Development of strategies for the control and eradication of Japanese knotweed

Submitted by James Macfarlane to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Engineering.

I certify that all material in the thesis which is not my own work has been acknowledged and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Name in full____

Signed_____________________________________Date_________________

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Abstract

This work has investigated a range of aspects of the physiology and management of *Fallopia japonica* (Ronse Decraene) and closely related invasive introduced plant species, colloquially referred to as Japanese knotweed. Prior to this work very little detailed scientific research had been done into the nature of the plant and its related species or into the effectiveness of control methods over the long term.

This work has highlighted the need for education of the public to prevent further spread by inappropriate disposal, and advice on suitable and practical methods of control in a wide range of environments. The creation of an online GIS database has led to an increase in reporting of sites on private land by the public and this has in turn strengthened the Cornwall database which is the most comprehensive of its type ever created. This database has enabled detailed analysis of distribution, identification of likely areas of colonisation and indicated mechanisms of spread. It has also provided a basis for targeting of resources and prioritisation of treatment.

Initial field observations also prompted research on physiological aspects of the plant which have particular implication for determining methods for its control. The work has shown that much smaller fragments of rhizome than those previously tested are capable of regeneration (down to 0.01g) and that there is a significant likelihood of fragments of 0.06g regenerating in suitable conditions which has implications for separation techniques. It has demonstrated that typical rhizome material is capable of survival for at least three months under saline conditions thus highlighting a risk of marine spread along coasts. Extension rates of above ground material of up to 13.8 cm over a 24 hour period have been recorded. Cutting of above ground material caused a stimulation of new above ground stems – thus any proposed treatment should continue consistently over a number of years. A temperature of 40C maintained over a period of 7 days removed rhizome viability in chopped fragments of up to 10cm thus suggesting that temperature controlled in-vessel composting may be a possible disposal route for chopped rhizome. Main underground extension growth has been shown to occur in the Autumn with no particular orientation to the growth. Up to 50kg (wet weight) of underground material has been discovered in a

cubic metre of excavated material. Rhizome disturbance has been shown to promote underground extension. The way in which rhizome desiccates, leaving viable buds separated by necrotic material, means that underground connections within an area cannot be assumed. This has implications for the effectiveness of chemical treatment. The suggested regeneration from leaf material has not been demonstrated, nor has a reliable chemical method of testing the viability of rhizome material.

The implications of these physiological aspects on a wide range of treatment methodologies have been considered and control methods have been tested. Excavation and separation of material can be effective in appropriate soil conditions. The need to use glyphosate based herbicides primarily in the Autumn has been demonstrated. This work has called into question the current methods of assessment of effectiveness of control and the use of viability assessments on sites. It has highlighted that monitoring of treated sites needs to be continued over a number of years in order to determine whether eradication has been achieved. In view of the legal proscriptions about the plant, it is considered that some control measures currently deployed could have the potential to breach current legislation by being likely to cause the plant to spread.

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Chapter 1

Introduction

This work considers a number of aspects relating to the control of a range of species and varieties of the plant commonly referred to as Japanese knotweed. The principal species of concern is *Fallopia japonica* var. *japonica*.

Observations of a wide range of sites over a period of more than ten years on which Japanese knotweed has been recorded and/or treated indicated that the methods of control advised were not necessarily effective or founded on a sound scientific basis. It was therefore decided that a number of areas needed more detailed investigation and that a targeted approach was required.

Firstly, appropriate and targeted communication was required to gain a sufficient breadth of knowledge of areas colonised by the plant, to provide appropriate information to promote a proportionate response to concerns about the plant, particularly in view of information being widely promulgated in relation to it, and to attempt to prevent further spread of the plant, either through deliberate or unwitting actions. Field observations suggested that aspects of the plant's physiology required further investigation. A range of methods being used for the control of the plant required refinement to ensure their effectiveness on the wide range of sites and in the varied circumstances in which the plant has been noted.
Finally, some realistic assessment methodology in relation to judgement of success of control was required.

1.1 The plant

Japanese knotweed (*Fallopia japonica* (Houtt) Ronse Decraene (syn *Reynoutria japonica* (Houtt), *Polygonum cuspidatum* (Sieb & Zucc)) is a vigorous herbaceous plant native to Japan and northern China. Aspects of the plant in its native environment are further explained in Chapter 2. It has been included in the list of the world's worst 100 invasive species (Lowe et al. 2000). The reasons for inclusion on the list are not closely defined, but are likely to relate, in areas to which it has been introduced, to damage in the built environment, its vigorous colonising ability and suppression of native species in the wider environment. It is included in the top twenty environmental weeds for classical biological control in Europe (Sheppard et al. 2005). It has been referred to as the “UK’s most pernicious weed “(Mabey 1998).

1.2 Why is it considered to be a problem?

The cost of eradication of the plant in Britain has been estimated at £1.56 billion (Defra 2003). The annual costs, in relation to control and ongoing management, to the British economy of Japanese knotweeds including *Fallopia japonica* var. *japonica*, Giant knotweed *Fallopia sachalinensis* and the hybrid *Fallopia* x *bohemica*, have been estimated at £165,609,000 (Williams et al. 2010). This analysis of costs indicates expenditure in the development sector of in excess of £150 million and varying costs to local authorities, transport bodies, those responsible for riparian areas and the household sector. The figure of £1.116 million in relation to house devaluation appears very conservative in relation to the perceived long term risks by mortgage companies when the plant is present within the grounds or on adjacent property (Daily Telegraph May 10th 2010).

The research for the report (Williams et al.2010) acknowledged that insufficient data were obtained in relation to full assessment of costs of the plant regarding agriculture, leisure and tourism or biodiversity to permit provision of relevant costs for these sectors. Adverse effect in relation to biodiversity has been recorded (Urgenson 2006; Gerber et al. 2008) but costs were not attributed in these works.

A report considering the effectiveness of control and eradication operations (Kabat et al. 2006) highlights the lack of long term information available in this field.

1.3 Background

The *Fallopia* species that are the subject of this work are frequently found as colonisers of brownfield sites, areas regarded as a government redevelopment priority. The plant has a demonstrated capacity to outcompete native plants and to alter mineral concentrations in the soil (Dassonville et al. 1997) and has also shown potential for causing serious damage in the built environment. (Child and Wade 2000)

Fig. 1.1 Japanese knotweed penetrating bitmac surface, Camborne, Cornwall GR SW 6513 3977

The species can survive in conditions considered adverse for the growth of a wide range of plants, such as very acid soils, as well as in more benign locations (Kanai 1995). An example of the colonisation of areas contaminated with heavy metals is provided by records of establishment on Cornish mine spoil.

Japanese knotweed rapidly colonises disturbed ground and disturbance of the plant leads to its rapid spread (Nakamura 1984).

Within the built environment, problems include the plant's colonisation capability in a wide range of situations (Child and Wade 1997), and its ability to exploit any points of weakness in a structure. Such factors have resulted in substantial costs in relation to site preparation and remediation (Williams et al. 2010) (Fig.1.2). Further demonstration of the colonising capability of the plant includes its ability to penetrate between concrete revetment blocks (Beerling 1991a).

Fig. 1.2 Penetration through a crane bearing point in a concrete floor on redevelopment site, Camborne, Cornwall GR SW 6556 4012

In the example cited in Fig.1.2, the costs of the remediation directly related to the plant, for a site of 6.85 hectares, of which 0.9 hectares had been GIS recorded to have Japanese knotweed present, were reported at £2 million (West Briton 2008).

The capacity for small material to regenerate and its noted ability to colonise construction materials makes any form of control particularly difficult where structures are present. (Fig.1.3). Within the highway environment, visibility can be rapidly compromised by the strong growth of the plant. Access can also be impaired, and dense stands in the urban environment can result in litter accumulation and cover for anti social activities.

In the wider environment, colonisation of banks of watercourses results in a monoculture which is subject to erosion due to the lack of cover of the bare banks when the plant dies back during the winter. Obstruction to flow can be caused both by growing and detached material, with the associated risks of colonisation downstream.

The dense cover, combined with the very durable leaf litter, are considered ways in which the species outcompetes many native plants in a wide variety of circumstances and, apart from providing some physical refuge, provide little demonstrable ecological benefit. (Brock 1994;Maerz et al. 2005; Maurel et al.2010).

Fig. 1.3 Penetration of mortared joints of a bridge structure GR SW 3728 3181

1.4 History of the introduction of the plant

Japanese knotweed was introduced into Britain in the early part of the nineteenth century (Conolly, 1977), principally as an ornamental garden plant, though reference is also made, in the original cataloguing, of its slope stabilising qualities (Beerling et al., 1994). It is likely that rapid transport development, particularly post 1945, has encouraged its spread.

Fallopia japonica was awarded a gold medal in September 1847 by the Society of Agriculture and Horticulture at Utrecht for the most interesting new ornamental plant of the year, according to the catalogue of Von Siebold and Company, Leiden (Siebold 1848). This accolade is likely to have promoted its use within gardens in the United Kingdom, with its strong gardening tradition, and across Europe. *Le Bon Jardinier* (Bois and Grignan 1910) refers to the species without any caveat regarding its placement and mentions the use of *Fallopia sachalinensis*, referred to as *Polygonum sachalinense*, for waterside locations.

Some concerns in relation to the invasiveness of the plant were voiced before the end of the nineteenth century. *Fallopia japonica* var. *japonica*, under the name *Polygonum cuspidatum*, is mentioned by William Robinson in The English Flower Garden (Robinson 1906):-
"It should be grown apart on the turf or in the wild garden. It is easier to plant than to get rid of in the garden".

William Robinson is often cited as one of the most influential of the late Victorian gardeners and this book is cited as a classic reference work which would have had wide circulation.

Despite such caveats, *Polygonum cuspidatum* and *P.sachalinensis* are detailed by Graham Stuart Thomas in his book “Plants for Ground Cover “(Thomas 1970) as:-
”only suitable in a large wild garden where clumps twenty to thirty feet across can be tolerated.” This is concerning in that it demonstrates some knowledge of the risks, but still suggests a planting location highly liable to result in further spread.

As late as 1994, when concerns were already being noted, the Joint Council for Landscape Industries included *Fallopia compacta* (*Reynoutria compactum*) in their recommended list of herbaceous perennials for landscape planting (Joint Council for Landscape Industries 1994). Even in March 2002, the well known garden commentator, Alan Titchmarsh in the BBC magazine, “Garden Answers” cited *Fallopia* x *bohemica* “Spectabilis” as “*A striking form of Japanese knotweed”* (Titchmarsh, 2002). No caveats in relation to its spread were noted in the text.

Escape to the wild by *Fallopia japonica* was noted in the last years of the nineteenth century in Wales and in the early twentieth century in Cornwall (Connolly, 1977). Botanical surveys now record its presence throughout the British Isles, being noted in 2340 of the 3500 10km squares (Botanical Survey of the British Isles, 1999). This spread appears to be predicated to a large extent on human activities.

The plant has been introduced in many temperate zones of the world including many parts of Europe, the United States of America, Australia and New Zealand. Similar concerns regarding its invasive properties have been recorded in all of these regions (Urgenson 2006).

1.5 Suggested benefits of the plants

Stated benefits of the plant, apart from early references to its ornamental qualities, include its use for a variety of medicinal purposes in its native environment (Spainhour 2008), its edibility – in its early growth stages, (Child and Wade 2000) its use as a pottery glaze (Rosudgeon Pottery, Cornwall) and its screening potential and capacity for stabilisation of slopes (Siebold 1856). It has been used as a fodder source (Beerling et al. 1994) and a nectar source for bees (Farrazi and Marletto 1990). There have been suggestions that it could be used as an energy source (Callaghan et al. 1981, 1984). Gilbert, (2001) has suggested that it can emulate deciduous woodland, having noted that the larvae of Brick and Hebrew Character moths have been noted to graze on it, and that it can:- "*hide rubbish for much of the year giving the (river) corridor a green and tidy appearance, which is appreciated by estate agents as housing and businesses return to its banks*".

1.6 Legal position

Despite many records of the escape of this plant into the wider environment, there are currently no restrictions on the cultivation or sale of any Japanese knotweed species. However, it is considered by the Environment Agency to be a major problem, and a Code of Practice has recently been developed in Britain (Environment Agency, 2005).

The seriousness of the problems the plant can cause may also be considered from the fact that it is one of only two land plants whose spread into the wild was made an offence under the original version Wildlife and Countryside Act 1981 (WCA 1981). This Act states, in Part 1 Section 14 (2): "Subject to the provisions of this Part, if any person plants or otherwise causes to grow in the wild any plant which is included in Part II of Schedule 9, he shall be guilty of an offence".

All parts of the plant and soil that contains them are considered to have the potential to cause ecological harm. For this reason it does not qualify for exemption under the terms of Section 34 of the Environmental Protection Act (EPA)1990, meaning that it should be classed as controlled waste and can only be transported by appropriately licensed carriers to licensed disposal sites, with appropriate permissions for their receipt, according with the EPA (Duty of Care) Regulations of 1991.

Action has been taken in the courts when Japanese knotweed has invaded adjacent property. In a case where the applicant took action against a council as Japanese knotweed was colonising his property, the judge found in favour of the applicant and required the council to take action to prevent the plant spreading into the adjacent land. (Flanagan v Wigan MBC (Unreported 1995)) Actions for nuisance have also been taken in relation to the plant. (Appendix 1).

1.7 Approach of the research

This study draws on a wide range of field work. Recording methods have been modified to increase accuracy and to provide information relevant to decisions on control methodologies. This information has provided evidence of likely mechanisms of spread. Potential areas of colonisation and methods by which spread is further accelerated are studied.

There has been considerable publicity regarding the attributes of the plant. The refusal of mortgages when the plant is present within the property or in adjacent land (Daily Telegraph 2010) is likely to lead to concealment of its presence and to further fly tipping and consequent spread. The work has emphasised the importance of provision a wide range of public information to ensure appropriate identification and to demonstrate that there are appropriate methodologies for the control of the plant in a variety of situations. This has provided feedback from a wide cross section of the public which has resulted in provision of data relating to situations which would not normally be accessible to survey e.g. enclosed private gardens. It is believed that this may assist in reduction of fly tipping which has been an important factor in further dispersal of the plant.

A number of aspects of the physiology of the plant that are relevant to its control had not been investigated to a level necessary for development of appropriate methodologies. An example of this is the assessment of success of a control programme using the criterion of presence or absence of above ground material. The work also considers the practicality of the control methods by which these findings can be delivered in a work situation.

Information drawn from site observations has been assessed, in controlled conditions, to highlight appropriate control methodologies in work situations in the wide range of locations in which the plant is likely to be encountered. Specific case studies have been undertaken with observations continued for periods of up to ten years.

1.8 Aims of this work

- Chapter 2 deals with the issues of obtaining improved information regarding the location of the plant and to clarifying mechanisms of its spread, by improved communication and encouraging feedback. It considers a number of sociological aspects and identifies the role of man as a primary factor in the spread of the plant. It considers the need to avoid prevarication in order to achieve cost effective control and the areas likely to be particularly liable to be colonised.

