTITATIVE PEST RISK ASSESSMENT FOR THE POTATO BROWN ROT BACTERIUM *RALSTONIA SOLANACEARUM* (RACE 3 BIOVAR 2) IN FRESH POTATO IMPORTS TO NORWAY FROM EGYPT

PATHWAY ORIGIN	EGYPT
PATHWAY	FRESH POTATOES FOR CONSUMPTION
PEST RISK ASSESSMENT AREA	NORWAY
PEST ORGANISM	RALSTONIA SOLANACEARUM (RACE 3 BIOVAR 2)
COMMISSIONED BY	NORWEGIAN FOOD SAFETY AUTHORITY
DATE	NOVEMBER 1ST 2004
AUTHORS	DR. TROND RAFOSS; DR. ARILD SLETTEN

CONTENTS

FOREWORD

Currently, there are no internationally agreed standard, scheme or prescribed way to conduct a Quantitative Pest Risk Assessment for Plant Pests. The present Quantitative Pest Risk Assessment is based on the International Standard for Phytosanitary Measures (ISPM) No 11 (ISPM Pub. N° 11 2004) with respect to what qualitative aspects that have been considered and regarding the proposition of the risk assessment report. The Pest Risk Assessment scheme developed by the European and Mediterranean Plant Protection Organisation (EPPO 1997d) has also been used as a supporting tool for the present Pest Risk Assessment (PRA).

For definitions of the terminology used in this PRA it is referred to the Glossary of Phytosanitary terms (FAO 2002).

Stage 1: Initiation

1.1 INITIATION POINTS

1.1.1 PRA INITIATED BY THE IDENTIFICATION OF A PATHWAY

This Pest Risk Assessment (PRA) is initiated by the identification of a new pathway. The pathway is import of fresh potatoes from Egypt to Norway. Egypt represents a new country of origin for import of potatoes to Norway. It is decided for this PRA to limit the assessment to one specific pest likely to be associated with the pathway. That is the bacterium *Ralstonia solanacearum* (race 3 biovar 2). This bacterium presents a potential pest hazard to the country of Norway. The potato brown rot bacterium *R. solanacearum* (race 3 biovar 2) is known to occur in Egypt (EPPO 1997a).

1.2 IDENTIFICATION OF PRA AREA

The PRA area is Norway.

1.3 INFORMATION

Information sources utilised for this PRA are all published material available in international scientific journals, books, reports, personal communications, geographic data and unpublished results that has been made available to the risk assessors. Where these information sources have been used, this is indicated in the text by references enclosed in brackets.

1.3.1 PREVIOUS PRA

There exist a previous PRA for the pest *R. solanacearum* for PRA area of Norway (Sletten 1998). In ISPM Pub. N° 11 terminology, the work by Sletten (1998) represents a “Pest Categorization” of *R. solanacearum* for the PRA area of Norway. That is, a determination the pest status of *R. solanacearum* in relation to the PRA area of Norway. Dr. Sletten has recently updated his work from 1998 in Sletten (2004), taking into account the new knowledge and relevant information that has accumulated. Thus, most of the work of Sletten (2004) has been integrated in this report to constitute the paragraph 2.1 “Pest categorization”.

1.4 CONCLUSION OF INITIATION

The initiation point for this PRA is the identification of a new potential pathway, the export of fresh potatoes from Egypt to Norway, and the potential pest hazard, *R. solanacearum*, likely to be associated with the pathway.

2 Stage 2: Pest Risk Assessment

2.1 PEST CATEGORIZATION

2.1.1 IDENTITY OF PEST, NAME AND TAXONOMIC POSITION

2.1.1.1 Name

Ralstonia solanacearum (Smith) Yabuuchi et. al.

2.1.1.2 Synonyms

Bacterium solanacearum (Smith) Chester

Burkholderia solanacearum (Smith) Yabuuchi et. al.

Pseudomonas solanacearum (Smith) Smith

2.1.1.3 Common names of the disease

Potato brown rot (English)

Pourriture brune de la pomme de terre (French)

Braunfäule, Schleimkrankheit der Kartoffel (German)

Mørk ringråte på potet (Norwegian)

2.1.1.4 Taxonomic position

Bacteria: Gracilicutes

2.1.2 METHODS FOR DETECTION AND IDENTIFICATION

Brown rot in potato plants and tubers can be diagnosed on the basis of symptoms, isolation of the pathogen, and subsequent identification of the isolate as *R. solanacearum* with the methods described in EU Council Directive 98/57/EC (EU 1998).

2.1.2.1 Visual inspection in the field

Symptoms on the foliage are at first wilting of the leaves towards the top of the plant, later external brown discoloration as streaks on the stem, and if stems are cut transversely, white, bacterial slime exudes from the vascular bundles, or it can be expressed by squeezing the stem with pliers. Finally the vines wilt completely and die. External symptoms may be visible on tubers as bacterial ooze that emerges from the eyes and stem-end attachment. Cutting the tubers may reveal a browning and necrosis of the vascular ring and the immediately surrounding tissues. A creamy fluid exudate usually appears spontaneously on the vascular ring of the cut surface a few minutes after cutting.

Plants with foliar symptoms caused by *R. solanacearum* may bear healthy and diseased tubers, while plants that show no signs of the disease may sometimes produce diseased tubers.

2.1.2.2 Laboratory techniques

The bacterium may be detected, also in its latent form, in plant tissue, water and soil by laboratory techniques such as immunofluorescence (IF), ELISA, PCR, or by isolation on a selective medium. A positive result should be confirmed with a pathogenicity test on tomato. With the use of these methods potato tuber lots may be screened for infection by taking samples of 200 tubers per 25 t of potatoes. The sensitivity of different methods for detection has been evaluated by Elphinstone *et al.* (1996).

Identification of *R. solanacearum* can be achieved by different biochemical tests, fatty acid analysis, RFLP, protein analysis and pathogenicity tests.

2.1.3 PRESENCE OR ABSENCE IN PRA AREA

R. solanacearum is absent from the PRA area. *R. solanacearum* has never been detected or intercepted in Norway.

Each year since 1998 seed and ware potatoes grown in different parts of Norway have been tested for the presence of *R. solanacearum* with the methods described in EU Council Directive 98/57EC (EU 1998). The bacterium was not detected in any of the samples. In 2003 a total of 250 samples were tested. In addition, watercourses in the main seed potato growing

areas, and where potato-processing plants are located in Southern Norway have been surveyed and tested for the presence of *R. solanacearum* (Perminow & Borowski 2004). In 2003 altogether 62 samples of water and 6 samples of *Solanum dulcamara* were taken from 9 watercourses. In 2004 correspondingly 49 samples of water, 4 samples of soil from potato processing plants, and 4 samples of *S. dulcamara* were taken from watercourses. *R. solanacearum* was not detected in any of the samples.

2.1.4 REGULATORY STATUS

Norway: *R. solanacearum* is a quarantine pest to Norway, regulated by The Food Law, Regulations relating to plants and measures against pests, Royal Ministry of Agriculture 1 December 2000.

EPPO: A2 list, No. 58
EU: Annex designation: II/A2

2.1.5 POTENTIAL FOR ESTABLISHMENT AND SPREAD IN PRA AREA

2.1.5.1 Biological information of the pest

R. solanacearum is an aerobic, Gram-negative rod, motile with a polar flagellar tuft. It is non-fluorescent, but some strains produce a brown, diffusible pigment. PHB (poly-β-hydroxybutyrate) is accumulated intracellularly. The species is heterogeneous and has been divided into four biovars (biotypes) according to acid production from three disaccharides and three sugar alcohols (Hayward 1964). It has also been divided into three races on the basis of pathogenicity (Buddenhagen *et al.* 1962). Within the species 38 RFLP-groups have been distinguished, and they form two genetically distinct major divisions with origins in Australasia and the Americas (Cook & Sequeira 1994).

2.1.5.2 Host plants of the pest

The host range, which includes over 200 plant species, is one of the widest of all the phytopathogenic bacteria. The most susceptible plant family, in terms of numbers of species affected is the *Solanaceae*, but more than fifty other plant families also contain susceptible species. Worldwide, the most important are: tomatoes, *Musa* spp., tobacco (*Nicotiana tabacum*) and potatoes. Many weeds are also hosts of the pathogen and therefore increase the

potential of *R. solanacearum* to build up inoculum. The different pathogenic races within the species may show very limited host ranges (Buddenhagen *et al.*1962):

Race 1 affects tobacco, tomatoes, potatoes, aubergines, diploid bananas and many other (Solanaceous) crops and weeds, and has a high growth temperature optimum (35-37 °C).

Race 2 affects triploid bananas and *Heliconia* spp., and has a high temperature optimum (35-37 °C).

Race 3 biovar 2 has a lower temperature optimum (27 °C), and affects mainly potatoes and tomatoes. Occasionally it has been reported on *Solanum melanogena* (eggplant), *Capsicum annuum* and some natural occurring Solanaceous weeds such as *S. dulcamara, S. nigrum*, *S. cinereum*, and the composite weed *Melampodium perfoliatum*. A considerable number of additional symptomless weed hosts have been reported, which may enable race 3 biovar 2 to survive in latent form, or in their rhizosphere (Janse *et al.* 2004). By artificial inoculation the weeds *Eupatorium cannabinum*, *Cerastium glomeratum*, *Portulaca oleracea, Ranunculus scleratus* and *Tussilago farfara*, several of which commonly inhabit edges of waterways, have been shown to be potential hosts (Elphinstone 1996). There are also reports of natural occurrence of race 3 biovar 2 in *Pelargonium hortorum* (Janse 1996, Janse *et al.* 2004).

Within the EPPO-region it is race 3 biovar 2 (equivalent to biovar 2, Hayward 1983) that is present and has potential for spread (EPPO 1997a).