- Chapter 3 investigates aspects of the physiology of Japanese knotweed in order to provide wider information to inform and direct control methodologies. The work includes a number of aspects of the viability of the plant which have important implications regarding methods of sampling and assessment to provide some measure of the efficacy of any control methodology.
- Chapter 4 discusses case studies of methods of control used in specific situations to provide workable methodologies for delivery of these works on site

The information gathered has direct relevance to work in the field and much emphasis has been placed on applicability and deliverability in this environment. Education of the wider public has also been emphasised as, without adequate knowledge of the plant, its increase, and consequent damage to a wide range of habitats and the built environment, will continue.

Areas specifically mentioned in the work, in text or pictures, are detailed in Appendix 2.

Chapter 2

Recording, distribution and spread

2.1 General introduction

In order to fully understand how to develop strategies for the control and eradication of Japanese knotweed, it is important to understand where and in what quantity it is present and how it moves within the environment. Not only does the presence need to recorded, but the quantity needs to be assessed and any patterns of spread analysed.

It is particularly important to record introduced plant species in order to provide reliable data on the extent and rate of their colonisation as a number have become dominant at a cost to endemic species. (G.B. Non-native Species Secretariat website https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=55)

Knowledge of distribution of alien species around the world is dependent on accurate recording of their presence, their distribution and prediction of the areas likely to be colonised, (Keller et al. 2008). It is essential to gain initial knowledge as to whether an alien species is present in an area before an understanding can be developed of the types of location where it is likely to be found and how it spreads. It is therefore important to record presence and extent of the target species, describe distribution of the target species and to continue measuring presence, extent and distribution over time in order to analyse rate and pathways of spread. Only by standardising and refining the recording methodology can one obtain data that can be used reliably to assess the problem, identify pathways of spread and indicate possible methodologies for control.

A considerable number of plant species were introduced by plant hunters during the late eighteenth and nineteenth centuries. Japanese knotweed was introduced into the British Isles in the early to mid-nineteenth century (Conolly 1977). It has been demonstrated that introduced species may pass through a “lag phase” of establishment before exponential increase (Richardson et al. 2000). This may explain why the impact of such increase and invasiveness was not recognised or considered to be a strategic problem until well into the 20th century. This is evidenced by the fact that the conferences on the Ecology and

Management of Alien Plant Introductions (EMAPI) did not commence until 1992 and the journal “Biological Invasions” did not commence publication until 1999. An early quantification of the likelihood of a plant species becoming invasive was published in 1996 (Williamson and Fitter). The changing distribution of *Fallopia* spp. in the British Isles was catalogued by Conolly (1977) and its spread between 1930 and 2009 is well illustrated by the attached maps of the British Isles (Appendix 3a - 3h).

In order to acquire the required data, it is necessary to collect information in a systematic way. If presence is noted, it is highly desirable to record the extent of the plant’s colonisation so that the rate of any increase can be recorded and an assessment can be made as to whether the calculated rate of increase suggests that remedial action to control the species is necessary.

The reliability of data is dependent to a large extent on its quantity and its variability (Fowler and Cohen 1990). There are limits to the process of replicability when one is analysing an organism which is found in a wide variety of environments. The greater the number of times that a behaviour is observed, the more scientifically significant the observations will be. The normal scientific methods of proof require replicability in order to demonstrate statistically significant results, but the wide range of environments in which Japanese knotweed has been noted to grow, and the variety of methods that have been noted for its control, mean that the range of variables is wide and that clear statistical comparability can be difficult to achieve. As in medical scenarios, it is difficult to obtain large quantities of similar data when the range of variability is taken into account. As an example of this, the number of Japanese knotweed sites that can genuinely be categorised as undisturbed are few in number because many sites may have been previously subjected to many and varied control attempts. However, observation of a wide range of sites can provide some useful information on common factors affecting plant growth and responses.

The evenness of recording effort in the way that data are obtained is also important. Effort in recording plants has tended towards native species and species of “interest” and has generally been more widely carried out outside the built environment. Plants considered as garden escapes have, until relatively recently, been considered a low priority for recorders. There are similarities with a number of other species, as an example, in relation to birds:-

“It is often the so called "common" birds which are overlooked for which we do not have reliable maps of distribution or abundance. Changes in the abundance of such species may be overlooked just because they are assumed to be "common". The House Sparrow is a

good example. It has become increasingly scarce, particularly in the urban and suburban areas, but its demise has only recently been recognised."
(http://www.sorby.org.uk/recording/bird-rec.shtml#What).

A further issue in relation to evenness of recording is that an individual may have taken great effort in one geographical area, perhaps reflecting personal interest and commitment. It is also likely that such data will be more comprehensive closer to the individual's residence or areas which he/she frequents frequently. Very great effort in one area of the study contrasted with little recording effort in a neighbouring area will not provide an accurate and reliable assessment of overall quantity and distribution.

The greater the accuracy of recording, the more accurately can the need for control be assessed, and the costs likely to be involved in carrying out the work determined.
The need to record accurately should not, however, be used as a reason to delay action, particularly when there are strong indications that the organism concerned can be environmentally or otherwise disadvantageous, as the consequence can be, in a relatively short timescale, an exponential increase in population, increased costs and/ or the lack of ability to control the issue (Timmis and Braithwaite 2002; Mandak et al. 2004; Kraus and Duffy 2010). The precautionary principle, a way of approaching policy and decision making where there is a lack of total scientific certainty, is applicable to the development of strategies for the control and eradication of Japanese knotweed. This approach is discussed in both the Declaration and Convention on Biological Diversity. Principle 15 of the Rio Declaration states:-

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

The preamble to the Convention on Biological Diversity is as follows:-

"Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat."

Various authors have demonstrated the desirability of early intervention for control of invasive plant species (Anderson et al. 2003; Anderson 2005).

Records indicate that a number of different species and hybrids of the plants known colloquially as Japanese knotweed are present within the British Isles; these include *Fallopia japonica var. japonica. Fallopia sachalinensis, Fallopia japonica* var. *compacta, Fallopia* x *bohemica* and *Fallopia* x *conollyii* (BSBI records 2011) although the records and further research by Bailey et al. (1995) indicate that the great majority of plants present are an individual female clone of *Fallopia japonica* from the southern part of Japan. Although this work clarifies the fact that the large majority of plants recorded are male sterile and thus that the principal method of spread is by vegetative means, failure to differentiate between species and sub species could lead to poor understanding of distribution of such individual species and hybrids. Ignorance of the need to carry out adequate identification and to record the presence of hybrid forms such as *Fallopia* x *bohemica* or related species could mean that possible spread by seeding could fail to be taken into consideration when control is planned, with consequences on cost and efficiency of control.

The definition of the geographical area for which information is required should take account of the surrounding areas and consider the possibility of transferability of material to the target zone. For this reason it may, particularly when dealing with watercourses, require a catchment wide approach. It is certainly more effective in relation to assessment of control to start the process of recording at the highest upstream occurrence.

Although it can be very helpful to use information on the likelihood of an organism being present in specific environments, there should be adequate flexibility in the areas of investigation. The fungus *Phytophthora ramorum* was initially associated with its effect on specific species, but list of host species is widening with further observation (Forestry Commission 2011). Once accurate information on spread is collected it can then be used to determine whether action to control the plant is considered to be necessary by means of risk assessment (Phelong et al. 1999; Baker et al., 2006), and to design an appropriate strategy, if such control is required (Mullin 1998). The greater the accuracy of such information, the more effectively and appropriately control operations can be planned and thus the more likely they are to succeed. Failure to gain adequate information can lead, as an example, to poor planning that can then lead to the deployment of insufficient resources to gain adequate control. The economic benefit of such accuracy is also demonstrable (Keller et al. 2008).

Plants may be dependent on specific environments in order to thrive. As an example, Rhododendron is only found growing in acidic soil conditions. Studying distribution can indicate where a plant is likely to be found and where it is most likely to thrive. It may also give indication of conditions inimical or limiting to growth of the specific object of study. As an example, light levels have been demonstrated to be a significant factor in the ability of Japanese knotweed to establish, more limited levels such as in coniferous woodland showing greater resistance to colonisation (Seiger 1993). Japanese knotweed has been recorded growing in soil pH ranges ranging from 3.7 to 8.5 and of varying moisture retention capacity (Palmer 1990; Beerling et al.1994).

Human activities can also influence the distribution, either by the accidental or deliberate introduction of new species. The initial introduction of Japanese knotweed was deliberate in that it was promoted as an ornamental garden plant (Bailey and Conolly 2000). Other human activities that can promote spread include such factors as changing environmental conditions by activities such as fertiliser application, alteration in pH, hydrogeological disturbance etc. (Hobbs and Humphries 1995; Hester et al. 2007).

The plant is a primary coloniser of volcanic areas in its native habitat so it might be expected to require specific conditions. However, work carried out by Kanai (1995) in connection with recording of the plant in its native environment in Japan indicates the presence of Japanese knotweed in a wide variety of locations including roadsides and rivers as well as the noted harsh volcanic environments. Comparisons between the plant in its native and environments into which it has been introduced have been undertaken (Wade 1997). It has also been found in unanticipated habitats such as saltmarshes (Richards et al. 2008). Analysis of distribution over time can provide information as to patterns and rates of spread. It can be anticipated that different species, with different factors affecting their evolution, may have different distribution patterns.

Plants can spread by seed and vegetative fragmentation. Response to physical damage to shoots might result in the production of more shoots. The viable plant material may be spread by a number of means including wind, water, soil transport, birds and animals (including humans). The method of spread will influence the plant's final distribution. In its native environment, the spread of Japanese knotweed is largely by seed, with high seed production, but a relatively low rate of seedling survival (Maruta 1983), whereas in many areas of Britain to which the plant has been introduced, a single female clone is present and thus seed spread is not the main mechanism of spread in the British Isles (Bailey et al.1995).

The plant was considered to be naturalised in the United Kingdom by 1886, 60 years after its introduction (Bailey 2000). By 1905 the Royal Horticultural Society, in its Journal, no longer recommended its planting, because of its noted ability to spread, unless the cultivation was in extremely controlled circumstances – *"most carefully kept in check"*. Correlation of the presence of the plant with populated areas has been noted in work carried out in Swansea (Child 2001). It has been previously noted that, despite the fact that seed spread is not generally a factor, the plant can be easily spread vegetatively in mobile ecosystems (Beerling et al.1994). Areas of spread have been suggested to focus on transport corridors (Beerling 1991).

Knowledge of the phytosociology of the plant will provide information on likely areas of colonisation and thus aid targeting of control operations.

2.2 The situation in Cornwall prior to the start of this research

2.2.1 Recording

Previous work in the British Isles had provided data on the presence of the species according to BSBI criteria, mostly noting presence or absence in 10km or 1 km grid squares. This did not provide the level of accuracy required in adequate detail to assess the extent of any problem in Cornwall and to enable the development of deliverable solutions. The data in relation to this were, in common with other plant species, recorded as point data. It is necessary to gain sufficient information not simply to determine presence or absence of the plant within an area, but also to accurately determine its location and to quantify the amount of material within those specific areas.

The recording had been modified within Cornwall to provide more detailed information, but the data available at the start of the work were insufficient to provide a full record of the situation and therefore this research focussed on providing more comprehensive information on a wide scale and encouraging participation from a wider audience. The plant can be found in places to which the public does not have access, so a recording body can remain unaware of the presence of the plant in such situations. Survey data can be very dependent on the location of those willing to participate and send in information and this can result in very good recording in certain areas, but a lower recording standard in others. An overall survey with a dedicated recording system over the whole of the area being considered was therefore required to optimise the quality of the database. Further detailed survey work was also required to verify the area colonised by the plant in each locality, rather than just simply recording its presence.

In addition to *Fallopia japonica* var. *japonica*, *Fallopia sachalinensis*, (Giant knotweed) had been recorded in Cornwall and its hybrid with *Fallopia japonica* var. *japonica, Fallopia* x *bohemica* (Bailey et al. 1996). There were also some records of *Fallopia japonica* var. *compacta*. A hybrid with *Fallopia baldschuanica*, (*Fallopia* x *conollyi*) had been recorded in the British Isles, though not in Cornwall. The vigour of this hybrid is not strong (Bailey 2001).

Japanese knotweed in Cornwall had been recorded according to national criteria which record presence or absence in 2 km (tetrad) or 10 km (hectad) squares. These indicated much increased reporting after 1987 with only 6 tetrad records of the species prior to 1930 (Appendix 4), 44 between 1930 and 1969 (Appendix 5) 62 between 1970 to 1986 (Appendix 6). The greatest period of increase was 1987 to 2009 with 605 additional tetrads added to 1999 and 428 more added to 2009 (Appendices 7 and 8). Only 104 records have been added post 2009 to 2011 (Appendix 9).

More detailed surveys and GIS mapping were proposed in the Japanese Knotweed Manual (Child and Wade 2000). Considerable detailed survey work had been carried out by them in Swansea, an area (400 km^2) primarily urban and post-industrial. A systematic survey was initiated in Cornwall by biological recorders in 1987, looking at each 2 km grid square in all four seasons to record all plants growing wild, and looking at as many habitats as possible for a Flora of Cornwall. (French, et al. 1999)

Botanical recording specifically related to Japanese knotweed in Cornwall was developed by Dr Colin French in 1998. Recording sheets (Appendix 10) were designed and distributed to the general public and parish and town councils were sent maps of their areas and requested to provide information as to the known locations of the plant. These were added to the Cornwall Biological Records Centre database (ERICA) and plotted largely as point data on acceptance with a view to verification by survey. The distribution of the plant and the problems it caused in the riparian environment resulted in the provision by the Environment Agency to Cornwall Council for the Cornwall Knotweed Forum of GPS equipment and Arcview software which allowed for recording in polygon format during the study, rather than as point data. This followed previous work using such recording methods in the urban environment (Child and de Waal 1997).

The initial findings of the 1987 Cornwall plant survey gave some indication of the extent of Japanese knotweed in the area, though the number of sites recorded subsequently gives further credence to the necessity of strategic targeting in relation to survey of these specific invasive introduced species.

Previous survey work cited cannot easily be equated with the area of Cornwall (3563 km^2) and the wide variety of habitats that are found within the area, ranging from post-industrial habitats and settlements through to largely undisturbed areas of upland moorland. Investigation of the records already held led to the discovery that some reports were of other species, such as Himalayan knotweed and even apple. This is indicative of one of the issues of acceptance of reports without verification. The 1998 survey did not distinguish between the various species and varieties likely to be encountered.

The information requested from the public in the survey initiated in 1998 did not determine a number of factors, for example, proximity to watercourses. These criteria were required in order to better inform any control methodology. The situation reported did not always concur with the actual situation of the plant as it was necessary for the person collating the reports to record the site within the limits of the information provided. For example, the use of a six figure grid reference could mean that the location was at any point within 10000 $metres^2$.