2.1.5.3 Host plants growing in the PRA area

Potato is one of the major crops in Norway. Tomato is commercially grown only in greenhouses. *Solanum dulcamara* (Figure 1) and *S. nigrum* are both common weeds in Norway, but they are not growing further north than the county of Nordland (Lid 1985). *Pelargonium hortorum* is an important plant for the greenhouse industry in Norway. *P. hortorum* is a very popular and common plant in private and public parks and gardens as well.

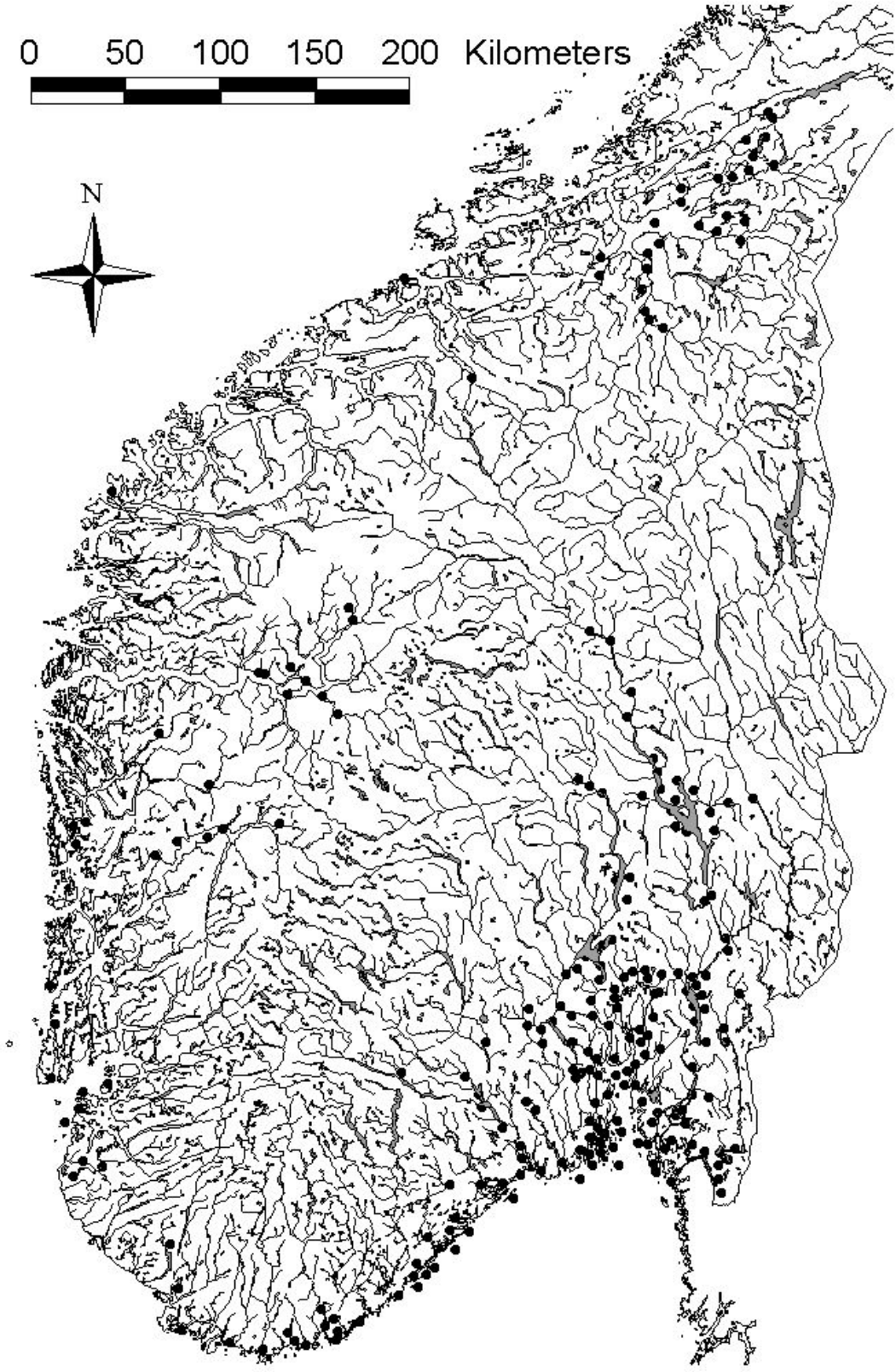

Figure 1 Official field records of *Solanum dulcamara* (•) and watercourses in Southern Norway. Reproduced with permission from Fægri & Danielsen (1996).

2.1.5.4 Interaction pathogen / host

R. solanacearum enter into plants by way of injured roots, stem wounds or through stomata. Within the plant, the bacteria move in the vascular bundles, a process which is accelerated by higher temperature. Speed of movement is also dependent on the plant part colonized. Blocking of the vessels by bacteria is the major cause of wilting (EPPO 1997a). The disease is most severe at 24-35 °C. It is seldom found in temperate climates where the mean temperature for any winter month falls below 10 °C. There are distinct temperature requirements for optimum disease development and reproduction for the different races (biovars) (Swanepol 1990). High soil moisture and periods of wet weather or rainy seasons are associated with high disease severity. Soil moisture is also one of the major factors affecting reproduction and survival of the pathogen (Nesmith & Jenkins 1985).

2.1.5.5 Dissemination and dispersal

The natural spread of *R. solanacearum* is usually limited and slow. Root-to-root spread of the bacterium has been recorded (Kelman & Sequeira 1965), but there is little evidence of long-distance spread from field to field. However, race 2 is known to be transmitted by insects and has a high potential for natural spread. Race 3 biovar 2 has been shown to be spread over long distances with surface water when infected *S. dulcamara* grows with its roots floating in water. The bacterium may be subsequently spread to other hosts, such as potato, when contaminated surface water is used for irrigation. A likely source of infection of *S. dulcamara* in the first place is sewage effluent from potato processing industry and households using infected ware potatoes (Olsson 1976, Stead *et al.* 1996). In Norway there are no regulations to safeguard sewage effluent (water) from potato processing industries and from private households to contain bacteria such as *R. solanacearum*.

R. solanacearum can be carried over very long distances in symptomless, infected vegetative propagating material. Examples of well-documented cases of long-range dispersal are the use of infected ginger rhizomes as planting material within China, Indonesia and Malaysia (Lum 1973), tomato transplants in U.S.A. and Canada, and latently infected potato tubers being spread locally and internationally (Hayward 1991, Olsson 1976, Turco & Saccardi 1997).

Substantial evidence of spread by infected true seed has so far not been given. Neither is there evidence that *R. solanacearum* survives as an epiphyte on leaf and other plant surfaces, as with some pathovars of *P. syringae* (Kelman *et al*.1994).

2.1.5.6 Survival

R. solanacearum may survive in soil, but probably only in relatively short periods on its own (Sequeira 1994). Survival is strongly influenced by a number of interacting physical, chemical and biological factors. It is known that *R. solanacearum* persists longest when it is protected from desiccation and antagonism by other microorganisms, and in sheltered environments such as alternative crop and weed hosts, self-sown volunteer potatoes, host debris or in deeper soil layers sown to at least 75 cm (Graham *et al.* 1979). It may also survive in the rhizosphere of non-hosts (Sequeira 1994). The range and variety of weed hosts is very extensive, but their significance also varies greatly in different environments and cropping systems (Kelman 1953). Some are symptomless carriers (Hayward 1991). Soil type is an important factor affecting survival (Moffet *et al*. 1983), and different soils may be conducive or suppressive to pathogen survival and subsequent disease development (Nesmith & Jenkins 1985). Soil moisture affects pathogen persistence (Moffet *et al.* 1983). It tends to be longest in moist, well-drained soil, but is inhibited by desiccation or flooding (Hayward 1991). Different strains and races of the pathogen vary in their ability to survive in soil. Race 1 may persist in the same soil for many years, while race 2 and 3 disappear rapidly after a disease outbreak when weed hosts are eliminated (Sequeira 1994). Survival of race 3 biovar 2 in soil in cool climates seems to be restricted to one or two years after harvest of potato crops infected by brown rot. The bacterium may also persist in groundkeepers for the same length of time. Long-term survival in perennial weed hosts like *Solanum dulcamara* has however been an important means of persistence and subsequent spread in several countries in Northern Europe (Olsson 1976, Elphinstone 1996).

R. solanacearum may survive in tap water for 25 days at room temperature (Olsson 1976), in ditch water at 4 °C for 33 days (Janse 1996). In sterile distilled water the bacterium may survive for many years and even multiply (Wakimoto *et al.* 1982). van Elsas *et al.* (2000) monitored the fate of race 3 biovar 2 after outbreaks of potato brown rot in three different fields in the Netherlands. The population densities declined progressively to low levels over time. In two fields the pathogen persisted for periods of 10 to 12 months. Indications were found for the occurrence of viable but non-culturable cells (VBNC) of *R. solanacearum* in

soil, however, the potential of such cells to revert to healthy and possibly infective cells is unknown.

2.1.5.7 Adaptability

R. solanacearum race 3 biovar 2 is homogenous and in contrast to the other races very well defined genetically and epidemiologically (Gillings & Fahy 1994) The bacterium has a growth optimum (27 °C), well adapted to more temperate and cooler climates than the other races. It is presumed to originate in South America and has been disseminated to other parts of the world in seed tubers (Hayward 1991). No report has so far been presented after the recent introduction of race 3 biovar 2 in Northern Europe regarding any change in host range, epidemiology or damage potential.

2.1.5.8 Climate in the PRA potato growing areas

Potato is grown in every county in Norway, but production of economic importance takes only place in the following counties: Østfold, Akershus, Hedmark, Oppland, Buskerud, Vestfold, Telemark, Aust-Agder, Rogaland, Møre og Romsdal, Sør-Trøndelag and Nord-Trøndelag, and Nordland. Tables 1-13 give the normal values for mean monthly temperature and precipitation during the years 1961-1990 in these counties. Data were provided by the Norwegian Meteorological institute (DNMI) in Oslo. The tables also include observations on soil temperature 10 cm below ground made by weather stations placed in close vicinity to, or at the DNMI stations. The latter data were provided by the Agro Meteorological Service at the Norwegian Crop Research Institute.