The recording by point data restricted the ability to determine the area covered by the plant and plant size was not detailed. This can be a relevant factor for methodologies for control. Details of any control operations that had already commenced were not requested. The data recording did not embody sufficient detail to assist in methodologies of control e.g. accessibility and individual/joint ownership. Although the work carried out previous to this research had produced approximately 1500 records, field observation suggested that this could be a considerable underestimate of the plants' abundance.

One of the issues of invasive plant recording can be that colonies in the built environment may be difficult to record and that, until comparatively recently, cultivated plants that have escaped into the wild may not have been considered as a priority for recorders who have tended to focus on the recording of native plants rather than those which have been introduced. An additional point can be that some members of the public might be concerned to acknowledge that they had a plant that has been the subject of much negative comment within their property. This concealment could lead to inappropriate disposal and further spread. More accurate data were therefore required in order to quantify the extent of the plant in Cornwall and to gain knowledge of its abundance in order to provide accurate information for control measures.

2.2.2 Distribution

In relation to distribution, there had been some indication of association of the plant with watercourses and human activities, but this was not detailed to an extent to clearly demonstrate this. Much of this information was apocryphal. Closer study in an holistic manner was required to more clearly demonstrate where there was a higher likelihood of presence of the plant.

The plant has been recorded in its native habitat in a variety of growing conditions, from volcanic areas with high levels of heavy metals through to rice growing and urban areas. There is therefore a demonstrated accommodation of a wide range of environments and nutrient levels (Richards et al. 2008).

Observation and mapped data from a number of countries indicate association between transport corridors and the presence of *Fallopia* s.l. (Beerling 1991).These corridors may be either roads or rivers, and previously recorded data in Cornwall gave some indication of this. Settlements were also noted to have the plant present, as were post-industrial sites. The fewest records in Cornwall appeared to be where there were few habitations or an absence of such connecting features. A further area of low presence was noted on agricultural land under active husbandry.

Cornwall is roughly triangular in shape and has an area of in 3563 km^2. It is approximately 118 kilometres from end to end and 72 kilometres wide at its widest point. There is a single boundary with the adjacent county, the area being surrounded on the other sides by sea. It has considerable variation in relation to its geological formation. There are few large settlements and the county is primarily rural. Mining and quarrying activities are now of lesser importance, but formerly covered considerable areas. Major watercourses include the Tamar, the Camel and the Fowey.

From the climatic viewpoint, the area is the mildest within the mainland of the British Isles. Gale force winds are frequent in the autumn and winter. Exposure in particular areas varies widely.

When these factors are taken into account, Cornwall can be seen to provide a wide variety of locations with the potential to provide considerable data of relevance to the potential spread of the plant. Previous information was indicative, and, while giving some guidance as to the areas where the plants were likely to be encountered, did not provide adequate information for detailed analysis. 39% of the 3953 kilometre squares were noted to have recordings of infestations, but the method of recording of points within kilometre squares did not provide sufficient detail for analysis of distribution at a suitable level.

Table 2.1 Climate data for Truro Cornwall 2008

Source; Foreca. Retrieved 2008-05-20

http://weather.uk.msn.com/monthly_averages.aspx?wealocations=wc:34002.

Climate data for Truro, Cornwall

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	8 (46)	8 (46)	10 (50)	12 (54)	15 (59)	17 (63)	19 (66)	19 (66)	17 (63)	14 (57)	11 (52)	9 (48)	13.3 (55.9)
Average low °C (°F)	5 (41)	4 (39)	5 (41)	6 (43)	8 (46)	11 (52)	13 (55)	14 (57)	12 (54)	10 (50)	7 (45)	6 (43)	8.4 (47.2)
Precipitation mm (inches)	81 (3.19)	63 (2.48)	49 (1.93)	54 (2.13)	40 (1.57)	47 (1.85)	48 (1.89)	51 (2.01)	57 (2.24)	87 (3.43)	87 (3.43)	78 (3.07)	742 (29.21)

More detailed survey work was required in a coordinated fashion, particularly in areas considered to have elements of connectivity. Sampling work was also required in areas with low levels of interference by man to verify the presumption that man's interference is a primary factor in relation to spread.

2.2.3 Spread

Work has been carried out regarding the pattern of biological invasions (Baker 1986; Bailey 1997).Various comments had been made regarding the potential of the plant to spread rapidly. There appeared to be few case studies which clearly indicated individual pathways of spread and mechanisms by which the plant is transferred. Detailed observations, combined with knowledge of the physiology of the plant were needed to determine if and how practices contributed to the spread of the plant.

Japanese knotweed has been recorded in Cornwall for well in excess of 100 years. (Conolly 1977). Cornwall housed a number of landed families who were involved in plant collection, and this, combined with the mildest climate within mainland Great Britain may have provided a trialling ground in respect of the capacity for plants to grow in this country. The early presence of the plant is evidenced by the second record of the spread of Japanese knotweed into the wild being recorded at Fowey in 1906 (Conolly 1977). Gauntlett's nursery at Redruth (GR SW 6985 4231) was notably active in the promotion of the plant in the early part of the twentieth century (Bailey and Conolly 2000; Harris pers.com 2002).

It had been established that spread of *Fallopia japonica* var. *japonica* within the United Kingdom is not, to any considerable extent by seed, all male plants investigated having been determined to be of hybrid origin (Bailey et al. 1995). Fertile hybrids have been recorded (Hart et al.1997) and further work has been undertaken (Hollingsworth et al 1998;1999). The method of spread of the plant is therefore predominantly by vegetative means, either from the rhizome system or from above ground shoots. Detached material of both types has been demonstrated to have capability of regeneration (Child and Wade 2000). The quantity of such material which is present in a stand, combined with work which has demonstrated that relatively small amounts of material could regenerate, indicate a considerable likelihood of distribution by disturbance. When this is combined with the noted ability of the plant to survive a wide range of conditions, including variable soil acidity, heavy metal and salt contamination (Child 2000), it appears clear that significant spread, in a variety of locations, is highly likely.

The capacity of the plant for rapid regeneration from fragmented vegetative material and accelerated and larger scale movement of materials, e.g. soil excavation and movement, particularly post 1945, are strongly suggestive that these mechanical factors are key in relation to a rapid increase in the number of recorded sites during the latter part of the 20th century (Conolly 1977). Movement downstream within watercourses had been noted as a route of spread in many river systems including the Earn, the Tweed and many rivers in South Wales and Cornwall (Child & Wade, 2000). It was anticipated that the seasonal fluctuation in flow patterns of rivers would result in the increased likelihood of the detachment of viable plant material, which would be likely to colonise lower reaches of the watercourses.

After the start of this study, some reports of plants tolerating estuarine conditions were also noted. A communication received by the author raised the question of spread in saline conditions:-

"Following the casual discovery of the species in several remote coastal locations in Argyll, Scotland, where dispersal by sea appeared to be the most likely method of spread, it was

decided that a more formal study should be conducted in an attempt to identify whether movement by sea was a true method of dispersal for Japanese Knotweed."

"A coastline survey in western Scotland revealed a single incidence of Japanese Knotweed which had clearly been deposited on the beach by the sea. This is the first documented occurrence of sea dispersal by this species in the United Kingdom and it highlights the importance of effective riparian control not just for specific rivers but for coastal areas further afield." (Hayward 2003 pers.com about Hayward 2002). There were indications from other sources that this transmission by sea may occur (Child and Wade 2000).

Previous work had indicated the ability of the plant to spread by environmental and mechanical means, but no detailed studies had been undertaken. The size of material capable of regeneration was not clear and the mechanisms of movement had not been systematically studied. There was a considerable amount of apocryphal information, but little information which could provide definite proof of spread, and the variety of situations made replication difficult.

Comments on the speed of spread of the plant have been made from a variety of sources and the BSBI maps provide evidence of the rapid increase of reported locations. The speed of spread in areas with little or no disturbance had not been clarified.

2.3 Materials and Methods

2.3.1 Recording

The formation of the Japanese Knotweed Forum for Cornwall in 1997 resulted in responsibility for the recording of these species being assumed by Cornwall County Council and specifically the author. This provided the opportunity for the expansion of the recording system to increase the quantity and quality of data. An open approach and encouragement of the public to make contact and seek advice were important factors in gaining information.

Public information was a primary objective in order to encourage reports and thus to gain as much information as possible. This involved collating both printed and web based data to provide accurate information in relation to recognition of the plant. This information was put forward in a way that did not vilify the plant, (in order to minimise the likelihood of information being withheld, leading to reduced accuracy of recording, particularly in built up areas).

This work has modified the recording options in order to accept data on the extent of the plant by written description or sketch plan and collection of more detailed information online. This widening of the types of information requested was intended to gain more information by making the process simpler and thus open to a wider section of the population. To ensure proper verification of the data, particularly in line with the fact that a wider group with, perhaps, a more limited knowledge in relation to plant identification, was being encouraged to participate in the gathering of information, the protocol of inclusion within the database was altered in that reports were not accepted at face value, but marked on the map to be checked by the author or a specified, trained individual. This was considered necessary as, when some of the previous reports received were checked they referred to unrelated species, even in one instance, apple, and also that differentiation between different species of knotweed was considered necessary.

The initial public report was followed up by detailed survey by the author or a trained individual. Once on site, the trained individual could provide information upon the wide range of data considered necessary to provide an adequate basis for determining a possible control methodology. The location of the plant was also defined more precisely. As an example, the proximity to watercourses was requested, a factor which could be relevant to accelerated spread.

The recording form was modified to improve the quality of data on location, and to determine parameters and so provide the information required to programme appropriate treatment. This resulted in the incorporation of further fields on the feasibility of access for a variety of control methodologies. These ranged from limited pedestrian access through to access by large excavating machinery.

The further development of the recording form resulted in the extension of the use of the Geographical Information System (GIS) for the purpose of developing and enlarging the previous recording capacity. The methods of recording were detailed within the database, ranging from sites surveyed directly by Global Positioning System (GPS), edited data using the system, physical surveying of the site, or estimation from a distance where access was not possible. This permits recording in the widest range of situations as GPS does not having universal coverage. It also allows for an assessment of the accuracy of the information in relation to the method by which it was obtained. The opportunity was taken to expand the information database and to map the extent of the plant where possible, rather than to simply record point data.

Since legal parameters preclude the inclusion of information when a site cannot be viewed from a place accessible to the public a form of permission for the landowner to permit inclusion of such data was developed.

The record was defined as a biological unit, so that scattered shoots within an area would be recorded individually. Groups of shoots that appeared to be biologically connected (i.e. material within 14 metres of an adjacent group of shoots) were recorded as a unit since the underground parts of the plant have been recorded at a distance of seven metres from above ground material (Smith 2006). If barriers or other apparently impenetrable features were noted within an infested area, but within a range considered likely to be connected in normal circumstances, such groups of shoots would be recorded individually. The reasoning for this was to provide more accurate data for control purposes.

Further parameters were set for accuracy of recording; location, proximity to water, accessibility, density of cover, stem diameter, treatment regime individual or joint ownership and incorporated into a new recording schedule to accord with the GIS database (Appendix 11). The quality of the data, ranging from on site survey to observation from a distance was detailed for each entry (Appendix 12). Greater detail was collated when the site was being assessed for experimental purposes (Appendix 13).

A methodology was developed to further refine the recording process, linked with control in those areas for which Cornwall Council has responsibility. Those carrying out control on behalf of the Council were required to complete a report form on the quantity of material present on the control site on a twice a year basis within the growing season (Appendix 14). A protocol was put into place to require that such recording should continue for at least five years after above ground shoots were observed on individual sites. This was put into place as observations had been made that, in certain circumstances, the plant may not produce above ground shoots for more than one growing season.

With advice from the author and the Cornwall Knotweed Forum, a website was developed by Cornwall County Council which incorporated a link to the recording form and the facility to report the plant online direct onto a map base as well as providing information on a wide range of issues relating to these species. This avoided the need for provision of a grid reference, which had been found to present difficulties for some observers. The online recording can be found at: -
http://www.cornwall.gov.uk/default.aspx?page=22413

In order to encourage participation by the public at large and to maximise data input, a number of specific communication initiatives were been undertaken. Exhibits in relation to the plant and its attributes were staged at the Royal Cornwall Agricultural Show, other shows and at Chelsea Flower Show at which a Gold medal and Silver Gilt medal were awarded in successive years in the Education Section. Information leaflets and booklets were developed in association with the Cornwall Japanese Knotweed Control Forum (Appendix 15) and are subject to continuing updating, both in printed format and online http://www.cornwall.gov.uk/default.aspx?page=13789.

A particular concern was raised within the highway network. A specific incident occurred in which soil contaminated with rhizome was widely spread during the final phase of trench restoration on a main trunk road in the county. This clear evidence of spread of the plant in such an observed environment resulted in a comprehensive programme of recording of the plant and treating it, based on the concern relating to the damage the plant could cause on adjoining land and the potential for adjacent landowners to take action against the Council for nuisance, should, as was very likely, the plant spread onto their property.

2.3.2 Distribution

Road corridors were investigated as a particular focus because a primary objective for Cornwall County Council was treatment of all Japanese knotweed growing in these areas. Specific river catchments were also the subject of study, particularly the Fowey, Camel and Tamar. Detailed survey work was also carried out in the Tregeseal Valley, St Just and an area on the Roseland in an area traversed by a number of pedestrian and agricultural routes.

Particular areas of post-industrial land were assessed to provide further information. As these areas are often primary areas for redevelopment, the opportunity was taken by the author to study distribution within these situations. Cooperation was achieved with a large number of owners of land of this type, often in exchange for advice on possible control options, such previously developed or disturbed land often being a primary target for redevelopment.

Liaison with other departments of Cornwall Council provided access to data in relation to highways and the estate as a whole, so study of distribution in a wide variety of circumstances was possible. Public rights of way were a further potential transport corridor and therefore a particular research area in relation to distribution. The extensive farm portfolio of Cornwall Council of 106 holdings and 11,500 acres covers a wide range of agricultural land and activities and was also assessed. Contact was also made by the author with bodies including the National Farmers Union and the Royal Institution of Chartered Surveyors and information on sites was received from these sources.

Maps of distribution of the species were plotted and related to a number of factors such as transport networks, waterways and land use.

2.3.3 Spread

Detailed study of individual sites and areas was undertaken combined with investigation of site history of spread. A detailed study could not be carried out of historic management so site observation and an attempt to identify common factors that might be causing spread was undertaken on a site by site basis.

A number of cases were therefore investigated where dumping of viable plant material was suspected to be a likely cause of spread. Such deposit was considered to be likely to be, in some instances, deliberate, but in others to be due to lack of knowledge of the content of the material being handled.

Cases were investigated where acceleration of spread by disturbance by a variety of activities was suspected as being relevant. This included interviews with long term residents of the area about their activities in relation to the plant during their childhood years.

For each site the extent of the problem was noted, and, where applicable, digital images secured. It was attempted to identify means by which the plant was likely to have been introduced. A number of individuals who had long term local knowledge of particular areas were interviewed.

In order to investigate the proposition that the plant could spread without any interference, a site at Coverack GR SW 7743 1801, used for the assessment of speed of growth and also used by Smith (2006) as part of work on spatial spread, was also used in order to provide some guidance in relation to spread.

The site was monitored from 2003 to 2012. Soil samples were assessed for nutrient levels using a standard colorimetric analysis and the pH measured electronically. The site was bordered by an earth and stone bank on the northern side, 3 elm trees were present within it, a road bordered it on the southern side, woodland of elm and willow was present to the west and an open area with herbaceous growth to the east. No pathway or other line of communication was noted at any time through the site. Badgers had been noted to be present in the near vicinity, but none of their runs passed through the site and no setts were present. No burrowing activity by moles or rabbits was noted during the observation period. This may have been partly due to the moist and silicaceous nature of the soil in the vicinity and the presence of waste slate material which had been deposited, perhaps with the Japanese knotweed, at some earlier date. No cultivation, cutting or other land management operations were carried out during the period of observation.

2.4 Results

2.4.1 Recording

The result of these actions has been to increase awareness of the plant amongst the public at large and to enlarge the information flow. This has resulted in increased information regarding the location of the plant, which has resulted in a more complete data set.

The work has confirmed the belief that *Fallopia japonica* is the most widespread of the range of species generically referred to as Japanese knotweed present in Cornwall. Of the 4222 sites analysed, the results were as follows:-

Table 2.2 Proportions of Knotweed: September 2010

Analysis of percentage of each species of Japanese knotweed recorded in Cornwall up to Sept. 2010

Species/ Hybrid/ variety	*Fallopia japonica* var. *compacta*	*Fallopia sachalinensis*	Unidentified *Fallopia*	*Fallopia* x *bohemica*	*Fallopia japonica*
Percentage of sites	0.04%	0.28%	1.48%	1.49%	96.71%
Number of sites (out of 4222)	2	12	62	63	4083

The use of GPS has provided a means for increased accuracy of definition. This has been of particular significance for assessment of sites in relation to adjacent features, such as transport corridors, which are likely to be areas where spread can be rapid.

The use of a number of survey techniques ranging from observation at a distance through to GPS survey or physical measurement has permitted assessment of relative accuracy of the data. A particular point of relevance when considering control methodologies is whether the site is in individual or multiple ownership. The wider range of questions provides further information permitting consideration of appropriate control techniques in advance of a visit to a site.

In combination, the recording protocol developed during this research has provided a reliable data set of records of Japanese knotweed across the whole of Cornwall. The survey can reasonably be considered to be the most complete in relation to the plant for any equivalent geographical area in Europe.

An example of the increased accuracy of recording is the site at West Portholland, (GR SW 950409), cited elsewhere in this work. Previous survey information on this area indicated 4 records by point and 5 records by polygon data. Further detailed survey work by the author established 20 records within an area of 18 hectares, four points and one polygon of which did not coincide with the previous records. The remaining five previous records coincided to some degree with the later records, but the others, including the main site of 6179 square metres, were not previously recorded.

2.4.2 Distribution

The plant was found in a wide variety of soil conditions and nutrient levels across Cornwall. Analysis of locations of records indicate that verge and boundary habitat types contain a higher proportion of records than agricultural and woodland areas (Table 2.3)

Table 2.3. Determination of locations of Japanese knotweed in Cornwall.

Type of Environment	Verge	Boundary	Garden	Built environment	Cornish hedge	Agricultural	Woodland	Waste
Percentage of records	33.04	26.43	10.1	5.06	5.62	5.01	5.9	8.81
Number of records	1395	1116	426	214	237	212	249	373

Locations were identified from records of Japanese Knotweed on the Cornwall Council database up to September 2010 (Total = 4222)
NB 'Boundary' includes a number of habitat types.

Map data (Appendix 16) indicate a low occurrence of the plants in situations such as upland moorland with low levels of habitation, in contrast with areas of settlement.

Further analysis was carried out on sites recorded within 10m and 20m of the centre line of roads, a network of 7525km. The data were analysed according to the class of road.

Table 2.4: Analysis of Japanese knotweed on roadside sites 2011

Using a 10metre buffer from the centre line of the road

Class of road	Trunk	A Road	B Road	C Road	Unclassified
Total Length (km)	189	554	583	2645	3554
Number of sites	37	279	225	639	610
Average distance between sites (m)	195.8	503.6	385.9	241.6	171.7
Total area recorded (m^2)	14,518	55,782	61,716	194,219	109,774
Mean area per record (m^2)	392.38	199.94	274.29	303.94	179.96

1790 sites were analysed – this is 34.59% of total sites recorded on the aggregated database (5174sites) and 36.52% of the confirmed sites recorded on the full location database (4902sites)

Table 2.5 Analysis of Japanese knotweed on roadside sites 2011

Using a 20metre buffer from the centre line of the road (Appendix 17 Maps 1,2,3,4,5)

Class of road	Trunk	A Road	B Road	C Road	Unclassified
Total length (km)	189	554	583	2645	3554
Number of sites	59	382	304	774	726
Average distance between sites (m)	312.2	689.5	740.1	292.6	204.3
Total area recorded (m^2)	19,153	75,128	78,825	217,697	141,831
Mean area per record (m^2)	324.63	191.67	259.29	281.26	195.36

2245 sites were analysed – this is 43.39% of total sites recorded on the aggregated database (5174sites) and 45.80% of the confirmed sites recorded on the full location database (4902sites)

There appears to be a greater density of sites on roads in Camborne, Redruth and St Austell. All of these areas have a connection with urban areas, mining or quarrying activities.

Table 2.6 Analysis of Japanese knotweed adjacent to watercourses 2011

Using a 20metre buffer from the centre line of the watercourse. Watercourses included all those identified on the 1:25000 Ordnance Survey map. (Appendix 18)

Total length (km)	4560
Number of sites	1035
Average distance between sites (m)	227
Total area recorded (m^2)	406922
Mean area per record (m^2)	393.16

1035 sites were analysed – this is 24.52% of total sites recorded on the aggregated database (4221sites) and 26.21% of the verified sites recorded on the full location database (3949 sites)

Table 2.7 Observations on location of Japanese knotweed in specific areas

Grid square ($1km^2$)	Location	Number of sites surveyed	Road/ track	Watercourse	Other	Nature of sites
SW 6640	Brea	79	14	17	48	Mainly heavily disturbed mining areas
SW 6841	Carn Brea	15	13	0	2	On tracks through area
SW 8245	Truro	8		8		No records upstream of

						urban area
SX 0052	St Austell	8	8	8		On river by road
SX 0049	Levalsa Meor	17		17		Downstream of quarry and settled area
SX 0149	Levalsa Meor	0	0	0	0	Agricultural land east of river
SX 1277,1278,1279,1280, 1377,1378,1379,1380, 1477,1478,1479,1480, 1577,1578,1579,1580	NW of Bolventor	0	0	0	0	Moorland. Only 167m of road. No settlements
SX 1876	Bolventor	8	4		4	Village

Notes on above table

In Carn Brea, the former tramway which connected to the area has 32 sites within 50 metres of the track bed in a 1.3 km length between GR SW6749 4088 and GR SW 6865 4121.

An average of two sites per kilometre square in each of the adjacent connected squares to the south east of Bolventor along the River Fowey has been recorded. The data indicate association with hedges and other boundary features. In all noted occurrences in Cornwall on watercourses, the occurrence of the plant is downstream of the highest noted habitation or point of disturbance e.g. a quarry.

Agricultural sites account for only 4.3% of sites on the database, 182 out of 4222.

Landfill sites at Trezise GR SW 7308 2215 , Connon Bridge SX 1882 6240, Newbridge SW 4146 3171, Tregongeeves SX 0005 5148, Tiscott Wood SS 2229 1089, Helston SW 6529 2689 and elsewhere have recorded occurrences.

The geology of the area studied would appear to have less influence than other factors relating to distribution. The map of the geology of Cornwall (Appendix 16) annotated with recorded Japanese sites shows a marked difference in the number of sites between upland areas on the granitic subbase of the above mentioned site near Bolventor and the similar formation in the Camborne Redruth area. There is a considerable difference in elevation, between 200 and 400 metres, but other influences, discussed below, would seem to have greater relevance regarding presence of the plant than geological variation.

2.4.3 Spread

Observations on mechanisms of spread were collated and classified by vector. Table 2.8 gives some indication of vectors of spread that have been noted during the study.

Table 2.8 Examples of vectors of spread for Japanese knotweed in Cornwall

Vector	Example	Evidence for mechanism of spread
Water action	Boscastle. Material which was washed down by the flood event on 16th August 2004 was noted at a number of downstream locations (Fig.2.1)	The area upstream of that affected had been recorded prior to the event. The material noted after the event was in positions, in some cases, and of a size to indicate recent disturbance.
Soil movement	East Hill Camborne. Material spread in relation to mine capping activities which was previously recorded in a restricted area was noted to have spread widely.	The site was recorded in detail prior to the works as part of a recommended methodology which was not followed. The site has been under observation since these operations for a period of more than five years.
Linear disturbance	Vegetation cutting, with the possible spread from above ground material and disturbance by digging through an infestation. (Fig.2.2)	The site was surveyed prior to the operation and the material was noted in further locations following the work.

Soil import	A30. Contaminated topsoil imported to provide a finished surface after trenching resulted in infestations between Penzance and Bodmin.	Cornwall Council records and observation prior to and post works revealed material in situations where the plant had not previously been recorded. Sites were correlated with the trench works.
Quarried material import	Gwenter GR SW 749181	Statement by resident which identified quarried material as the source of the Japanese knotweed
Animal action	Veryan. Burrowing activities (Fig.2.9) indicate potential spread of the plant by this means.	The excavation was verified as a badger working by an ecologist and progressive excavation of the site by the mammals with consequent revelation of rhizome was observed.
Play activities	St Agnes. (Children as the vector)	A statement by a resident included below, (Sherriff) suggests the likelihood of spread by this means
Fly tipping	Nanstallon (Fig.2.3)	This site was known to be clear of infestation as it was regularly monitored. The nature of the deposition, typical of tipping from a trailer, clarifies that this was a case of fly tipping.
Demolition and site clearance	Camborne. Holistic demolition, rather than removal of demonstrably non contaminated above ground material followed by separate removal of underground material resulted in the	The site had been surveyed in detail well in advance of works and Japanese knotweed identified within the floor structure. The demolition methodology of digging under the whole structure rather than

	requirement for the decontamination of a far larger body of material. (Fig.1.2)	differentiating between demonstrably uncontaminated above ground material and problematic material in contact with the soil lead to spread of the plant material.
Transport activity	Machinery on construction sites can be operated in infested areas and pick up plant material.	Material has been noted in situations including the level undersurfaces of excavation machinery.
Uncoordinated treatment activities	Boundaries between ownerships	A lack of coordination of activities by the parties involved can result in spread e.g. by excavation if the plant on one side of the boundary.

This list is not comprehensive and in many situations it is extremely difficult to identify clearly the principal vectors involved.

Further observations

Fresh water

Physical spread of detached parts of the plant by water was notable from the survey data in a number of areas, the White River (St Austell) being a particularly notable example. This watercourse has been modified at various points along its length and the bank material consists to a large extent of siliceous waste, structurally a particularly unstable material. In view of the fact that the plant has been very frequently recorded in the china clay extraction area in which the river rises and the material has been recorded along much of its length leads to the conclusion that the material emanated from the upstream source area and was brought down by water flow. The use of water for extraction purposes for this industry and the noted colonising of areas of loose material, physically similar to those in its native habitat, are also features of consideration.

Field observations in watercourses and elsewhere have show regenerating material less than half the size of material (0.7g) previously tested in laboratory conditions (Brock and Wade 1992).

Spread down watercourses was observed in a most marked fashion, by the flood event at Boscastle on 16th August 2004 where rhizome and stem material were carried downstream and regrew rapidly. It is not unreasonable to assume that a percentage of material detached in this way would reach the sea.

Fig. 2.1 Regeneration from lodged material, Boscastle GR SX 098 910

Coastal

Japanese knotweed has been observed at a number of coastal sites around Cornwall including Newlyn (GR SW 4667 2839) Millook (GR SX 1846 1000) Cot Valley (GR 3561 3087) and Talland Bay (GR SX 2261 5159). At the last named site, *Fallopia* x *bohemica* was found on shingle at a point where small material washed down from the valley above is apparently supplemented by material from the soft cliff above which falls in large lumps when eroded by the sea. The bay itself is predominantly rocky and, apart from material established in the close vicinity, there are no reports of infestations in the nearby coastal zone. It is postulated that colonisation may be possible when dune or mud features are in close proximity. Some survey work has been carried out in the vicinity of the Cornish sites, but there is no clear evidence of colonisation of upper tidal limit areas in their close proximity. This may be due to the fact that these outlets are generally small, with rocky coastlines on both sides.

One particular area where such conditions differ markedly from the above in relation to shelter is to the north east of the Lizard peninsula. The rivers which feed into Carrick Roads commence as streams within former mining areas where there are many records of established Japanese knotweed. The nature of the land behind high tide mark might suggest vulnerability to colonisation, though a countering factor is reduced wave action which might have the potential to project any sea borne material to sites where growth might be less inhibited by saline conditions. There is at least one report of Japanese knotweed in a situation in the area where it seems likely that transport by sea of vegetative material may have initiated the colony.

Soil and rhizome movement

On land a number of operations have demonstrated spread of the plant. One of the most dramatic of these was the importation of contaminated topsoil to top off trenching operations within the highway. This resulted in the emergence of the plant over a length of 80 kilometres. The occurrence of the plant in the line of the excavation, the comparable size of the plant in all locations and the lack of previous records of the plant in the areas of regrowth are factors which, in combination, draw the observer to the conclusion that this operation can be reasonably considered to have resulted in such spread.

Other operations which have been observed to result in spread include, particularly, roadside ditching. In this operation, the digging of small channels from the hardened surface of the highway to provide links to adjacent drainage features has been noted to have, on occasion, been carried out through areas infested with Japanese knotweed, resulting in rhizome material being directly propelled into the watercourse.

The digging of ditches parallel to roads has been observed, resulting in linear spread of the plant by the action of the machinery and subsequent water action.

Again within the road environment, a further concern is that material containing rhizome may well require to be removed from site as there is often insufficient room for the material to be left near the point of excavation. Ditching operations are primarily a winter activity and it may well happen that the plant is not noticed. If this occurs, it is unlikely that appropriate disposal is undertaken and the material may well be deposited in such a way that it becomes a further focus for infection, such soil having the potential to be stored and reused as required in other situations.

Ploughing of vegetation spreading from adjacent land onto roads is another activity which can result in rhizome material being separated from the parent colony. Again, this is primarily a winter operation and the plant may not be readily indentified, resulting in the same distribution concerns outlined in the previous paragraph.

Other linear activities such as cable laying can have a similar effect to ditching in physically detaching material from its source and drawing such material along the line of the highway.