2.1.5.9 Climate in areas in Europe where *R. solanacearum* race 3 biovar 2 has occurred.

Table 14 gives the normal values for mean monthly temperature and precipitation during the years 1961–1990 in Birmingham in England, De Bilt in The Netherlands and Stockholm in Sweden. Data were provided by the Norwegian Meteorological Institute (DNMI) in Oslo. Brown rot in England has been reported from Oxford shire region (Stead *et al*. 1996), which is close to Birmingham. In the Netherlands there was an outbreak in Levered, near the border to Belgium in 1992 (Janse 1992), later outbreaks elsewhere, but the localities have not been given. De Bilt, which is close to Utrecht, most likely has climatic conditions, which could be regarded as representative for many areas where potatoes are grown in the Netherlands. The infestation reported in 1976 in Sweden was in the southern part of the country, but

unfortunately climatic data from this area were not available. However, in connection with investigations concerning the outbreak, successful field infection experiments with *R. solanacearum* were carried out at Solna, which is close to Stockholm (Olsson 1976). This area is at a latitude of 59 °N, which is the same latitude as for Oslo, the capital of Norway, while the natural outbreak of the disease in Sweden was at 55 °N, most likely an area that usually has somewhat higher temperatures.

2.1.5.10 Comparison of the climate in the PRA-area and in areas where *R. solanacearum* has occurred

As can be seen in Tables 1-14, the differences in mean temperature and in precipitation in the growing season between Norway and three European countries where brown rot has occurred are at least for the southern part of Norway minor, and most likely not a hindrance for an establishment of the disease. In infection experiments with potato and *R. solanacearum* race 3 biovar 2 in growth chambers with a dark/light temperature of 14/16 °C, Swanepoel (1990) obtained a mean percentage of wilting of 18.3, and the disease was transmitted to 34.4% of the plants grown from these tubers. At 18/20°C and higher temperatures, the percentage was 100, and no tubers could be harvested.

Olsson (1976b) has given soil temperatures at Solna, Stockholm for a three-year-period when infection experiments with *R. solanacearum* where carried out. The temperature was below 0 °C for about two months during the winter 1974-1975, and somewhat lower the following winter. The bacterium was found to survive in *S. dulcamara* under these conditions. Soil temperatures at several of the localities given in Tables 1-14 are at the same level, in Rogaland (Table 9) some years considerably higher.

2.1.6 POTENTIAL FOR ECONOMIC CONSEQUENCES IN PRA AREA

R. solanacearum causes wilting of plants, with extensive rotting of tubers. Rotted tubers will be rejected for quality reasons. Latent infected tubers detected by laboratory testing will be rejected as seed potatoes because of their potential to transfer disease to future generations of potatoes.

R. solanacearum is in particular a limiting factor in tropical agriculture, where losses up to 75% of the potato crop have occurred in several countries (Cook & Sequeira 1994, Oerke *et al.* 1994). Extensive losses have also been reported from Mediterranean countries. No records

of the economic impact of the disease outbreaks in countries such as Belgium, England and the Netherlands could be found. Apart from the considerable cost of infected ware and seed potato lots being rejected, the cost of eradication programmes and disease surveys in connection with the disease outbreaks must have been very large. In addition, most likely the export of seed and ware potatoes has been considerably reduced.

Potato is one of the major crops in Norway. In 2002 the number of farms growing potatoes at an area of more than 0.5 ha was 7 244, with a total area of 15 118 ha, producing 392 800 tonnes of potatoes at a value of 887 mill NOK (Statistics Norway 2004). A considerable potato production is in addition taking place at a great number of small farms (less than 0.5 ha) and in private gardens.

Tomato is commercially grown only in greenhouses, on around 31 ha, producing 11 082 tonnes of tomatoes in 2002 (Statistics Norway 2004).

2.1.7 CONCLUSION OF PEST CATEGORIZATION

If *R. solanacearum* was introduced into Norway, the climatic conditions and other factors of importance for the development of the disease will not prevent its establishment and survival in groundkeepers, soil, water and common weeds. Because of the cool climate, the rotting of tubers would probably be of minor importance. But all infected potato lots and related lots would have to be destroyed in order to control the disease, as well as strict measures for hygiene and crop rotation would have to be put in action, to a considerable cost for the affected grower, and the official authorities. The high number of small farms and private gardens where potatoes are grown will make it difficult and expensive to enforce the necessary statutory orders to control the disease. Potential export markets would be lost, and reduced supply of homegrown potatoes would make the country more dependent on import from other countries. Brown rot has the potential to become a devastating disease for potato growers in Norway. Many of them have small farms, and have to rely on potato in their crop rotation schemes. The social impact of a disease outbreak could therefore become considerable. *R. solanacearum* race 3 biovar 2 also has the potential to be established in greenhouses growing tomatoes. Particularly in some districts in Norway this is a very important production, and the economic impact of a disease outbreak could be substantial.

2.2 ASSESSMENT OF THE PROBABILITY OF INTRODUCTION AND SPREAD

2.2.1 PROBABILITY OF ENTRY OF A PEST

2.2.1.1 Identification of pathways for a PRA initiated by a pest

As determined under paragraph 1.1.1, this PRA is principally initiated by the new pathway of import of fresh potatoes from Egypt to Norway. Moreover, this PRA is limited to consider only one specific pest, *R. solanacearum* race 3 biovar 2, potentially associated with the pathway.

2.2.1.2 Probability of the pest being associated with the pathway at origin

The potato brown rot bacterium *R. solanacearum* race 3 biovar 2 is known to occur in Egypt (EPPO 1997a). The internal monitoring and control of *R. solanacearum* in Egypt, described in Anonymous (2003a), resulted for 2003–2004 in two positive cases out of 9,400 lots controlled and tested (Personal communication by letter on the 27th of October 2004 from Dr. Safwat El-Haddad, Director of the Potato Brown Rot Project in Egypt). Average size of these lots was 233 tons (Dr. Safwat El-Haddad, personal communication by letter). This is the only information we have available on the prevalence of *R. solanacearum* associated with the pathway. We define prevalence as the number of potato consignments for export that is infested with *R. solanacearum* relative to the total number of potato consignments for export. This definition is in accordance with that of Zadoks & Schein (1979), which used this term to describe the percentage of fields with a particular disease. With a standard classical, or frequentist, approach to statistics, the corresponding estimate $\hat{\theta}$ for the long run disease prevalence θ will be equal to $\frac{2}{9400} \approx 0.0002$. The standard error for θ, computed by the formula $\hat{\sigma}(\theta) = \sqrt{\hat{\theta}(1-\hat{\theta})/N}$ where N = 9,400 is the number of observations, gave $\hat{\sigma}(\theta) = 0.00015$. A 95% confidence interval for θ, computed by the formula $\hat{\theta} \pm 1.96\hat{\sigma}(\theta)$, gives the confidence interval of [-0.00008, 0.00051] for disease prevalence θ. However, the latter confidence interval is logically incorrect because the prevalence will never be a negative number. In risk assessment, another approach to statistics, Bayesian statistics, has been gaining ground. This is much because of its more intuitive interpretation of the concept of probability. A description of the uncertainty based on Bayesian statistics about the prevalence of *R. solanacearum* in the Egyptian potato lots, given the monitoring data, can be done with the Beta(3, 9399) distribution displayed in Figure 2 (calculations in Appendix 1). The

interpretation of Figure 2 is that the curve expresses the probability of the value of the true prevalence of infestation of *R. solanacearum* in Egyptian potato lots, given the data of two positive cases out of 9400 controlled and tested.

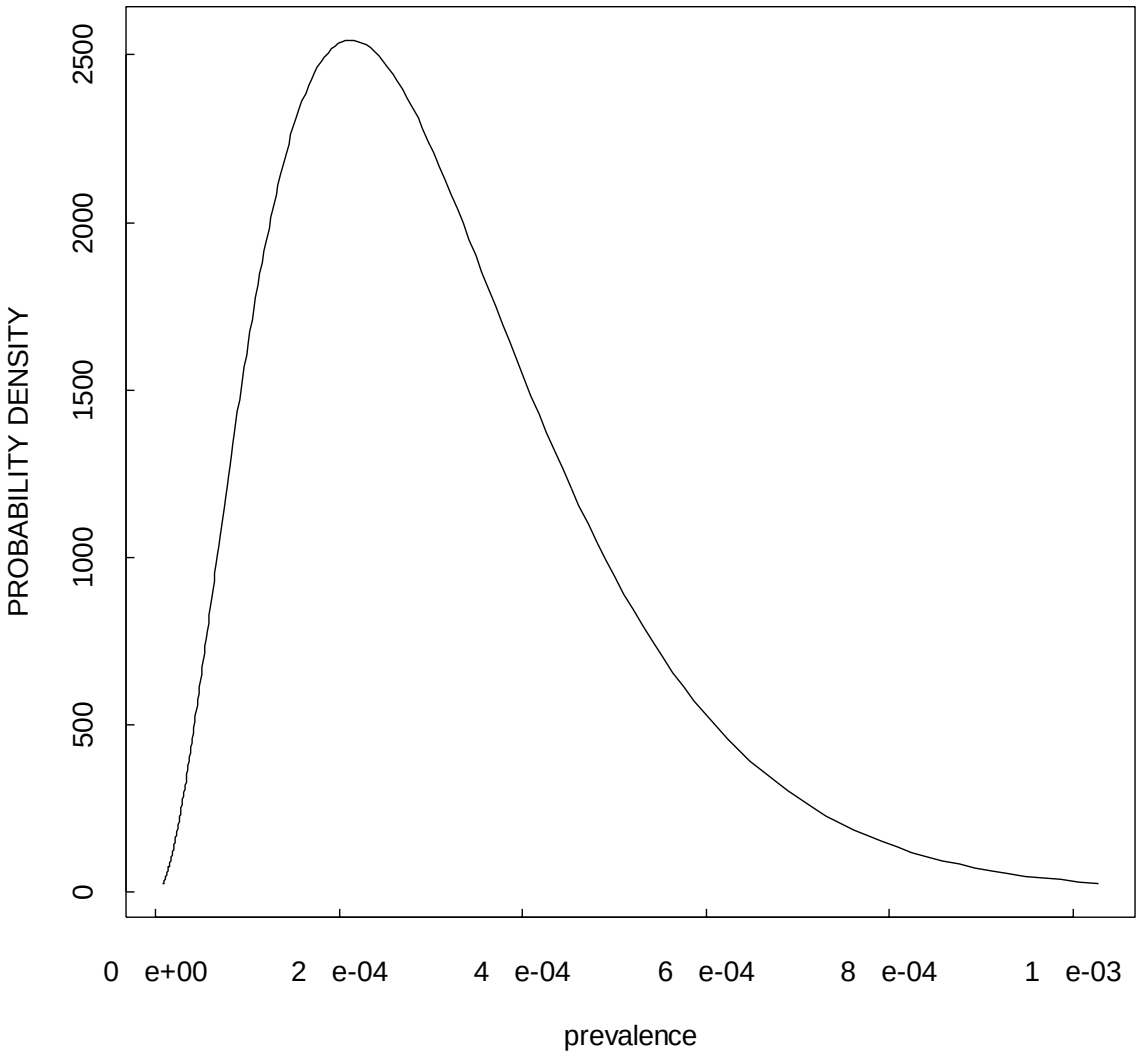

Figure 2 Probability density plot of the Beta(3, 9399) probability density function

Although, the two positive cases out of the 9,400 potato lots controlled and tested were destroyed, so that all the remaining 9,398 lots were classified as free of the disease, we have to assume that there still is a probability that some of the lots are infested with *R. solanacearum*. The two main reasons are that the control program is based on sampling, i.e. not all potato tubers are checked (200 tubers per 25 tons), and the sensitivity (i.e. ability to predict presence of the pathogen when it is actually present) of the test (Immunofluorescence) used for testing of samples is 70% (Dr. Safwat El-Haddad, personal communication by letter).

2.2.1.3 Probability of survival during transport or storage

According to paragraph 2.1.5.6, transport or storage will not reduce survival of *R. solanacearum* in infested fresh potato export consignments. However, possible development of the brown rot disease in potato tubers with latent infections of *R. solanacearum* at the time of testing in the country of origin may increase the probability of detecting diseased consignments in the import control.

2.2.1.4 Probability of pest surviving existing pest management procedures

No specific treatment is applied to the consignments neither against this or other pests from origin to end-use. However, the phytosanitary procedures of inspection and testing applied to the consignments, both at country of origin and in the importing country, will reduce the probability that the pest will go undetected during export and import.

2.2.1.5 Probability of transfer to a suitable host

Paragraph 2.1.5.5 describes the main dispersal mechanisms for the pest considered. The intended use of the commodity is for fresh consumption. For potatoes, this usually implies the process of peeling and rinsing, whether in industry or in private households, before further processing (e.g. by boiling, deep-frying etc.). Accordingly, the most likely transfer of the pest to a suitable host is by effluent water transporting bacteria released by peeling of diseased potatoes, that either could reach *S. dulcamara* weeds growing downstream the watercourse or by use of contaminated water for irrigation of potato fields. Another way of transfer to suitable host, is by the unintended use of the potatoes as seed potatoes for planting. This is illegal, but not uncommon practice in Norwegian private gardens.

(1) risk from effluent from potato peeling
(2) risk of planting as seed potatoes
(3) risk from waste potato peel

In Norway regulations to safeguard sewage effluent (water) from potato processing industries and from private households not containing bacteria such as *R. solanacearum* have not been implemented.

2.2.2 PROBABILITY OF ESTABLISHMENT

2.2.2.1 Availability of suitable hosts, alternate hosts and vectors in the PRA area

The availability of suitable hosts in the PRA area for *R solanacearum* has been described in paragraph 2.1.5.3 and Figure 1. Regarding the host plant *S. dulcamara*, its distribution within the PRA area is relatively well known from official field records (Figure 1; Fægri & Danielsen 1996). Lid (1985), provides a description of the distribution of *S. dulcamara* coinciding with Fægri & Danielsen (1996) by the statements of north to the county of Nordland and vertically up to the altitude of 240 meters above sea level. Regarding its abundance, Lid (1985) describes *S. dulcamara* as common within these geographical distribution limits. Rafoss (2003) developed a method for quantifying establishment and spread potential of pathogens based on spatial stochastic simulation. Fortunately, the study by Rafoss (2003) used *R. solanacearum* as model organism and the current PRA area (Norway) as example area. Thus, the results from Rafoss (2003) can be utilised in the present risk assessment. Simulation outputs from Rafoss (2003) were obtained. The dataset contains the distribution of potential natural dissemination area based on simulated release points for *R. solanacearum* in agricultural land. For the purpose of this risk assessment, the simulated dataset is further refined to provide information about potentially affected potato cropping area. The latter operation was done by a spatial join, within a Geographical Information System (GIS), of the dataset from Rafoss (2003) containing spatial data on potentially affected area, with a dataset for Norwegian municipalities percentage of agricultural area utilised for potato cropping (Statistics Norway, 2000). A histogram summary of the potato cropping area potentially affected, based on 1,000 randomly simulated introductions in agricultural fields of *R. solanacearum* is shown in Figure 3.

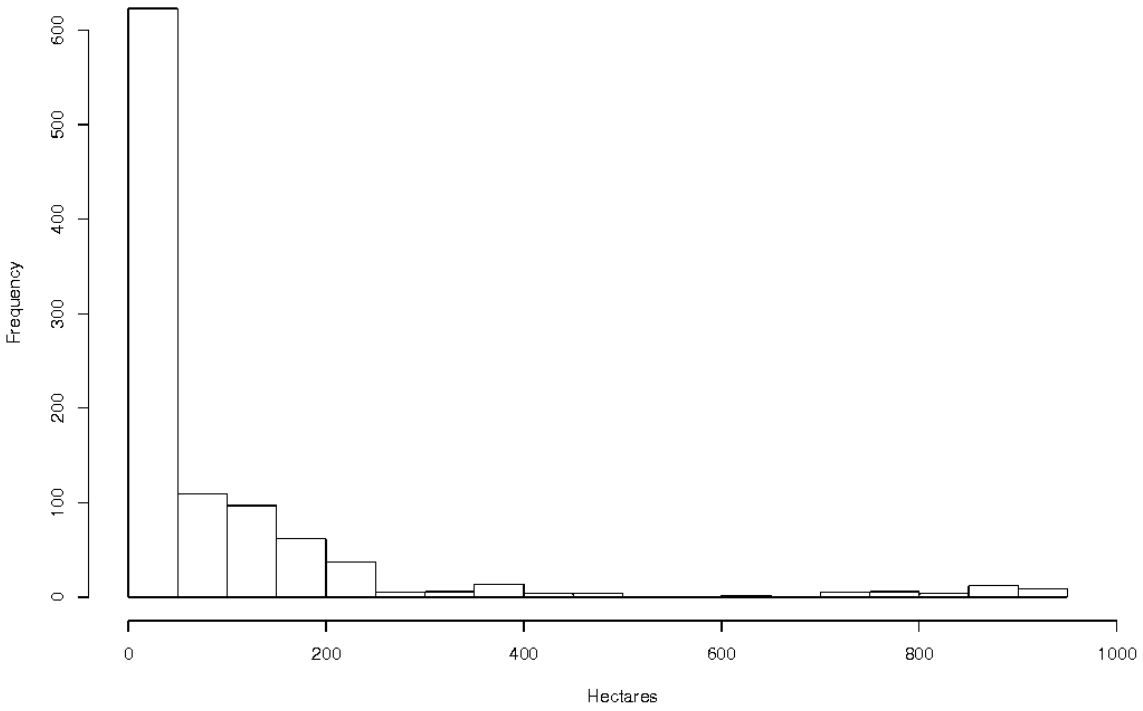

Figure 3 Histogram of potentially affected area (ha) of potato cropping fields, as calculated from the simulation of release of *R. solanacearum* into agricultural fields, and subsequent spread of the pathogen. The histogram is based on 1,000 simulated releases of the pathogen.

Assumptions underlying model simulations:

- Release or escape of the pathogen into the environment occurs in areas where host plants are present
- Release or escape of the pathogen into the environment occurs in a season where the host is susceptible to infection and/or the pathogen is able to infect its host
- Natural dissemination of the pathogen after entry
- Potato growing land lateral to the infected river or watercourse are affected up to 500 meters away from the riverside (e.g. by means of irrigation etc.)
- Sufficient time to disseminate downstream throughout the watercourse

2.2.2.2 Suitability of environment

Paragraph 2.1.5.10 in the Pest characterization section describes suitability of climate according to the scientific literature, and comparisons of climate data from the PRA area and

areas where *R. solanacearum* has been introduced but eradicated, or is known to occur. The conclusion based on these climate comparisons is that the climate of the PRA area will not prevent the establishment of *R. solanacearum*.

2.2.2.3 Cultural practices and control measures

No cultivation practices in the production of host crops in the PRA area are likely to prevent establishment of *R. solanacearum*. Restrictions on cultivation practices, such as the prohibition of use of surface water for irrigation, which has been applied in countries where *R. solanacearum* occur, does not exist for the PRA area.