Fig. 2.2 Spread by linear activity Rosewarne GR SW 648 413

Road improvements can be a source of spread. Lack of appropriate identification procedures resulting in dispersal of Japanese knotweed material within the body of material excavated can be an issue in such a case.

Fig. 2.3 Spread by fly tipping Nanstallon GR SX 029 672

In the case of a road traffic incident where the vehicle involved left the road and ended up in an area infested with Japanese knotweed, rhizome was trapped within parts of the damaged vehicle. A number of instances have been recorded where Japanese knotweed is found in vehicle dismantling yards.

Fig 2.4 Plant growing in building awaiting demolition GR SW 655 401

In the case of a road traffic incident where the vehicle involved left the road and ended up in an area infested with Japanese knotweed, rhizome was trapped within parts of the damaged vehicle. A number of instances have been recorded where Japanese knotweed is found in vehicle dismantling yards.

Fig 2.5 Vehicle in breakers yard GR SX 014 590.

It therefore seems a reasonable assumption that the vehicles brought in and/or the conveying machinery could convey the plant into such locations. As further confirmation, the jacking system for lifting appliances used in such work has been noted to be liable to contamination as, when extended, it pushes into soft ground, breaking underground material. When the jack is withdrawn, soil and other material within the medium is removed.

In relation to the construction industry, a number of cases of spread by site activities have been noted. In one case, the plant had been deposited at the entrance of the site, probably as a previous dumping operation by an unknown party. The plant was not observed or recorded in relation to site assessment, and was fragmented and distributed around the site in an operation to level the area.

Sourcing of material can also raise issues. On another observed occasion topsoil was brought onto a housing site as a finishing operation, resulting in Japanese knotweed material appearing in many locations.

Treated material has been observed, on occasions, to fail to produce above ground extension growth for more than one season. Stimulation by a preceding period of low temperatures has been suggested as a factor by a number of observations. The author also observed material, which had not previously been treated, emerging from a soil pile at Scorrier (GR SW 7157 4399). The material had been covered with a layer of approximately two metres of soil for a period which, according to those who had long term knowledge of the site, suggested could have extended for ten years (Semmens pers.com). Material from this store had been used on a site as it had been assessed as uncontaminated. The plant subsequently regenerated at the deposition sites.

A case which was examined in greater detail was at East Hill, Pool, GR SW 6621 4133. Mine capping operations had resulted in the spread of Japanese knotweed rhizome over the area and viable rhizome, without above ground shoots was discovered at a depth of up to two metres three years after the reprofiling procedure. Both of these factors may result in material being assessed as uncontaminated, resulting in situations such as that detailed in the preceding paragraph.

Inappropriate demolition methodologies can have a significant effect on spread. Apart from the factor of spread of the plant as a result of a failure to recognise its presence when carrying out a site assessment, rhizome can colonise rough concrete surfaces, such as foundations. The increasing requirement to reuse such material as primary fill can have considerable cost consequences. In one recorded instance, a demolition methodology failed to deal with the issue of separation of contaminated below ground concrete separately from the uncontaminated material above ground and this resulted in a ten fold increase in the amount of material which had to be treated within a separation process. In this particular instance, the cost stated in a newspaper was £2 million. (West Briton 2008). If the demolition material had been used without the separation work being carried out there would have been ongoing costs from dealing with its further spread.

Colonisation by the plant of merchants' sites used for the onward dispatch of building materials can be a further factor in spread, particularly where stockpiles of material are deposited.

Fig.2.6 Japanese knotweed within builders merchant's site GR SW 720 420

Records have also been made of material from quarries being exported contaminated with rhizome. This appears to be material of lower quality which may well have been stockpiled prior to distribution as low quality fill material for track surfacing etc. Stockpiling areas can have greater capacity if the angle of repose of the material can be steepened by the planting of a species, such as Japanese knotweed, with a large and stabilising underground growth system. A number of colonies of the plant on quarry sites have been recorded, a particular example being situated at Mabe (Fig.2.7).

An instance which demonstrates such likely spread from this vector:-

I have known this site at Ponsongath since the 1960s when my family moved into Poldowrian Farm. In the mid 1970s, sub base granitic material was imported from a quarry to improve the tracks in the area. The material was put against the wall of an old house on the site and then spread on the tracks. No Japanese knotweed was known on the site before this happened. Since that time, Japanese knotweed has been present, particularly on the site on which the stone was dumped. It is still present on the site.

P.Moore Pers.com 2011

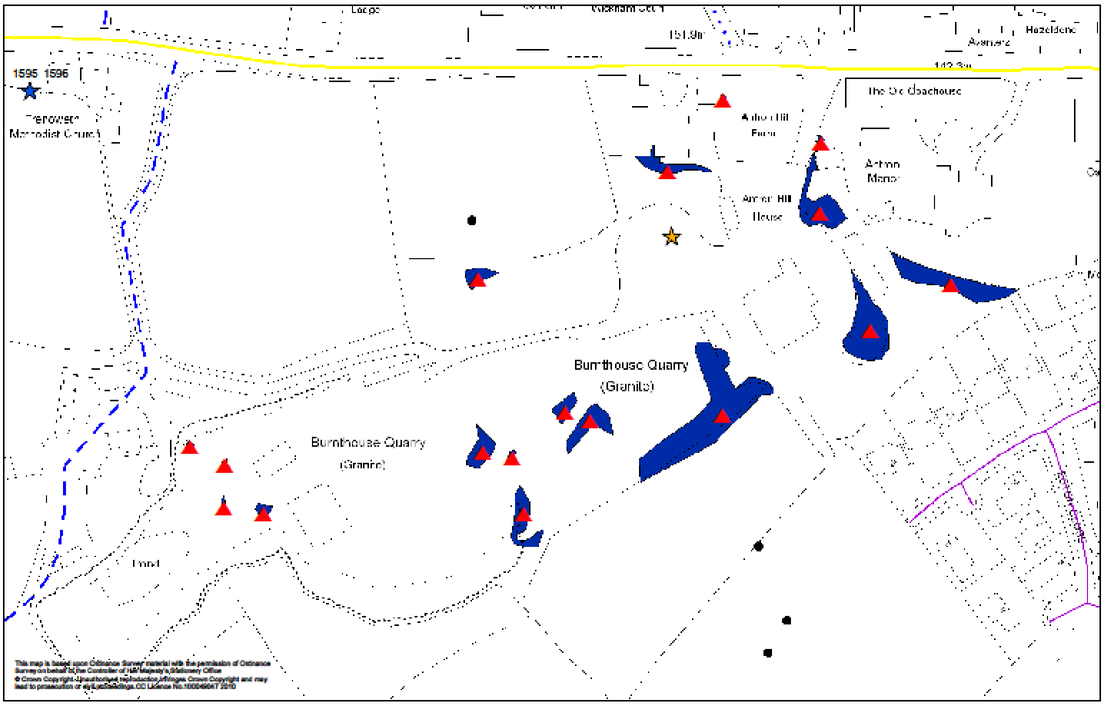


Fig.2.7 Quarry at Mabe GR SW 760 339 with surveyed Japanese knotweed indicated by blue polygons

Planting for stabilisation

This promotion as a stabiliser for loose materials on slopes (Siebold 1856) has been encountered in a number of areas. There are apocryphal records of its use in relation to the stabilisation of railway embankments, but confirmation of this use has not proved possible to establish. A specific example has been recorded north of Carn Brea village at GR SW 6893 4155 where it appears that steep embankments appear to have been contaminated in such a fashion. Colonisation from the railway onto land adjacent to such steep banks has been noted. Also in the railway environment, the plant has been noted in piles of ballast used for track bedding. Movement and use of such material is most likely to lead to further spread.

Machinery movement

In all the above quoted instances there is also the additional factor of spread by contaminated machinery. Rhizomes have been observed on the transport plates of tracked excavation machinery, and it is likely, when such machinery is transported between sites, that such material will be dislodged and result in further colonisation. Although such tracked machinery is a particular concern, any machine or equipment used on site has the potential to be contaminated and thus to cause further spread.

Ornamental planting

In the garden, the plant was originally introduced for its ornamental value. Its introduction coincided with a fashion for Japanese gardens, where water is a predominant feature. This could well have resulted in streamside planting with the very likely consequence, previously mentioned, of wash out of material and spread downstream. This would appear to coincide with the records previously mentioned that the plant has not been recorded upstream of human habitation or activities in Cornwall.

A further observation is that an interviewee stated that she had admired the plant, had obtained material and had then spent thirty years trying to get rid of it because it proved too vigorous for the intended purpose. A concern can be that disposal of such material may take place on a random basis.

Dumping

Many of the sites recorded on highways are strongly suggestive as having originated as dumped material. A particular site near Ruthernbridge GR SX 0138 6726 is clearly of that origin, it having been observed and reported by an adjacent landowner within a week of its appearance. The recent factor of refusal of mortgages on property on which the plant is present may well lead to an acceleration of such activity.

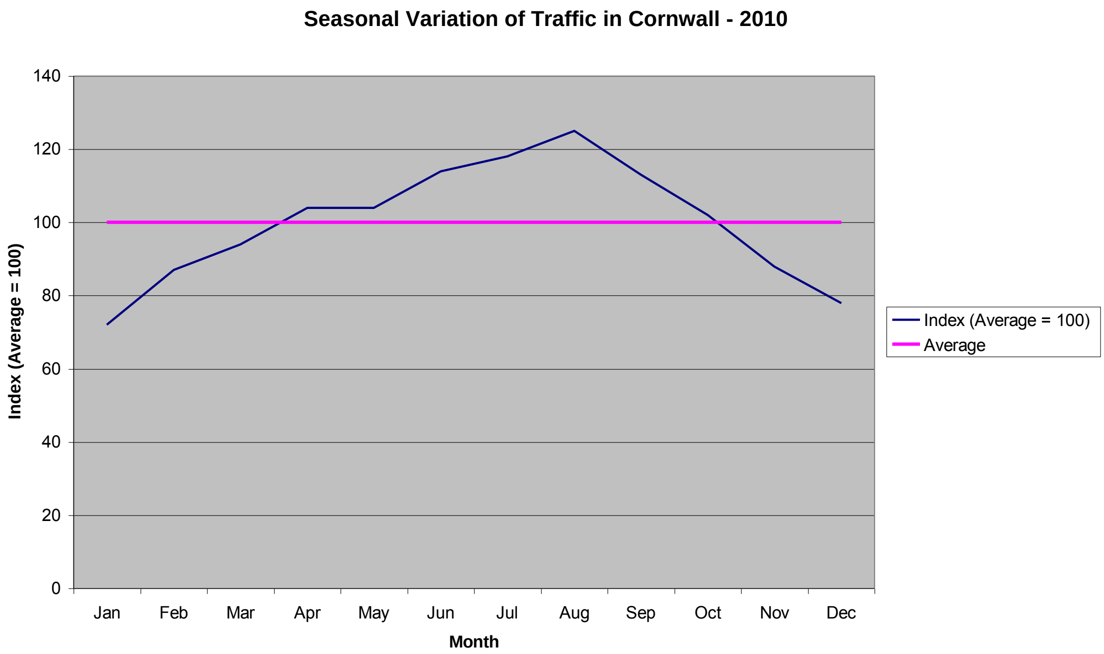
The incidence of the plant by highways is recorded in Tables 2.4 and 2.5. Table 2.9 and Figure 2.10 provide information on traffic flows according to class of road. Fly tipping statistics were not available for the area studied, but the tables indicate much lower levels of vehicle movements on lower classes of road. The higher likelihood of the presence of the plant in these less frequented situations is indicated above.

Table 2.9 Vehicle movements recorded according to class of road

Road Class	Vehicles per Day

Trunk Road	23,800
A (non Truck)	9,200
B Road	3,700
C Road	1,000
Unclassified	400

Fig. 2.8 Seasonal variation in traffic flow



Play activities

Children's play activities are a further factor in spread. The comment has been made on a number of occasions that blow pipes were made from the canes or that mock fights were carried out using them. Cane material, when pulled from the ground, has been noted by the author to bear viable bud material at its base, irrespective of the time of year of its acquisition.

'Spreading the ~~Weed~~ Word

Between the ages of 5 and 6, I spent every weekend and the summer holidays at St Agnes with my sister and her son, my nephew, who is my senior by six months.

My sister lived in Angwin Avenue in 1964, the gardens of which backed on to what were locally known as 'The Burrows' which were, in actual fact, mining spoil heaps. These *burrows were an adventure playground for us and we spent hours searching through the heaps for pieces of chalk and other 'treasures'. Japanese Knotweed grew in abundance all over the burrows and one of our favourite pastimes was 'sword-fighting'. My nephew and I would frequently uproot long pieces of it, strip all the leaves off and throw them onto the ground in order that we could use the branches as 'swords'; when one 'sword' got too battered we would just pull up another cane and follow the same process all over again; another favourite game was to pull up pieces of knotweed to make 'muddy pies'. We often pulled up very long pieces and used them to whack our way through long grass and to knock down various nuts and berries and they came in very useful for scrumping apples. When the cane became too battered to use we would just throw it away and leave it wherever it fell. We spent many happy hours scrambling over The Burrows and I can clearly remember many, many large clumps of knotweed growing all over the area, especially in and around the old engine house. Another favourite haunt was the local playground where we pretended to be elderly people and used knotweed canes as walking sticks, again throwing these away when we tired of them.*

We often walked down the lane to the village dragging knotweed canes behind us – often squabbling as we went and hitting each other with the canes! As a result of this the canes would split and meant that we just threw the broken canes into the hedge wherever we happened to be and found another patch of knotweed to pull up a new one! I vividly remember us pulling the leaves and flowers off the canes and throwing them onto the ground and into the undergrowth – the cane would follow suit whenever we got fed up with it. I think you can rightly say that we did all we possibly could (in all innocence) to aid the dispersal of knotweed far and wide!' (Pers. com. Sherriff, B. 2011)

Once the play activity ceases, the material is highly likely to be discarded
and there is a strong possibility of regeneration at its site of deposition. The concealing nature of the plant may lead to dens being constructed within it. Such activities are likely to lead to material being pulled up and removed and there is particular concern, where they are near watercourses, that such above ground material may end up in the water with the considerable likelihood of downstream transport and regeneration at deposition sites.

Stimulation of growth

Stimulation by a number of factors may result in increased spread of the plant. A particular instance was noted at Tuckingmill,. (Fig.2.9). This area had been treated with overall with herbicide (glyphosate), including a path running through the area. Early growth was noted in close proximity to and along the line of a path through the area. Such early appearance of material above ground is evidence of extension, and therefore spread. The site was visited subsequently and material appeared at a later period in the environs.

Fig. 2.9 Apparent stimulation by foot traffic Tuckingmill, Camborne GR SW 6567 4143

Disturbance

Disturbance of below ground material has been recorded to result in extension growth of the rhizome system.