2.2.2.4 Other characteristics of the pest affecting the probability of establishment

Both the probability of entry of infested consignments (i.e. passing the control), and the probability that they will result in an establishment, will be a function of disease incidence. Disease incidence is here defined as the number of plant units that are diseased relative to the total number assessed (Campbell & Madden 1990, Madden & Hughes 1995). The higher incidence of diseased potato tubers in an infested consignment, the higher the probability is that the infestation will be detected, and the consignment rejected for import. On the other hand, the higher incidence, the more inoculum available for dissemination of the bacteria in the PRA area. Unfortunately, to the author's knowledge, no data on incidence levels of *R. solanacearum* infested potato consignments have been documented, neither for Egypt, nor for other areas where *R. solanacearum* is known to occur. Moreover, aggregation of diseased tubers in infested consignments, is another complicating issue. Naturally, diseased tubers will be aggregated within a lot. On the scale of potatoes from a single cropping field, patterns of aggregation of diseased tubers (e.g. infection spots in the field originating from diseased seed potatoes) may propagate into potato lots coming from this field due to little mixing during harvest. Or, on the scale of big lots, potatoes coming from diseased fields are not perfectly mixed with potatoes coming from non-diseased fields. The efficiency of the currently employed sampling protocol of 200 tubers per 25 ton of potato assumes perfect random mixing of disease tubers within the lot. The more aggregated eventually diseased tubers occur within an infested lot, the higher is the probability that the sample contain zero diseased tubers.

2.2.3 PROBABILITY OF SPREAD AFTER ESTABLISHMENT

Evidence from areas where *R. solanacearum* is known to occur, or has occurred, but has been successfully eradicated, show that this pest has a high potential for dissemination. However,

the rough topography of the PRA area is likely to reduce the dissemination potential of the pest in the PRA area compared to areas with a more even topography. This is because the bacterium by natural means, with few exceptions, only will be disseminated downstream a watercourse.

2.2.4 CONCLUSION ON THE PROBABILITY OF INTRODUCTION AND SPREAD

Summarising the quantitative information of probability of entry yields:

- The fraction of Egyptian potato lots infested with *R. solanacearum* is at least 2 in 10,000 based on results from the Egyptian internal monitoring programme 2003-2004
- The sensitivity (i.e. ability to predict presence of the pathogen when it is actually present) of the Egyptian testing procedure is reported to be on average 70%
- The efficiency of the sampling procedure (200 potato tubers per 25 tons) is reported to be on average 70% (i.e. samples from infested lot will contain diseased tubers in 70% of the cases)
- Assuming independency of sensitivity of the test and the efficiency of the sampling procedure, the probability of detecting an infested lot is $0.7 \times 0.7 = 0.49$

Concluding these "on average" considerations, approximately 50% of the infested lots will be rejected in the export control and testing. Consequently, infested will enter Norway at a minimum average rate of one infested lot per 10,000 imported (without import control).

The above calculations are only done on a per-lot basis. To take the calculation of probability of entry further will require information of the potential size of the import volume and frequency to Norway, in the case of an import permit. This information has not been available so far. Moreover, to calculate the amount of inoculum/propagules that will enter, we need to include information on incidence of *R. solanacearum*–infested potato lots as discussed in paragraph 2.2.2.4. However, it is apparent that only potato lots with a relatively low diseased incidence level may pass control and testing, which, consequently is an effect of this risk management measure.

The relationship between amount of bacteria that is released (e.g. by effluents from potato peeling) and the probability of transfer to a suitable host, on which a successful infection take place, will clearly vary both temporally and spatially. The estimation of this relationship as a function of time of year (e.g. climate conditions, potato cropping stage) and geographical

location of point of release (e.g. from data on human population/private households; location of potato industry and the respective level of treatment of effluent water) is a complicated task. As long as this information is not documented, we have to agree on estimates based on expert judgement. Examples of such simplified estimates could be:

- import of one infested lot of average size 25 tons that is distributed to private households will on average lead to an introduction of *R. solanacearum* to Norway in 5 of 10 cases (50%). The background for this example judgement is that potatoes are normally sold in 2.5 kg packages in Norwegian supermarkets. It is therefore possible that one potato lot sized 25 tons could be distributed to 10,000 different private households in Norway.
- import of one infested lot of average size 25 tons that is distributed to one potato industry plant will on average lead to an introduction of *R. solanacearum* to Norway in 1 of 10 cases (10%). For a potato processing plant located close to the coast, and far from potato cropping areas, the probability that bacteria will be transferred to a suitable host will be minimal. However, the majority of the Norwegian potato industry is located in the important potato growing districts. Consequently, processing infested potato lots at the latter industry plants will presumably have a high probability of transfer to a suitable host.

The calculation of the consequence of an introduction is also complicated, but fortunately, more methodology has become available. Calculation of the potential for establishment and consequence of an introduction is described in paragraph 2.2.2.1. The distribution of potato cropping area potentially affected by one introduction (based on the model) could be read from Figure 3. It is interesting to note that the shape of this distribution is far from the Gaussian (normal) distribution. The distribution in Figure 3 has at least two peaks. The major peak of the distribution is in the left end of the x-axis, indication that an introduction of *R. solanacearum* in most cases will affect a small area of potato cropping land. However, in the right end of the x-axis, also a small peak of the distribution could be identified, indication that introduction of *R. solanacearum* in some areas will affect large areas of potato growing land. The introductions that will give such big impacts, are introductions early in the largest watercourses of Southeast Norway. This result could also be read from Figure 4, which depict the spatial variations in the simulated area of affected arable land dependent of geographical localisation of introductions of *R. solanacearum*. The average area of potato cropping land affected by one introduction (based on the model simulations) is 90 hectares. Standard

measures of variability such as standard deviation provide little meaning as long as the frequency distribution is shaped as indicated in Figure 3.

2.2.4.1 Conclusion regarding endangered areas

The geographical distribution of the host plant *S. dulcamara* in the PRA area is regarded as a key ecological factor that favour the establishment of the pest where it occurs. In the model simulations of entry and establishment, the assumption was made that only potato cropping areas within the distribution limits of *S. dulcamara* are being considered endangered areas.

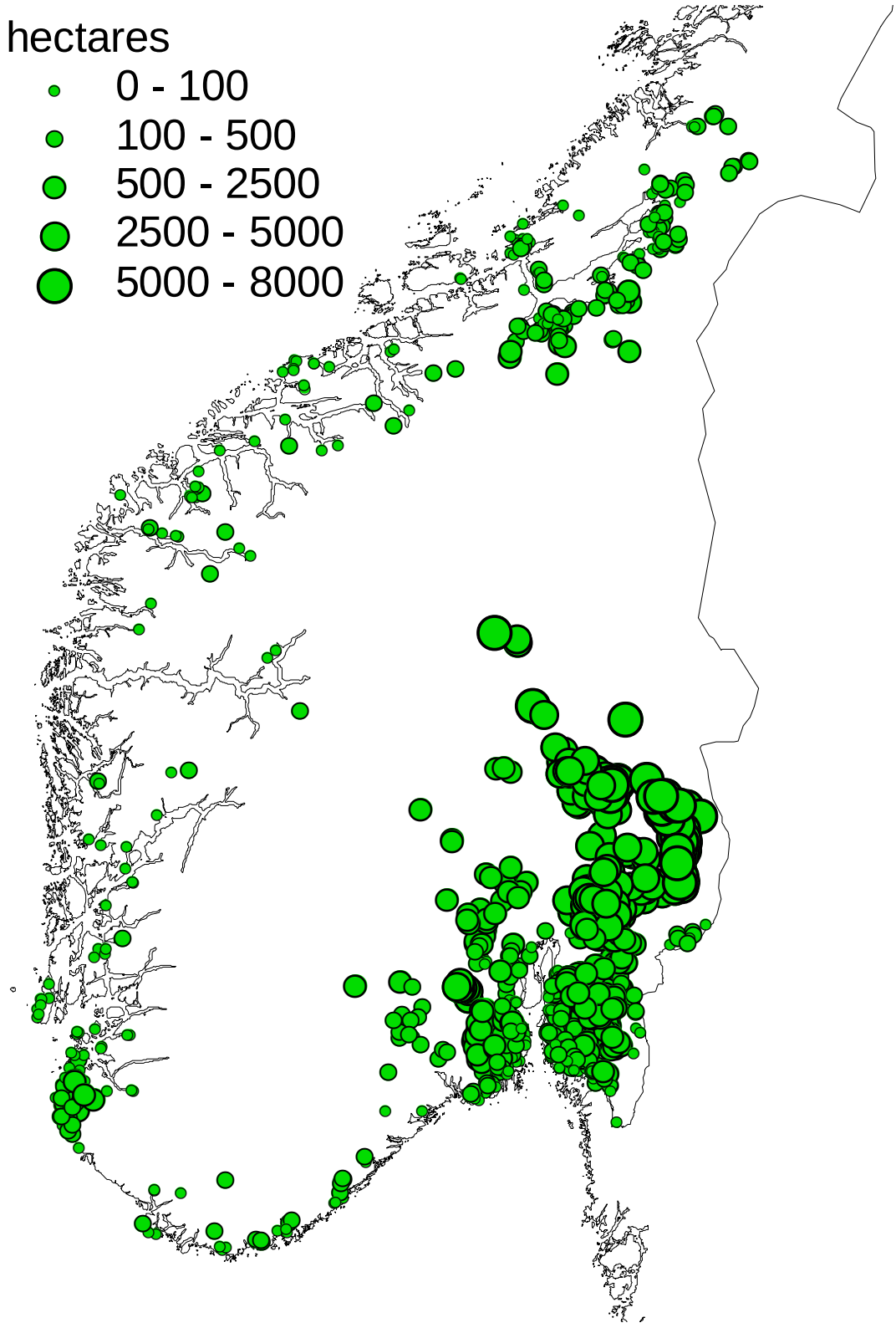

Figure 4 Spatial variations in the simulated area of affected arable land dependent of geographical localisation of introductions of *R. solanacearum*.

2.3 DEGREE OF UNCERTAINTY

There is a major uncertainty concern regarding the prevalence of *R. solanacearum* in Egyptian potato export. The current estimates are solely based on the results from the internal monitoring and testing programme for 2003–2004.