Grazing by pigs of areas of Japanese knotweed has been noted to be a means of spread. A specific instance was observed at Maker with Rame GR SX 426 491. In this instance, which was observed at intervals over a period of weeks, disturbance and viable rhizome were observed at the peripheries of the grazed enclosure. There was no clarity as to preference by the animals for either above or underground parts of the plant. No data were available regarding any supplementary feeding regime, but the presence of viable and shoot producing detached rhizome is suggestive that the plant is not a preferred food for this species and that there is considerable danger of spread by their activities.

Where there is a low level of disturbance of the plant, primary spread has been noted to occur at the peripheries of the clump. No instances of central clump die back recorded in its native habitat (Adachi 1996a) have been noted. The rate of this extension has been noted to be quite variable and may vary between half and one metre per year.

Further evidence of mechanisms of spread

a) Veryan

A particular case of study in relation to spread is situated at East Portholland in the parish of Veryan. An area of coastal land of approximately 1 hectare was subject to a major scrub fire in June/ early July 1959. The then landowner, Major Withers, planted *Fallopia* x *bohemica* to stabilise the site in late summer of the same year (Mrs Tisdale pers. comm.). The areas which were the subject of the planting were parts of fields 1088, 1089 and 1091.

This is particularly relevant as this is the only area in the region in which *Fallopia* x *bohemica* has been recorded, the nearest site of this hybrid being at a distance of more than 10 kilometres. The pattern of growth of the hybrid is similar to that of *Fallopia japonica*, so it is considered that this provides adequate indications of common methods of spread.

The area which was originally planted is bordered on two sides by the Coast Path, a National Trail. To the east the area consists of coastal scrub with a preponderance of hawthorn, blackthorn, bramble and bracken. To the north is agricultural grazing land and to the west land used for grazing by horses. To the south there is some coastal scrub before the slope descends to cliffs which form the coastline. The field boundaries are Cornish hedges, constructed of stone and soil and usually planted with blackthorn or hawthorn on the top.

Colonisation was noted extending along the pedestrian route running through the area. This spread has been particularly noticeable along the route to the north which is defined as a public bridleway, defined on both sides with Cornish hedges, but which is also used to some extent, for vehicular access to fields.

There were a number of other outbreaks that were largely confined to access routes through the area, which are mostly public rights of way, though an infestation was noted on the stream running down to Great Perles beach. Apart from these areas, Veryan parish and the adjacent St Michael Caerhayes parish appeared to have few records of Japanese knotweed. As this was the case and all the material noted on the site and its environs was the hybrid, *Fallopia* x *bohemica*, there are good reasons to believe that all the material noted had spread from the original planting.

The pattern of spread recorded – with 12 of the sites being recorded along corridors through the site, the furthest 635 metres to the west and 240 metres to the east of the main infestation along the route – is a frequently noted distribution pattern. A particular factor in this case is that much of the length recorded is rarely used by vehicles of any description, foot traffic being the major usage.

Strimming of the material along the routes of the public rights of way had been carried out for a number of years in order to maintain access, and this would appear to be a likely cause of spread by the distribution of potentially viable material (Bailey et al. 1995). The density of the growth may equally have incited those using the route to pull up canes to aid access and to leave them at the end of the worse affected areas, thus increasing spread.

Reference has been made earlier regarding children who grew up in areas heavily colonised by Japanese knotweed that they used to pull the canes and use them for mock fights, then discard them. It would seem conceivable that this could have been responsible for some of the spread, pulled canes frequently being noted by the author to have viable crown material attached when detached by pulling or when walking through an affected area.

A further factor is that the lane was noted to host considerable badger activity. Sett entrances were noted, on the stone and earth banks which border the lane and which are colonised by the plant. Activities of excavation cutting through rhizome systems have been noted. The correlation of badger corridors with spread recorded suggests that some material may have been spread by this means as well as physical spread by the sett digging.

Fig. 2.10 Disturbance by burrowing activities, Veryan GR SW 951 410

Three of the sites which were not on the sides of the lane through the site were on Cornish hedge boundaries between fields. These areas appeared to have been under permanent pasture for a number of years. There is no clear reason why material had spread to these areas which are 60, 65 and 138 metres from the lane. They are, however, on the slope towards the coast. Material disturbed by badgers, as noted previously, and left on a bare soil surface, may have been considered by birds to be stick like and therefore potential nest building material. The above ground parts of the plant have been noted to be palatable to a range of grazing species, and it is possible that grazing activity can have resulted in detachment of underground stem and this being subsequently discarded and regenerating. Linear agricultural activities, such as hedge cutting, may have resulted in such displacement of plant material.

There is no clear indication of the origin of the more southerly of the other two recorded sites, which are separated by a stream and on waste ground, approximately 200 metres south of the lane. The more northerly of these sites allegedly resulted from dumping of material from elsewhere in the area.

b) Boscastle

The flood event which occurred at his location in August 2004 provided further evidence in relation to the spread of the plant. The area was visited on a number of occasions after the event and digital images secured of a number of observations. The plant had previously been recorded at a number of situations within the watercourses which were affected. The likelihood of detached material to colonise areas downstream was again highlighted.

c) Newlyn Green

This is an area which demonstrates the ability of the plant to survive in saline conditions, the colony being established at a point in boulders just above the level of high tides.

Fig. 2.11 Japanese knotweed on foreshore, Newlyn, GR SW 464 291

d) Crantock dunes

In this colony the material has the appearance of having been flytipped within an area of sand dunes. This is further evidenced by the fact that the material is adjacent to a vehicular access point.

e) Spread by seed

This has largely been discounted, but has been observed at Coverack, in finely ground quarried material adjacent to a number of Japanese knotweed species and varieties in the author's garden.

Measurement of extension of spread in a site of low disturbance

Soil sampling indicated nutrient levels within the site of N 4.79ppm P 5.97ppm K 13.8ppm and a pH of 6.5. The site was traversed for measuring activities in the early part of the growing season. One of the elm trees noted died and fell in 2009 on the eastern side of the plantation. Some disturbance was also noted on this side in 2010 when a tracked mini digger was driven across the far eastern side of the clump.

Initial measuring of the site in 2003 determined a furthest extent of visible cane material in a north-south direction of 10 metres and an east-west extent of 14 metres.

Density of canes within the clump increased during the assessment period, but less than a metre of further extent was noted into the woodland. On the open side to the east, the only notable increase in extent was noted after the fall of the elm tree with its consequent soil disturbance, and the disturbance by the tracked digger. The final measured extent in 2011was 18 metres east to west by 19 north to south.

2.5 Discussion

2.5.1 Recording

The work has provided considerable additional site information, and, with its concentration on recording area data, has provided a capacity for analysis of the areas covered by the plant in total, individual and specific locations.

The accuracy of the data has demonstrably improved, due, to a large measure, to the requirement for verification of the data by a trained individual, in the majority of cases, the author. Further reports are becoming rarer, with less than forty additions in 2009. This suggests that most sites have been recorded. Taken in proportion to the total already recorded and allied to raised public and institutional awareness and the author's personal knowledge of the area, this would suggest that the data, from this aspect in particular, are reasonably reliable. It is likely that increased awareness of the significance of invasive plants due to the work of the author and The Cornwall Japanese Knotweed Forum has contributed to this large increase in records. The current BSBI record for 2011 shows that Japanese knotweed has now been recorded over much of Cornwall in the majority of the tetrads.

One possible limitation is that recording can only be carried out when the material can be viewed from a point to which the public have access, unless the owner gives permission to access and record the site. In practice this has not been found to be a significant issue, only two instances having been encountered where the owner, while seeking information in relation to control of the plant, has denied permission for its incorporation within the database. This reluctance to allow a record to be made may be related to the fact that the period for which the plant may remain viable has not been determined, the protocol being for records to remain on the database. In view of much published data in relation to the cost of dealing with the plant, such a record could be conceived by the owner to be a negative factor in relation to the potential value of a site.

It would have been better to have further fields within the recording data sheet and to promote the use of a number of fields where applicable, rather than concentrating on analysis according to the considered principal factor of the site. As an example the definition of waste land has the potential for wide interpretation, particularly between rural and urban situations.

This protocol of requiring choice of a single option in relation to location was also somewhat limiting within agricultural practices in view of the wide range of activities in relation to such land use ranging from periodic heathland grazing through to intensive horticulture.

As treatment works had been initiated within the highway network before the involvement of the author, two different databases have been used. Combination of these at an earlier stage could have been useful.

Despite these concerns, it is considered that the work has assisted towards a most detailed recording of the plant within the area and the records provide a reliable basis analysing distribution and from which detailed planning of control methodologies can be reliably planned.

2.5.2 Distribution

The information collected gives further clarification of the situations where the plant is most likely to be encountered, and therefore gives indication of areas of low likelihood of occurrence. There is strong correlation with human activity. This is emphasised by the contrast cited between the area of Bodmin Moor and the adjacent populated area.

There is likely to be some overlap between road and river sites in that often they are closely aligned. Even allowing for this overlap, the proportion of sites found within these transport corridors is significant and demonstrably greater than the number found in areas without these features.

The work carried out extended more widely and in greater detail than that carried out before and therefore provided a more complete picture of the whole of Cornwall. The scope and scale of this work, frequently by taking advantage of access in relation to work planned for the areas, allowed the author to obtain detailed information.

The widening of the information base by actively promulgating public participation and the offering of advice has resulted in a source of information in relation to private premises which would not normally be accessible to recorders and thus a more complete picture in areas of settlement.

The number of infestations on boundary features was notable as such situations are likely to be subject to varying treatments.

The patterns of distribution can be clearly determined from the sites surveyed and this information can be used to determine methods to prevent wider colonisation.

2.5.3 Spread

The fact that the plant, in its native habitat, is a primary volcanic coloniser, is indicative of its capability of survival and spread in adverse and mobile conditions.

This work, carried out in a wide range of environments, provided indication of a number of factors which are likely to result in spread of the plant. A common factor is the acceleration of spread due to stimulation by disturbance. In order to more clearly quantify the risk, further work to study to a number of the key physiological factors – such as size of material capable of regeneration - was undertaken and is detailed elsewhere in this work. In sites which are not subject to disturbance, the rate of increase is not considerable..

In the situations which have been investigated the primary agent of spread has been by human activities, with secondary spread by a variety of means, particularly by displacement of the material into watercourses. The high number of records in the proximity of unclassified roads, with their relatively low traffic flow, may provide some evidence of connection with fly tipping of plant material in that the chances of observation of such illegal activity in such areas is low. The effect of movement by animal and bird activities would appear to be relatively minor. An issue with field observations is the lack of ability to duplicate them fully under controlled conditions, but it is believed that the scope of the observations provides a reasonable level of comparability from which conclusions can be drawn.

On the relatively undisturbed site where measurement was carried out, there may have been some physical restraint to the site to the north and south by the hedge and road respectively. The shading by the woodland on the western side may have had effect as may the presence of slate within the soil over part of the area. The fertility of the soil within the area may have resulted in densification rather than extension of the clump. The lack of lateral extension of the clump until some external interference occurred is, however, indicative of the point that the plant is not likely to spread rapidly in the absence of external influences.

The identification of the main vector of spread is further justification for the approach of education in relation to the plant, in the anticipation that a greater depth of knowledge and understanding will result in fewer actions of spread by ignorance. The wider knowledge base has also resulted in a greater flow of information and reporting back when deliberate actions of spread have occurred. This may not prevent illegal spread of the plant, but early provision of information should promote earlier intervention and thus reduce secondary spread.

2.6 Conclusions

This chapter has demonstrated the need for accurate recording in order to assess the full extent of the problem. This recording has to be comprehensive and draw from as wide a range of sources as possible. It has been shown that the general public are able to identify sites when given a map based recording system. However the records do need to be verified in order to ensure that they are accurate by a trained verifier who can map the extent of the problem and identify the further information needed to identify the characteristics of the distribution of the species. Using the detailed database it has been demonstrated that human activities heavily influence the distribution of the species as the species is far more often found on urban and disturbed sites than in wild habitats and agricultural land. By using the recording data and distribution characteristics found during this study, it has been possible to start to identify the possible mechanisms of spread of the species. This is useful to start to plan methods of control, but does not fully identify how the plant is spread, so it is important to also consider the physiology of the plant in order to develop effective control methodologies and to ensure public cooperation.

Chapter 3

Physiology

3.1 Introduction

An understanding of the physiology of the plant is an essential starting point for the development of methodologies for its control. The point that the plant is a primary volcanic coloniser in its native habitat provides an indication of its ability to survive in conditions adverse to the growth of many types of vegetation and the likelihood, therefore, that it may have mechanisms for such survival and for rapid regeneration, to take advantage of what may be brief periods of favourable growing conditions. Rupture of the underground system is a likely factor in a volcanic area, and thus determination of the size of material capable of regeneration is important to determine the degree of attention needed when developing separation methodologies. In adverse conditions, the last points of viability within the system need to be clarified as much of the plant may be dead or appear so. The rate at which growth occurs needs close determination to tie in with control methodologies, not only in relation to mass, but also to ensure, when chemical control is being employed, that the material being used is being deployed at the time when it can be anticipated to have maximum effectiveness. Clarification of those parts of the plant which have the capacity to regenerate is important for holistic control, as is an understanding of reaction to physical intervention on varied parts of the plant. Clarification of survival ability in varied conditions allows for planning to ensure that all relevant areas of potential colonisation are taken into account and that control methods encompass adequate parameters. The quantity of material likely to be present in both above and below ground situations is material to the likely effect of herbicide in relation to available application area and to adequately plan when physical extraction is required. A reliable method of assessing the viability of sample material is also desirable.

The work considers several species colloquially referred to as Japanese knotweed. These include *Fallopia japonica* var. *japonica, Fallopia japonica* var. *compacta*, *Fallopia sachalinensis* and *Fallopia* x *bohemica*.

Fallopia japonica is a primary volcanic coloniser in its native habitat (Ohwi 1984). It is a rapidly growing perennial plant which produces successive flushes of reddish shoots (from the presence of anthocyanin) from its rhizome system early in Spring. In established plantations these hollow shoots are often in excess of 600mm in stature before leaves, which are heart shaped and pointed with a flattened base and alternate up the stem, fully expand from them.

Fig. 3.1 Early shoots of Fallopia japonica on highway site 559, GR SW 7014 2405

In established plantations, the usual pattern is for 10 to 30 mm diameter spear like shoots to be produced – one or two from each clump – in the early stages of above ground growth. Further shoots follow in successive flushes. The leaves on these shoots remain unexpanded – and therefore capable of only limited photosynthesis – often until the shoot exceeds 1 metre in height (Fig. 3.1).

The extent and vigour of this extension prior to the initiation of photosynthesis, is demonstrative of the significance of the underground storage system. Trichomes (hairs) are not present on the under surface of the leaves which are typically 100 to 150 mm in length and up to 120mm in width. As the season progresses, the shoots, that are hollow and are often speckled with purple, tend to arch as they reach their maximum height of approximately 2.5 to 3 metres. Clusters of creamy white flowers are produced in summer at the top of the plant from the angle between the stem and leaf. After leaf fall in autumn the canes remain standing for two to three years, the brown outer cortex being shed in the first winter to reveal whitened internal canes. The leaf material can form a dense layer on the ground (Ohwi 1984).

The rhizome system is a storage organ on which buds are formed in the autumn as nutrient reserves are withdrawn from above ground material (Price et al. 2002). The buds do not all develop the following spring. A considerable percentage of the buds which do develop are close to old stems. The rhizome system can penetrate into the soil to a depth of 2 metres and can extend laterally several metres away from above ground shoots. The rhizome initiates growth as white shoots. These shoots develop an outer cortex, reddish brown in colour, which becomes darker brown with age. The internal parts of the rhizome are light yellow to orange in colour. The root system consists of fine white fibrous material (Ohwi 1984).

Fallopia japonica introduced in the British Isles is a female clone (i.e. male sterile). Viable seeds are occasionally produced by fertilisation by *Fallopia baldschuanica* (Russian vine) but the resultant hybrid, *Fallopia* x *conollyana*, is not frequently encountered (Bailey 1988). *Fallopia sachalinensis*, often referred to as Giant knotweed, can reach a height of 5 metres. Leaves can be up to 400mm in length by 230mm in width. Long trichomes are present on the undersides. *Fallopia* x *bohemica* is a hybrid between this and *F. japonica* above two species. It can reach a height of 4 metres. The leaves can be 280mm in length and 210mm in width. Numerous short trichomes are present on the under surfaces (Bailey and Conolly 1991). *Fallopia japonica* var. *compacta* is similar to *Fallopia japonica*, but does not exceed a metre in height. The leaves are similar in shape to *Fallopia japonica*, but are smaller, more rounded, and have crinkled edges (Bailey & Conolly 1991).

In its native habitat *Fallopia japonica* has been observed to translocate resources from the initial centre of establishment to radial areas of colonisation. The plant thus progresses from an initial centre of establishment to radial areas of colonisation. As these foci develop, they eventually lose their connection to the mother plant (Adachi et al. 1996a; b; c). This loss of the central crown, resulting in the detachment of the expanding shoots and their establishment as discrete individuals, a commonly observed phenomenon in herbaceous plants, has not been recorded in the British Isles. It is unclear whether the length of establishment of these areas in the British Isles has been sufficient for this to have occurred, though the difference between the conditions found in the volcanic habitat and those found in this country may be significant.

The plant has been noted to be tolerant of a wide range of soil conditions, ranging in acidity from pH 3.0 to pH 8.5 (Hayward 2002).

Some measurement of growth of above ground shoots has been carried out to record the rate of growth of *Fallopia japonica* (Wolf 1971; Child 1994).This was carried out at weekly intervals in a single year. The timing and rate of growth is very relevant to control strategies, for example to clarify the time at which an assessment of initial growth can be made and to provide planning information, particularly for the time of application of herbicides which may be dependent on very specific stages of growth to maximise effectiveness. The size of growth may also have effect in relation to the practicality of control, large material being physically more difficult to deal with in this respect. Wolf (1971) measured growth rates at 4.65cm/day, measuring at intervals of two days from May 7th to 17th in Nashville, Tennessee, USA. Brock and Wade (1992) reported that shoots regenerating from *F. japonica* rhizome segments had a daily height increase of 4.8 mm.

It is possible that the plant can regenerate from foliar material. In his PhD thesis written in Czech, Brabec (1997) makes the observation that he saw *Fallopia* regeneration from leaf material. He confirmed this observation in an email in 2003 to Dr Lois Child;

From: "Jiri Brabec" <brabec@natur.cuni.cz>
To: "Lois Child" <L.E.Child@lboro.ac.uk>
Sent: Thursday, November 20, 2003 12:10 PM
Subject: Re: Reynoutria (Fallopia) japonica regeneration

"I saw establishment of Reynoutria japonica from fallen leaves only one time - three leaves of R. japonica on the bank of small brook (Chøibská Kamenice, North Bohemia) after small flood (local flood during the storm). It was in 1994. Leaves had new roots and two of them had small stems (about 5 cm) with leaf bud. I do not know whether plants survived or not. In my thesis (thesis is only in Czech) I has only small note about it (no more than here)."

The capability of the plant to spread by vegetative means has been indicated from a number of sources (Brock and Wade 1992; Brock et al. 1995; Bailey et al.1995) but regeneration from foliar material had only been noted on this single occasion, so it was considered important to carry out further investigation to clarify this. If the plant proved capable of regenerating from foliar material this could significantly increase the risk of further spread.

The technique of injection or insertion of herbicide into plant stems has recently been promoted from a number of quarters e.g. Japanese Knotweed Solutions http://www.jksl.com/?gclid=CPWk0rjDxa8CFQQMtAodNRIwaQ and JK Injection Systems http://www.jkinjectiontools.com/methodinfo.php?method=steminjection In Britain a cut and inject system similar to the above had previously been developed in Cornwall for the National Trust (NT) (Joy 2002). Concern had been raised that the number of stems per square metre could be such that application of a dose to all of them would result in the application of a quantity of active ingredient in excess of that permitted for foliar treatment. It was therefore resolved to assess the density of stems on a site which was proposed for this NT treatment methodology in order to calculate the proposed dosage. Previous work on NT sites has indicated a wide range of stem counts per square metre, varying from 1 to 50 and averaging 14.07 over a range of 24 sites of a total of 10343 square metres. The reduction in stem density resulted in increased species diversity (Joy 2002). More detail was considered necessary in order to assess the likely competitive ability of the plant and to ensure that the control methodology of injecting a measured dose of herbicide into each of the cut stems of the plant did not result in the application being above the legally permitted foliar limit due to the density of cane material.

Cutting is a technique which is frequently used to control vegetative growth. It has been noted in Japanese knotweed to reduce vigour and underground mass (Baker 1998). However there has been some suggestion (Morris 2000) that such cutting could result in the extension of underground material but this was not investigated further. It is suggested that removal of some part of a plant may result in the stimulation of growth from the remaining underground material. If such cutting could be demonstrated to result in the extension of underground material, cutting could be considered to have the potential to breach the Wildlife and Countryside Act 1981 which makes it an offence in relation to the plant to:- “plant or otherwise cause to spread in the wild”**.** The assessment of reaction of disturbance to underground material was therefore considered a useful area of investigation.

Observations had been made regarding the size of rhizome which had proved capable of regeneration. (Brock and Wade 1992; Brock et. al 1995). These were largely based on observations in a greenhouse environment. This facet is important, particularly as any effective separation methodology for rhizome and its substrate must take into account the minimum size of rhizome material which may prove viable. The size of rhizome noted as being capable of regeneration has been previously quoted as 0.7 grams (Child and Wade 2000).

Some work has been carried out to determine the temperature level and the period for which it is required to be maintained to ensure that rhizome and above ground shoot material is not viable (Ward 2003). This was not very conclusive because it was not linked to field conditions. It was felt that further data were required which would relate temperature and duration to that which could be provided by commercially available soil treatment and composting equipment. Previous work has indicated that *Fallopia japonica* is capable of regeneration under composting conditions where a temperature level of 60 degrees C is periodically attained, Morris (1999). In many open composting systems there are no controls to ensure maintenance of a given temperature throughout the body of the material. Enclosed systems, often used for food waste, are now available where, typically, a temperature of up to 80C can be maintained, for a period of up to 14 days. The object of this research was to further clarify the temperature level required to render the material unviable after a standard time period and to see how far this could be reduced. This work concentrated on the rhizome and crown, which appear to be the most likely material to regenerate, as above ground material appears more liable to decay in composting conditions, Morris (1999).

Some toleration of saline conditions by the plant has been suggested. (Hayward 2002). This was largely observational, related to the positions in which established material was noted and based on the assumption that movement in the sea was the likely means of colonisation. Clarification of survival ability in these conditions was considered necessary to provide guidance on the potential for colonisation in estuarine conditions in that it was possible that material in riverside locations could be washed downstream during flood conditions and wash up further down the shoreline to form new colonies, particularly in rias and similar partially enclosed areas. The author had previously observed Japanese knotweed at a number of coastal sites around Cornwall including Newlyn (GR SW 4651 2924) (Crantock GR SW 7881 6099) Millook (GR SX 1846 1000) Cot Valley (GR 3561 3087) Charlestown GR SX 0387 5141 and Talland Bay (GR SX 2261 5159). Suggestion has been made that rhizome may be moved by tidal action (Hayward K. 2003 pers. com. re. the Isle of Arran) and there is suggestion from other sources that this may be the case (Child and Wade 2000).

One particular area where such conditions differ markedly from the above in relation to shelter is to the eastern side of the Lizard peninsula. The rivers which feed into Carrick Roads commence as streams within former mining areas where there are many records of established Japanese knotweed. The nature of the land behind high tide mark, with fertile land descending close to the high tide line, might suggest vulnerability to colonisation, though a countering factor is reduced wave action with likely reduction in potential to transport any sea borne material to sites where growth might be less inhibited by saline conditions. There is at least one report of Japanese knotweed in a situation in the Helford estuary (GR SW 735266) where it seems likely that transport by sea of vegetative material may have initiated the colony.

Physical spread of detached parts of the plant by fresh water in the White River (St Austell) is particularly notable (Joy, 2002). The watercourse had been modified at various points along its length and the bank material consisted to a large extent of siliceous waste, structurally a particularly unstable material. The source of this material is the china clay industry in the area, which brings the further factors of mining and quarrying into the equation. It is anticipated that the seasonal fluctuation in flow patterns of rivers will result in the increased risk of detachment of viable plant material, which is likely to colonise lower reaches of the watercourses. It would not be unreasonable to assume that a percentage of material detached in this way would reach the sea. Rhizome has been observed to be generally denser than water and will therefore sink. In freshwater conditions within the riparian environment this may be a less limiting factor than in saline circumstances where continuing abrasion against the sea floor may be a further debilitating factor. Rhizome is the material suggested to be appropriate for testing as it is considered to be the most likely material for colonisation in the given circumstances, though attached crown and above ground stem material would be likely to be attached. This would give some degree of buoyancy, increase the ease of transportation on the surface of the water and reduce damage by abrasion.

The crown and rhizome system of *Fallopia* spp. have demonstrated considerable resilience both in respect of maintenance of viability over protracted periods in adverse conditions and the small size of material which has been demonstrated to be still viable. A particular concern regarding viability is that it is possible the observed ability of the rhizome to remain in a viable condition without producing above ground shoots for a period which can extend into several years. One viability test recommended for use is that described in the Welsh Development Agency model specification (1998). This recommends that *“rhizome fragments should be sampled from not less than 5 points in the area covering full extent and depth. Two fragments per point should be taken, each not less than 150mm long and 10mm in diameter. Fragments should be kept damp, washed to remove soil and placed still wet in a clear polythene bag. The bag should be kept dark at between 50 and 70 ^{o}F and the contents* *inspected by the Engineer weekly for 4 weeks for signs of root or bud growth. All sample material should be burnt at the end of the test".* The drawback with this test is the time required to complete it delays immediate further treatment if the rhizome proves to still be viable. Assessment of effectiveness of treatment is frequently predicated on visual observation of apparent viability of above ground stems. This is unlikely to provide any realistic assessment of viability in view of the foregoing remarks in relation to underground material. The absence of a sampling protocol means that the material may not be a representative sample. The time required for the test may be of concern, particularly when construction projects are involved. A further point is that visual appearance may not provide conclusive evidence of capability of regeneration.

Various methodologies have been used to assess the viability of plant material (Steponkus et al. 1967; Pasha et al. 1982). Much of this is related to the viability of seeds rather than underground material. There is a requirement, particularly in areas such as the construction industry for a rapid testing method to ensure that the plant has been eradicated. If evidence is required regarding legal parameters of disposal of material, a method which can demonstrate viability without the requirement of allowing the plant to regenerate on the receptor site is desirable. Further investigation of a suitable method was therefore carried out. For the purposes of this work, viability is considered in its widest sense, to consider the ability of the organism to maintain itself and also to grow and develop. Assays can be carried out which determine viability in single cells, but the ability of the single cell to function as part of an entire organism is more relevant when dealing with multicellular organisms.

In this research an assessment was made of the underground mass of *Fallopia japonica* in order to provide further guidance regarding the plant's potential nutritive reserves. Some work had been carried out on this aspect (Beerling 1995). It is important to test survivability of that part of the organism which is most likely to remain viable under stress conditions. In its native habitat, *Fallopia japonica* has been observed to die back in the centre and for connectivity to extending rhizome through the central crown to be lost. Such central die back does not appear to have been observed in Europe, but the mode of action of many herbicides used for control of the plant would suggest that this model could be appropriate for assessment purposes as their effect may be to kill material within the crown area, leaving a number of previously connected individuals. Further confirmation of this is by observations from a number of individuals that herbicide treated areas of *Fallopia*, some of which have not been observed to produce shoots for a period exceeding one growing season, have produced shoots at some distance from the treatment site, often in a semi or fully circular pattern. As the proportion of below ground shoot material to above ground material can be so great, this needs to be determined in order to understand the actual amounts needing to be excavated.

The time at which rhizome extension occurs is a further indication of the period at which reserves may be being translocated back to the underground storage system. This can be an important point in order to maximise the efficiency of herbicides which have optimal effect at this period. It was considered that the herbaceous nature of the plant could give rise to extension of rhizome at the end of the growing season in line with the withdrawal of resources back into the underground system (Buschmann 1997) or alternatively that early new season extension might occur. This is suggested by personal field observations of new spring shoots at the periphery of established stands prior to shoot development at the centre of the stands.

In undisturbed conditions in level bodies of soil of standardised nutrient conditions and compaction, the direction of rhizome extension could be anticipated to be to the warmer southern direction. It was considered worthwhile to analyse, in conditions of comparable nutrient availability, and in a level area, the direction in which rhizome extends. This could provide data in relation to likely colonisation patterns.

Seasonal variation in the water content of rhizome may provide information regarding periods of greatest rates of translocation which may relate to periods of greatest efficacy for herbicide treatment. Determination of the moisture content of rhizome is therefore material in relation to the translocation of resources within the plant system and timing of control operations. Rhizome has been observed to range in form from white extension tissue, typically 3 to 4 mm in diameter, through to material of several years' maturity with a dark brown, leathery cortex surrounding woody tissue with a central core of varying yellow/orange colour. Work was carried out to determine the moisture content of such different types of rhizome at different times of year.

Much of the available data on Japanese knotweed is reliant on assessments of material in the field. In order to provide material for further work, it was considered necessary to establish material grown in relatively standardised conditions to establish true tests of comparability. The opportunity was also taken to assess the regenerative capacity of different types of material.

Observations in relation to physiology

While in the field a number of observations were made by the author which were relevant to the understanding of the plant.

i) Identification of the last points of viability in adverse conditions

The pattern of desiccation of rhizome is relevant to any sampling methodology in that many assessment methods rely on the integrity of the organism.