The assessment should have included information on export volumes and frequency to other countries, the average size of export lots, the number of lots found infested with *R. solanacearum* in the importing countries, and preferably, any information on incidence level in *R. solanacearum* infested potato consignments or lots would be valuable. Such information is underway from Egyptian authorities at the time of writing. Unfortunately, this information did not arrive before the deadline of this risk assessment set to November 1st 2004.

The calculations based on model simulations rely on a number of assumptions. Uncertainty inherent in some of these assumptions has not been accounted for in the current risk assessment estimates. This is either because no documentation has been found available for these factors or because the time and resource constraints of this assessment did not permit the studies necessary to obtain this information.

2.4 CONCLUSION AND SUMMARY OF THE PEST RISK ASSESSMENT

The Pest Risk Assessment (PRA) is based on the International Standard for Phytosanitary Measures No 11 (2004) and the PRA scheme developed by European and Mediterranean Organization (1997).

The bacterial wilt bacterium, *Ralstonia solanacearum*, is regulated as a quarantine pest, which has never been detected or intercepted by Norway. Import of ware potato from Egypt to Norway represents a new, potential pathway for the pathogen.

Data from field experiments in Sweden and establishment of the bacterium in Sweden, United Kingdom, and The Netherlands indicate that in the best agro-ecological zones of Norway *R. solanacearum* will be able to develop during the growing season and survive winters in groundkeepers, soil, water and weeds.

The distribution of the host plant *Solanum dulcamara* in the PRA area is regarded as a key ecological factor in the establishment of the pest. In the model simulation of entry and

establishment, the assumption has been made that only potato cropping areas within the distribution limits of *S. dulcamara* are considered endangered areas.

Based on published data from the Egyptian internal monitoring program during 2003-2004 the fraction of Egyptian potato lots infested with *R. solanacearum* is at least 2 in 10,000. The sensitivity of the testing procedure is reported to be on the average 70 %. The efficiency of the sampling procedure is reported to be on the average 70 %. Assuming independency of sensitivity of the test and the efficiency of the sampling procedure, the probability of detecting an infested lot is 0.7 x 0.7 = 0.49. Adjusting the reported statistics by the efficiency of the sampling procedure and the sensitivity of the testing procedure, we can assume that about 50% of the infested lots were detected, and thus the number of infested lots that remain undetected in the potato lots for export will be equal to the number of infested lots detected.

Single introductions of *R. solanacearum* to Norway, i.e. entry of the bacterium, establishment on suitable host, and dissemination of the bacteria downstream the watercourse to the coast, will on average affect 90 hectars of potato growing land. Geographical variation in damage potential has the effect that the consequence of a single introduction of *R. solanacearum* to Norway varies from a worst case of more than 900 hectares potato-cropping land affected, to a best case of less than 90 hectares affected by a single introduction.

The calculations based on model simulations rely on a number of assumptions. The uncertainty present in these assumptions has only been accounted for in the current risk estimates when documentation has been available.

The bacterium *R. solanacearum* presents a risk to the PRA area of Norway. This report shows that there is a risk of introduction of *R. solanacearum* to Norway through import of potato from Egypt.

3 REFERENCES

Anonymous. 2003a. Regulations and Procedures for the Production of Potatoes for Exportation. The Central Administration of Plant Quarantine & The Central Administration of Seed Certification. Ministry of Agriculture and Land Reclamation. Arab Republic of Egypt.

Anonymous. 2003b. Contingency plan for potato brown rot findings. The Central Administration of Plant Quarantine & The Central Administration of Seed Certification. Ministry of Agriculture and Land Reclamation. Arab Republic of Egypt.

Berger, J. O. 1985. Statistical decision theory and Bayesian analysis. Spinger-Verlag, Berlin, Germany

Buddenhagen, I. W., L. Sequeira & A. Kelman. 1962. Designation of races in *Pseudomonas solanacearum*. Phytopathology **52**, 726

Campbell, C. L. and Madden, L. V. 1990. Introduction to Plant Disease Epidemiology. Wiley Interscience, New York.

Cook, D. & L. Sequeira. 1994. Strain differentiation of *Pseudomonas solanacearum* by molecular genetic methods. In: Bacterial wilt: The disease and its causative agent, *Pseudomonas solanacearum* (Ed. By Hayward, A. C., & G. L. Hartman), pp 77-93. CAB International, UK.

EPPO. 1997a. Quarantine Pests for Europe, Second Edition. *Ralstonia solanacearum*, pp 1071-1081 CAB International, UK

EPPO. 1997b. EPPO Reporting Service no. 97/111

EPPO. 1997c. EPPO Reporting Service no. 97/167

EPPO. 1997d. Pest risk assessment scheme. EPPO Standards on phytosanitary measures 5/3(1). European and Mediterranean Plant Protection Organization. Paris.

EPPO. 2004. Sampling of consignment for visual phytosanitary inspection.

Elphinstone, J. G. 1996. Survival and possibilities for extinction of *Pseudomonas solanacearum* (Smith) Smith in cool climates. Pot.Res. **39**, 403-410

Elphinstone, J.G., J. Hennessy, J. K. Wilson & D. E. Stead. 1996. Sensitivity of different methods for the detection of *Ralstonia solanacearum* in potato tuber extracts. EPPO Bulletin **26**, 663-678

EU. 1998. Council Directive 98/57/EC of 20 July 1998 on the control of *Ralstonia solanacearum*. Annex II-test scheme for the diagnosis, detection and identification

of *Ralstonia solanacearum*. Official Journal of the European Communities, No. L235, 8-39.

Farag, N. S., S. M. Lashin, R. S. All-Abdel, H. M. Shatta & A. M. Seif-Elyazal. 1982. Antibiotics and control of potato black leg and brown rot diseases. Agr. Res. Rev. **60**, 149-166

FAO. 1990. FAO Glossary of phytosanitary terms, FAO Plant Protection Bulletin, 38(1) 1990: 5-23.

FAO. 1997. International Plant Protection Convention, 1997. FAO, Rome.

FAO. 2002. Glossary of phytosanitary terms. International standards for phytosanitary measures (ISPM) No. 5. Food and Agriculture Organisation of the United Nations, Rome.

FAO. 2004. Pest Risk Analysis for Quarantine Pests, Including Analysis of Environmental Risks and Living Modified Organisms. International standards for phytosanitary measures (ISPM) No. 11. Food and Agriculture Organisation of the United Nations, Rome.

Fægri, K. and Danielsen, A. 1996. Maps of the distribution of Norwegian vascular plants, The southeastern element. Fagbokforlaget, Bergen.

Gillings, M. R. & P. Fahy. 1994. Genomic fingerprinting: towards a unified view of the *Pseudomonas solanacearum* species complex. . In: Bacterial wilt: The disease and its causative agent, *Pseudomonas solanacearum* (Ed. By Hayward, A. C., & G. L. Hartman), pp 95-112. CAB International, UK.

Graham, J., D.A. Jones & A. B. Lloyd. 1979. Survival of *Pseudomonas solanacearum* race 3 in plant debris and in latently infected potato tubers. Phytopathology **69**, 1100-1103

Hayward, A. C. 1964. Characteristics of *Pseudomonas solanacearum*. J. Appl. Bacteriology, **27**, 265-277

Hayward, A. C. 1983. *Pseudomonas solanacearum*: bacterial wilt and moko disease. In: Plant bacterial diseases (Ed. By Fahy, P. C. & G .J. Persley), pp. 129-135. Ac. Press, Sydney, Australia

Hayward, A. C. 1991. Biology and epidemiology of bacterial wilt caused by *Pseudomonas solanacearum*. Ann.Rev. Phytpathology **29**, 65-87

ISPM Pub. N° 5. 2002. Glossary of phytosanitary terms, 2002. ISPM Pub. N° 5, FAO, Rome

ISPM Pub. N° 3. 1996. Code of conduct for the import and release of exotic biological control agents, 1996. ISPM Pub. N° 3, FAO, Rome

ISPM Pub. N° 8. 1998. Determination of pest status in an area, 1998. ISPM Pub. N° 8, FAO, Rome.

ISPM Pub. N° 7. 1997. Export certification system, 1997. ISPM Pub. N° 7, FAO, Rome

ISPM Pub. N° 9. 1998. Guidelines for pest eradication programmes, 1998. ISPM Pub. N° 9, FAO, Rome.

ISPM Pub. N° 2. 1996. Guidelines for pest risk analysis, 1996. ISPM Pub. N° 2, FAO, Rome.

ISPM Pub. N° 12. 2001. Guidelines for phytosanitary certificates, 2001. ISPM Pub. N° 12. FAO, Rome.

ISPM Pub. N° 15. 2002. Guidelines for regulating wood packaging material in international trade, 2002. ISPM Pub.N° 15. FAO, Rome.

ISPM Pub. N° 6. 1997. Guidelines for surveillance, 1997. ISPM Pub. N° 6, FAO, Rome.

ISPM Pub. N°13. 2001. Guidelines for the notification of non-compliance and emergency action, 2001. ISPM Pub. N°13. FAO, Rome.

ISPM Pub. N° 11. 2001. Pest risk analysis for quarantine pests, 2001. ISPM Pub. N° 11. FAO, Rome.

ISPM Pub. N° 11. 2004. Pest Risk Analysis for Quarantine Pests, Including Analysis of Environmental Risks and Living Modified Organisms. International standards for phytosanitary measures (ISPM) No. 11. Food and Agriculture Organisation of the United Nations, Rome.

ISPM Pub. N° 4. 1996. Requirements for the establishment of pest free areas, 1996. ISPM Pub. N° 4, FAO, Rome.

ISPM Pub. N° 10. 1999. Requirements for the establishment of pest free places of production and pest free production sites, 1999. ISPM Pub. N° 10, FAO, Rome.

ISPM Pub. N° 16. 2002. Regulated non-quarantine pests: concept and application, 2002. ISPM Pub. N° 16. FAO, Rome.

ISPM Pub. N° 14. 2002. The use of integrated measures in a systems approach for pest risk management, 2002. ISPM Pub. N° 14. FAO, Rome.

Janse, J. D. 1996. Potato brown rot in western Europe – history, present occurrence and some remarks on possible origin, epidemiology and control strategies. EPPO Bulletin **26**, 679-695

Janse, J.D., van den Beld, H.E., Elphinstone, J., Simpkins, S., Tjou-Tam-Sin, N.N.A. & J. van Vaerenbergh. 2004. Introduction to Europe of *Ralstonia solanacearum* biovar 2, race 3 in *Pelargonium zonale* cuttings. J. Plant Pathology **86** (2), 147-155

Kelman, A. 1953. The bacterial wilt caused by *Pseudomonas solanacearum*. NC Agr. Exp. Sta. Tech. Bull. **99**, 194 pp

Kelman, A. & L. Sequeira. 1965. Root-to-root spread of *Pseudomonas solanacearum*. Phytopathology **55**, 304-309

Kelman, A., G. L. Hartman & A. C. Hayward. 1994. Introduction. . In: Bacterial wilt: The disease and its causative agent, *Pseudomonas solanacearum* (Ed. By Hayward, A. C., & G. L. Hartman), pp 1-7. CAB International, UK.

Lid, J. 1985. Norsk, svensk, finsk flora. Det Norske Samlaget, Oslo, Norway

Lum, K. Y. 1973. Cross inoculation studies of *Pseudomonas solanacearum* from ginger. MARDI Res. Bull. **1**, 15-21

Madden, L. V. And Hughes, G. 1995. Plant disease incidence: Distributions, heterogeneity, and temporal analysis. Annual Review of Phytopathology 33:529-564.

Moffett, M. L., J. E. Giles & B. A. Wood. 1983. Survival of *Pseudomonas solanacearum* biovars 2 and 3 in soil: effect of moisture and soil type. Soil. Biol. Biochem. **15**, 587-591

Murakoshi, S. & M. Takahashi. 1984. Trials of some control of tomato wilt caused by *Pseudomonas solanacearum*. Bull. Kanagawa Hort. Exp. Sta. **31**, 50-56

Nesmith, W.C. & S.F. Jenkins (1985. Influence of antagonists and controlled matric potential on the survival of *Pseudomonas solanacearum* in four North Carolina soils. Phytopathology **75**, 1182-1187.

Oerke, E-C., H-W. Dehne, F. Schönbeck & A. Weber. 1994. Crop production and crop protection. Estimated losses in major food and cash crops. Elsevier, Amsterdam 1994

Olsson, K. 1976. Experience of brown rot caused by *Pseudomonas solanacearum* (Smith) Smith in Sweden. EPPO Bulletin **6**, 199-207

Olsson, K. 1976b. International planning conference and workshop on the ecology and control of bacterial wilt caused by Pseudomonas solanacearum. North Carolina State Univ. Raleigh, North Carolina 18-23.7 1976

Perminov, J. I. S. and Borowski, E. 2004. Analyser av vann for smitte av Ralstonia solanacearum (mørk ringråte på potet). (*In norwegian*) Commissioned by the Norwegian Food Safety Authority.

Rafoss, T. 2003. Spatial Stochastic Simulation Offers Potential as a Quantitative Method for Pest Risk Analysis. Risk Analysis, 23(4):651-661.

Sequeira, L. 1994. Epilogue: Life with a ”mutable and treacherous tribe”. In: Bacterial wilt: The disease and its causative agent, *Pseudomonas solanacearum* (Ed. By Hayward, A. C., & G.L. Hartman), pp 235-247. CAB International, UK.

Sletten, A. 1998. Pest Risk Assessment (PRA) for Norway on *Ralstonia solanacearum*”. Report from the Norwegian Crop Research Insitute, commissioned by The Norwegian Agricultural Inspection Service.

Sletten, A. 2004. Pest Risk Assessment (PRA) for Norway on *Ralstonia solanacearum*”. Report from the Norwegian Crop Research Insitute, commissioned by The Norwegian Agricultural Inspection Service (Updated October 2004).

Statistics Norway. 2000. Agricultural census 1999.Statistics Norway, Oslo.

Statistics Norway. 2004. Statistics Norway, NOS D 286, Jordbruksstatistikk.

Stead, D. E., J. G. Elphinstone & A. W. Pemberton (1996. Potato brown rot in Europe. Proceedings, Brighton Crop Protection Conference – Pest & Diseases 1996, pp 1145-1152

Swanepoel, Anita E. 1990. The effect of temperature on the development of wilting and on progeny tuber infection of potatoes inoculated with South African strains of biovar 2 and 3 of *Pseudomonas solanacearum*. Pot.Res. **33**, 287-290

Turco, P. & A. Saccardi. 1998. Monitoring of *Pseudomonas solanacearum* in the potato areas of Veneto region. EPPO Bulletin 1998, in press.

van Elsas, J.D., Kastelein, P., van Bekkum, P., van der Wolf, J.M., de Vries, P.M., & van Overbeek, L.S. 2000. Survival of *Ralstonia solanacearum* Biovar 2, the causative agent of potato brown rot, in field and microcosm soils in temperate climates. Phytopathology **90**, 1358-1366.

Wakimoto, S., I. Utatsu, N. Matsuo & N. Hayashi (1982. Multiplication of *Pseudomonas solanacearum* in pure water. Ann. Phytopath. Soc. Japan **48**, 620-627

WTO. 1994. Agreement on the Application of Sanitary and Phytosanitary Measures, 1994. World Trade Organization, Geneva.

Zadoks, J. C. and Schein, R. D. 1979. Epidemiology and Plant Disease Management. Oxford, New York, 427 pp.

4 Appendix

In Bayesian terms, the parameter θ is regarded a fixed quantity, unknown to the statistician. It is called a random quantity. The original uncertainty the statistician has about the value of θ is expressed by an á priori probability density $\pi_0(\theta)$. Recall that it was assumed a *Uniform*[0,1] á priori distribution for θ, which is a so called non-informative á priori distribution expressing that nothing is known about the value of θ before collecting data. It is assumed that the survey generates data from a binomial process with θ as the probability of success parameter. The á priori probability density $\pi_0(\theta)$ is given by:

$$\pi_0(\theta) = \frac{1}{1-0} I_{[0,1]}(\theta) = 1 \cdot I_{[0,1]}(\theta)$$

which is based upon the formula for the Uniform probability density function:

$$f(\theta \mid \alpha, \beta) = \frac{1}{\beta - \alpha} I_{[\alpha,\beta]}(\theta), \Theta = (\alpha, \beta), -\infty < \alpha < \infty, \varepsilon < \beta < \infty$$

where the symbol *I* is called the indicator function and is defined as

$$I_A(z) = \begin{cases} 1 \, if \; z \in A \\ 0 \, if \; z \notin A \end{cases}$$

The data collected in the survey are assumed generated from a binomial process with θ as the probability of success parameter. The binomial has the following probability density function:

$$f(x \mid n, \theta) = \binom{n}{x} \theta^x (1-\theta)^{n-x}, \; X = \{0,1,2,\ldots,n\}, 0 \le \theta \le 1, n = 1,2,\ldots,$$

where the binomial coefficient is given by:

$$\binom{n}{x} = \frac{n!}{(x!)(n-x)!}$$

Writing the data as a likelihood function *L* of θ given the data *D* from table 1 yields:

$$L(\theta \mid D) = \binom{9400}{2} \theta^2 (1-\theta)^{9400-2}$$

Updating of the á priori distribution to find the á posteriori distribution can then be done by applying Bayes Theorem:

$$\pi(\theta \mid D) = \frac{L(\theta \mid D)\pi_0(\theta)}{\int_\Theta L(\theta \mid D)\pi_0(\theta) d\theta} = kL(\theta \mid D)\pi_0(\theta)$$

where the k is a norming constant ensuring that:

$$\int_{\Theta} kL(\theta \mid D)\pi_0(\theta)d\theta = 1$$

This yields the *Beta*(3; 9399) distribution:

$$\pi(\theta \mid D) = \frac{\binom{9400}{2}\theta^2(1-\theta)^{9400-2}\cdot 1}{\int_{\Theta}\binom{2819}{10}\theta^2(1-\theta)^{9400-2}\cdot 1 d\theta} = k\theta^2(1-\theta)^{9398}$$

where $k = \frac{\Gamma(9402)}{\Gamma(2)\Gamma(9399)}$

The estimates in Bayesian statistics are based on the á posteriori distribution (Berger, 1985), and the Bayes estimate for θ is the expectation of the á posteriori distribution. The expectation of the beta distribution is $\frac{\alpha}{\alpha+\beta}$ which yields an estimate for θ, $\hat{\theta} \approx 0.0002$.

5 Tables

Table 1. Tomb, Østfold county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.8	59	-0.3	0.4	0.3	0.1	1.2
February	-4.6	44	-2.6	-0.4	-0.1	0.1	0.8
March	-0.8	54	0.2	2.0	0.3	0.0	1.6
April	4.2	42	5.4	4.1	4.1	4.7	4.8
May	10.3	57	9.5	9.4	12.0	9.3	8.5
June	14.7	66	12.4	15.3	13.6	10.8	14.4
July	16.1	72	15.9	16.2	14.6	16.4	15.8
August	15.0	74	16.7	14.6	13.3	16.0	17.1
September	10.6	92	12.4	11.7	9.1	11.9	13.2
October	6.0	83	7.6	6.0	6.0	7.1	10.7
November	0.6	90	3.5	2.6	2.3	4.2	
December	-3.0	64	1.3	1.7	0.3	2.6	

Table 2. Ås, Akershus county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.8	49	0.2	-0.4	-0.2	0.0	0.4
February	-4.8	35	-1.0	-0.9	-0.3	0.2	0.3
March	-0.7	48	-0.1	0.2	-0.2	0.1	0.3
April	4.1	39	4.4	4.1	2.8	4.0	3.1
May	10.3	60	9.0	11.0	11.4	9.7	8.7
June	14.8	68	13.0	17.1	14.4	13.3	15.0
July	16.1	81	17.7	-	15.9	18.2	16.9
August	14.9	83	16.6	15.2	14.4	16.5	17.5
September	10.6	90	12.1	12.4	10.2	11.6	12.4
October	6.2	100	7.3	6.1	5.8	6.1	9.7
November	0.4	79	2.6	1.7	2.0	2.7	
December	-3.4	53	0.6	0.9	0.3	0.7	

Table 3. Kise, Hedmark county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1993-1995.

	Climatological normals		Soil temperature		
Month	Temp.	Precip.	1993	1994	1995
January	-7.4	36	-2.2	-1.2	-1.2
February	-8.1	29	-	-1.1	-1.8
March	-3.1	27	-1.4	-0.9	-1.3
April	2.2	34	3.0	1.6	1.5
May	8.5	44	10.3	8.4	7.7
June	13.6	59	13.4	12.0	13.4
July	15.2	66	15.6	17.9	15.2
August	14.0	76	13.6	15.1	15.4
September	9.6	64	8.8	9.8	10.4
October	5.1	63	4.3	4.3	6.5
November	-0.8	50	0.5	2.0	
December	-5.3	37	-	-0.9	

Table 4. Apelsvoll, Oppland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-7.4	37	-0.3	-0.2	-1.3	0.4	-0.3
February	-7.0	26	-0.5	-0.6	-1.7	-0.1	-0.1
March	-2.5	29	-0.2	-0.1	-0.7	0.0	-0.1
April	2.3	32	3.1	1.8	1.3	1.2	0.2
May	9.0	44	9.7	11.5	10.9	9.2	8.0
June	13.7	60	13.8	18.0	14.3	12.8	13.7
July	14.8	77	18.3	16.9	15.9	18.3	16.1
August	13.5	72	16.8	14.4	-	15.6	16.6
September	9.1	66	11.1	10.7	9.6	10.4	11.1
October	4.6	64	6.2	5.1	4.8	4.6	7.4
November	-1.3	53	1.9	2.0	1.3	2.3	
December	-5.3	40	0.2	-0.1	0.8	0.0	

Table 5. Lier, Buskerud county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-5.5	70		-1.3	-0.3	0.1	0.2
February	-5.0	52		-1.3	-0.4	0.5	0.1
March	-0.4	60		1.0	-0.3	0.5	0.1
April	4.8	50		4.8	3.9	3.6	2.5
May	11.0	70		13.1	11.2	8.9	7.7
June	15.7	70		19.2	12.8	11.9	13.2
July	17.1	85		17.8	14.3	16.4	15.0
August	15.7	105		15.1	13.4	15.4	15.6
September	11.3	108		11.7	9.6	11.2	11.9
October	6.6	115	4.8	5.6	5.8	6.0	9.1
November	0.6	95	1.2	1.4	2.3	3.4	2.6
December	-3.5	70	-0.6	0.6	0.5	0.8	0.3

Table 6. Ramnes, Vestfold county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.5	85	0.0	0.0	0.8	0.0	0.4
February	-4.5	60	-0.2	-0.3	-0.2	0.0	0.4
March	-0.3	68	0.1	0.5	-0.2	-	0.1
April	4.0	55	5.2	4.0	3.1	-	2.2
May	10.2	75	10.4	11.7	12.3	10.6	8.7
June	14.5	67	13.4	17.8	15.2	14.1	15.2
July	15.5	87	17.7	-	16.3	18.5	17.3
August	14.4	106	16.5	15.0	14.6	16.7	17.8
September	10.3	116	11.9	11.7	10.2	11.8	12.8
October	6.2	132	7.0	6.0	6.1	6.4	9.6
November	1.0	122	2.5	1.7	1.9	3.5	
December	-3.0	87	0.5	0.7	0.4	0.8	

Table 7. Bø, Telemark county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-6.5	50	-	-	-	-	-0.3
February	-5.5	35	-	-	-	-	-0.2
March	-0.5	45	-	0.0	-	0.5	-0.1
April	4.3	40	-	3.4	4.9	3.5	1.9
May	10.4	65	-	12.0	11.9	9.8	8.1
June	14.8	65	-	18.2	15.1	13.2	14.7
July	16.0	75	-	-	16.1	16.8	16.4
August	14.5	95	-	15.2	14.2	15.7	16.8
September	9.8	95	-	12.1	10.2	10.4	11.3
October	5.5	95	5.1	4.9	7.2	4.7	8.0
November	-0.2	75	1.1	0.5	-	2.3	
December	-4.5	55	-0.8	0.2	-	0.1	

Table 8. Landvik, Aust-Agder county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-1.6	113	0.2	0.6	0.5	0.7	0.1
February	-1.9	73	-0.7	-	0.3	0.4	0.0
March	1.0	85	1.0	3.4	2.1	0.7	1.1
April	5.1	58	6.2	5.4	5.7	5.9	5.4
May	10.4	82	12.0	12.0	12.3	10.8	9.5
June	14.7	71	14.0	17.9	15.7	14.2	15.2
July	16.2	92	19.1	17.4	15.7	18.1	17.3
August	15.4	113	17.8	15.4	14.4	16.8	17.9
September	11.8	136	13.4	12.9	11.0	12.1	13.0
October	7.9	162	7.8	6.6	6.8	7.4	9.9
November	3.2	143	3.7	2.6	3.0	3.9	
December	0.2	102	0.9	1.8	0.9	1.6	

Table 9. Særheim, Rogaland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	0.5	105	1.9	3.3	2.2	0.8	2.2
February	0.4	75	-0.5	3.3	2.7	0.1	2.5
March	2.4	80	3.6	4.0	2.7	1.3	2.5
April	5.1	60	6.4	6.1	6.5	5.9	5.7
May	9.5	70	9.6	12.1	12.3	10.5	9.0
June	12.5	75	12.0	16.4	13.8	12.2	13.7
July	13.9	95	16.8	15.8	13.8	16.4	15.5
August	14.1	125	14.4	14.0	15.2	15.5	
September	11.5	160	12.2	12.4	10.8	12.1	12.7
October	8.6	160	8.2	6.6	7.3	7.7	10.1
November	4.4	150	4.7	3.9	2.8	6.3	
December	2.0	125	3.5	2.8	1.0	4.3	

Table 10. Surnadal, Møre og Romsdal county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1993-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-2.5	116		-0.8	-1.0	-0.6
February	-1.5	95		-0.3	-0.9	-0.6
March	1.0	99		-0.3	-0.7	-0.5
April	3.7	83		0.8	-0.5	-0.5
May	9.0	64		10.7	7.7	6.8
June	12.0	86		12.7	11.1	13.3
July	13.5	117		16.0	16.5	13.9
August	13.2	120		14.3	15.2	14.2
September	9.4	173		9.1	10.1	10.5
October	6.2	157	1.9	4.0	3.2	6.3
November	1.7	131	-1.4	-1.0	0.1	
December	-1.0	154	-1.4	-1.5	-0.5	

Table 11. Rissa, Sør-Trøndelag county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1992-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-4.5	162		-0.5	-0.5	-0.3
February	-3.5	132		0.5	-0.4	-0.3
March	-1.0	123		0.3	-0.4	-0.2
April	2.5	115		5.7	3.7	1.6
May	8.0	78		10.7	8.5	7.6
June	11.5	89		11.9	10.6	12.5
July	13.0	110		14.4	15.6	12.7
August	13.0	110		13.0	14.7	12.5
September	9.0	204		9.0	10.5	10.2
October	6.0	199	2.3	4.5	4.1	6.8
November	1.0	162	-0.5	0.0	1.8	
December	-2.5	201	-0.7	-0.7	0.6	

Table 12. Frosta, Nord-Trøndelag county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-1.5	74	-0.3	1.6	-	0.0	-0.1
February	-1.5	64	-1.7	1.1	1.2	-0.2	0.1
March	1.0	58	0.3	2.4	1.0	-0.1	0.1
April	4.0	50	5.5	-	4.2	3.6	2.6
May	8.5	45	8.7	-	9.0	9.3	8.4
June	12.0	60	13.7	14.6	9.9	11.7	13.5
July	13.5	80	17.4	15.0	12.7	16.4	14.3
August	13.0	73	16.2	12.6	12.2	15.0	13.7
September	9.0	105	9.5	10.2	8.8	10.0	10.3
October	6.0	100	5.6	3.9	5.2	4.8	6.6
November	2.0	75	2.4	1.0	0.9	2.2	
December	0.0	86	1.4	0.8	0.0	1.0	

Table 13. Sortland, Nordland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1992-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-2.0	130		-0.1	-0.3	0.2
February	-2.0	120		-0.1	-0.3	-0.1
March	-1.0	95		0.1	-0.2	-0.1
April	1.9	85	-0.1	0.2	-0.2	0.0
May	6.3	65	6.6	5.7	2.4	1.2
June	10.0	65	13.1	8.8	8.8	9.7
July	12.0	75	12.8	13.4	12.0	11.5
August	12.0	85	12.1	13.1	12.8	11.6
September	8.4	130	8.9	7.6	8.0	8.8
October	4.5	190	3.7	2.5	3.8	4.5
November	0.8	150	0.4	1.3	0.6	
December	-1.4	145	-0.1	-0.1	0.6	

Table 14. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm) in England, the Netherlands and Sweden.

	Birmingham, UK		De Bilt, NL		Stockholm ,SE	
Month	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
January	3.1	57	2.2	69	-2.8	39
February	3.1	48	2.5	49	- 3.0	27
March	5.2	51	5.0	66	0.1	26
April	7.6	49	8.0	53	4.6	30
May	10.6	56	12.3	61	10.7	30
June	14.0	56	15.2	70	15.6	45
July	15.8	46	16.8	76	17.2	72
August	15.4	66	16.7	71	16.2	66
September	13.2	54	14.0	67	11.9	55
October	10.0	52	10.5	75	7.5	50
November	6.0	59	5.9	81	2.6	53
December	4.2	66	3.2	83	-1.0	46