A method for the assessment of viability is the use of conductivity testing. This relies on not only physical, but also physiological, connection of material. This could produce misleading results if viability remained at specific points, such as nodes. If foci of viability remain, but with a lack of living tissue connections allowing translocation, results from such a methodology will not provide a reliable source of information.

ii) Rhizome dormancy

If rhizome may remain viable without producing above ground shoot growth for more than a growing season, any technique which assesses presence or absence of the plant by visual assessment alone over what may be considered a normal assessment period will not be adequate to provide reliable information.

iii) Rhizome survival in water

The issue of downstream transport of rhizome in watercourses has been noted (Charter 1999) but there is little evidence of the period for which rhizome may remain viable in saturated fresh water conditions.

iv) Rhizome survival in low nutrient conditions

The range of sites where the plant is found encompass many areas of low levels of the major nutrients e.g. where it has been used for stabilisation of slopes in quarry areas. There appeared to be little work in relation to the capacity of the plant to survive for long periods in such conditions, the concern being that it could remain unnoticed and be transferred to more favourable growing conditions, particularly from such intensive areas of distribution.

v) Hybridisation

The fact that the majority of the records of the plant are of the male sterile form of *Fallopia japonica* var. *japonica* (Bailey 1989, Bailey and Conolly 1991, Bailey and Stace 1992) does not exclude the possibility of hybridisation (Bailey 1992,1994).

The range of species present in Cornwall could mean that hybridisation is a relevant factor.

vi) Depth of rhizome

The depth at which rhizome is found has not been previously ascertained. There have been suggestions that underground material may remain viable without producing above ground shoot growth. A greater understanding of the depth at which it could be expected to find rhizome in varying conditions is important for planning purposes when mechanical excavation is the required methodology. Site operations for removal of Japanese knotweed by Cornwall County Council permitted observations to be made to ascertain depth at which living rhizome could be found.

vii) Rhizome reaction to disturbance

Child et al (1998) indicated the use of disturbance to promote growth in order to treat actively growing material. Such promotion of growth can have legal consequences such as causing the plant to spread in contravention of the Wildlife and Countryside Act (1981). This can be significant when the plant extends over property boundaries and physical removal is carried out by one party. Observations at one of the treatment sites permitted assessment of the rapidity of growth due to disturbance.

3.2 Materials and Methods

3.2.1 Growth rate of above ground shoots

A stand of *Fallopia japonica* known to the author for a period of in excess of five years was selected for this work. The stand was in an environment where there was a reasonable element of control in relation to disturbance and knowledge that the plants had not been subject to control by herbicide or cutting. The site was more closely observed for a period of a year prior to the commencement of measurement. It was compared with other sites to ascertain that it could be considered representative. This comparison was largely observational, comparing stem heights during and at the end of the growing season at several different sites.

Fig. 3.2 Coverack GR SW 7743 1801 overview of site

The chosen site was situated at GR SW 7743 1801 (Coverack, Cornwall, U.K.). The clump was approximately 14 metres by 10 metres at the commencement of the work. The soil was a loam, tending towards clay overlying a gabbro substrate. There was evidence of building material and soil importation, the probable original source of the knotweed. Local enquiries lead to the conclusion that the material had been noted on the site for a period of at least ten years. Mature cane height at approximately 2 metres was comparable with other observed sites, and cane diameter equated with other stands. The position was adjacent to a small copse and its elevation in relation to surrounding land suggested that there would be little likelihood of soil moisture deficit. The site was bounded on the northern site by a stone and earth boundary feature.

The pH was assessed by the conventional methodology of removal of the top 100mm of soil, mixing of the next 150mm and taking a sample of approximately 100g from this mixed medium. The process was repeated at four other points through the site, though there was no obvious variation. The testing was carried out at more points than would normally be deployed in order to reduce variation and ensure accuracy. There was evidence of the importation of soil and building material and this was considered likely to have been the source of the knotweed.

The shoots measured were chosen on a random basis and each identified by a stake 1 m x 25mm x 25mm positioned, after investigation, not to interfere with rhizome and thus possibly to alter the rate of growth. A photographic reference point was set up to record the growth of an individual shoot at 24 hour intervals. In order to provide suitable datum points for measurement of the height of the shoots, pieces of 6mm thick slate approximately 75mm x 75mm, were used, placed approximately 25mm from the base of each shoot. This method was employed because, although there might be a potential for under recording due to rhizome or roots causing lifting of such light material, it was felt that the excessive thickness required for an immovable datum could interfere with normal rhizome growth, as could driving a further stake into the ground sufficiently close to the individual shoot. The surface area of the slate was chosen as a compromise between stability and potential rain shadow effect. The start of measurement was determined by the appearance of the first twenty five shoots in the sample area. Ten shoots were chosen of a variety of sizes. A second tranche of ten shoots was measured 2 weeks later. Measuring was carried out using a retractable tape measure checked for accuracy against a standard laboratory rule and the measurement taken from the positioned slate to the apex of the shoot. Measurement was repeated at 24 hour intervals until no further extension was noted over a period of 3 measurement periods. Further periods of recording were carried out in following years, these being carried out over two years at 12 hour intervals.

A photographic reference point was also set up to record growth of one individual shoot on a daily basis. The positioning of the reference remained constant during the work, but a more distant reference point was used to give a better overall reference as growth proceeded. (Digital appendices: 1 Trevothen measurement and 2 Trevothen distance measurement)
The first measurement was initiated on 2003.03.03 with the measurement of 10 shoots at 24 hour intervals, repeated until 2003.05.04. A second phase was initiated on 2003.04.11 and continued until 2003.05.12, again at 24 hour intervals.
Measurements in the first instance were taken in the morning, normally about 08.00, though times did range between 06.40 and 09.00 and, on two days, measurements were not recorded. In both cases recording stopped when increase in growth either ceased or slowed to the point where the small increase became difficult to measure accurately. This coincided in a number of cases with the arching of the shoot, a usual sign of the maturity of a shoot.

From the measurements a relative growth rate was calculated for each time period by calculating change in height (cm) divided by the starting height (cm) which was then divided by the duration of the growth period in hours.

Meteorological data were obtained from the naval air station at Culdrose, Helston, a distance of approximately 12.5 kilometres from the site.

3.2.2 Regeneration from leaf material

In order to see whether this method of increase might be possible, an experiment was set up using the facilities at Duchy College, Rosewarne, Camborne. On 27th August 2004 shoot material of *Fallopia japonica* var. *japonica* was gathered from two sites near Carn Brea, at GRs SW 691 405 and SW 691 408. The timing in the year was chosen on the theory that optimum resources would be in the leaves at this time, that the leaves were sufficiently mature to remain reasonably rigid and that this is the season often used in horticultural propagation from this type of material. The timing of the operation was chosen to be when weather was mild and damp and the leaves were damp when gathered. Material was chosen from non flowering side shoots and the material was maintained in a turgid condition by appropriate containment from the time of gathering to the time of insertion in the propagation unit.

The leaf stalks from which the leaf material was taken were 4 to 6 mm in diameter and soft tip material (the top 5 to 10 cm) was discarded. The material was detached by gently grasping the petiole at the base of the lamina and pulling gently away from the growing point of the plant. Thirty samples of this sort were produced and thirty leaves were also detached with approximately 1 cm of stem on either side of the leaf junction. (Fig. 3.3).

Fig. 3.3 Prepared leaf and leaf and stem material

The material was placed in 3 rows of 5 per standard seed tray in low nutrient propagation compost, with the base of the petiole approximately 10mm below compost surface level. (Fig 3.4).

Fig 3.4 Leaf material in propagation unit

The trays were then lightly watered and put into a mist propagation unit with a base level temperature of 18C. The material was kept in these conditions until leaf senescence was noted, then maintained without the mist, but with moist substrate conditions, until a time in the following spring when, from observations of outdoor plants, the presence of above ground shoot growth could be anticipated. This was in line with observations relating to growth measurement referred to elsewhere in this work. Images were taken using a digital camera on a number of occasions.

3.2.3 Stem counts per square metre

A quadrat measuring 1m x 1m internally was constructed from 25mm by 50mm timber and used on a number of sites at chosen locations. These included material on the slope of a stream and areas on the flat. Ten readings were taken on 25th August 2006. at Tregeseal GR SW 365 321. The canes were cut to a height of approximately 300mm to aid the work. A further area was assessed on 6th September.

3.2.4 Assessment of impact on *Fallopia japonica* of stimulation by cutting

20 samples of *Fallopia japonica* growing in 3 litre pots in outdoor conditions were watered to saturation point and then removed from the pots, to ensure that stimulus of the underground

system by friction during inspection was minimised. The samples were placed individually in clear polythene bags, with drainage holes at the base, (to further minimise stimulus to rhizome extension which could potentially be attributed to removal from the pot for inspection). 7 days later, plants were divided into two batches, removed from the pots and bags, numbered and photographed side on, two images per pot, 180 degrees apart, above ground shoots assessed and measured in relation to height. The number of young rhizomes (white in colour) extending laterally within each pot was assessed. No attempt was made to measure the root extension. The plants were then replaced in the original bags and pots then placed in a trough, again in outdoor conditions. Having assessed the shoot size and number, all shoots above ground level were removed from half of a representative sample at 25mm above ground level. Pots were maintained in moist condition. Extension of previously observed and newly initiated rhizome was observed in all samples from the point at which colour change was observed. The initial experiment was carried out in June 2006 and repeated in July 2007 and August 2008.

Fig. 3.5 Example of trial material for testing for stimulation by cutting.

3.2.5 Determination of the size of rhizome capable of regeneration

Rhizome was sourced in October and November 2008 from a number of locations. The timing was chosen to coincide with a period when rhizome was maturing. The rhizome was washed, dried and the smallest material chosen for the work. This material was generally 2 to 4 mm in diameter with a brown cortex.

100 samples were prepared, in five batches of 20, on 8th, 20th 24th October and two batches of 20 on 27th November 2008. This material was generally 2 to 4 mm in diameter with a brown cortex. The preparation consisted of cutting at right angles to the stem, either side of and equidistant from a bud, into sections 2 to 3 mm in length. The samples were then subdivided into two main forms, either an individual bud removed with a shield of bark and rhizome, prepared by cutting longitudinally along just below the bud, or by cutting transversely through the stem either side of a bud, and placed in batches of 20 on filter paper moistened with tap water in Petri dishes. A top was put on each dish to maintain a moist atmosphere and the dishes placed in cold glasshouse conditions, shaded, but with no attempt made to regulate temperature. The temperature was recorded during the time of the work on a maximum and minimum thermometer and observed to range from 8C to 21C. The samples were inspected on a daily basis and the filter paper moistened when it was observed to be drying out. The criteria for assessment of viability were the presence of both a leaf and evidence of root extension. A further sample of material was put through additional reduction by cutting horizontally through the stem below the bud.

3.2.6 Assessment of sustained temperature regime required to render rhizome material unviable

Rhizome material was obtained from a mature and untreated stand of *Fallopia japonica* at GR SW 6917 4054 on eight occasions starting on 12th December 2007 and continuing until 1st April 2008. The material was taken to the laboratory and washed with tap water prior to preparation. It was realised that this would not accord with a likely field methodology where as dug material would be put through a shredding machine, but determination of weight of the rhizome and crown was considered to be of prime importance. In the type of machinery usually used for the decomposition method there is usually very accurate control to ensure that the entire body of material reaches and maintains the required temperature for the required time and thus any potential insulation by a residual soil layer is likely to be irrelevant. Additionally the washing could have the result of removing contaminating organisms which could more rapidly lead to decay, so the process of washing could be seen as an extra safeguard.

At each sampling period rhizome and crown material of a size likely to be obtained by conventional shredding methods was selected, such material generally being approximately 100mm in length, and 30 samples of crown material of weights varying from 2.2g to 137.78g were selected. The rhizome material chosen was of a variety of thicknesses, and was individually placed in moist peat in polythene bags which were folded, but not tightly sealed, to ensure maintenance of moisture and a reasonable supply of oxygen. The bags were then placed in an oven regulated to 60 degrees C. The experiment was then repeated with further samples with the oven temperature lowered by 5 degrees per experiment until viable material was discovered after 14 days in the oven and the prescribed period in the growth chamber. The oven temperature was then raised by 2.5 degrees to attempt to establish more closely the point at which regeneration did not occur.

Fig.3.6 Rhizome as dug for heat treatment work

3.2.7 Survival of rhizome in saline conditions

In order to investigate the possibility that seaborne transport of Japanese knotweed may be a factor in its spread, an initial assessment of the potential for survival of parts of the plant was carried out. It was considered that a variety of factors needed to be taken into account at this preliminary stage. The widest fluctuations in water flow would seem to be likely to occur in autumn and spring so work was focussed at this time. The type of material most likely to be detached by water action, resulting in bank erosion, would appear to be rhizome, perhaps with some above ground material attached which would increase buoyancy.

Initial work was carried out in February 2003 and repeated at various periods until 2008. Early sampling work relied on a sample size which varied between 10 and 30 grams. Each sampling was treated in the same way:

20 samples were sourced from an established clump of *Fallopia japonica* and defined as either rhizome or rhizome with crown. The material was then washed free of soil, drained and weighed. (Fig. 3.7)

50 litres of seawater, varying between S.G. 1023 and 1027, was obtained by collection from GR SW 7852 1822 at the time of each sampling, and put into a glass tank in an open sided structure (so that ambient temperatures were maintained but protection was provided from dilution by rainfall). The specific gravity and temperature of the water was recorded. The plant material was then placed in the tank.

Samples of material were removed at regular intervals and assessed for viability. Two methods of assessment were used, either containment of the material after rinsing in tap water in folded clear polythene bags or rinsing and placing on the surface of a mixture of sand and decayed organic matter obtained from the high tide line of spring tides. The samples were kept moist. The material was kept in temperatures equivalent to those of outside conditions at the season. The trays of sand were kept outside, but the bagged material was kept in shaded, open sided shed conditions in order to avoid distortion of temperature due to the encasing material. Observations were then made at intervals until either growth was initiated, or the material was fully desiccated or broken down by fungal action.

Fig. 3.7 Material before saline immersion

3.2.8 Viability testing

For the purposes of this work, viability is considered in its widest sense, to consider the ability of the organism to maintain itself and also to grow and develop. Assays can be carried out which determine viability in single cells, but the ability of the single cell to function as part of an entire organism is more relevant when dealing with multicellular organisms.

Initial work was carried out following work by Steponkus and Lanphear (1967) using triphenyl tetrazolium chloride and analysing colour change, indicative of dehydrogenase activity, by use of a spectrophotometer. The expectation was the achievement of a spectrophotometer curve which would show marked differentiation between live and demonstrably dead rhizome material.

Rhizome was sourced from an established area which had not been subject to any form of control and was noted to have strong cane growth. The material was thoroughly washed twice in deionised water and thoroughly dried before final preparation. A proportion of the material was prepared in similar fashion and then placed in an oven for a 12 hour period. A further set of samples was boiled and a final set sourced from material which had been left to air dry for twelve months

A buffer solution was prepared. Samples were cut longitudinally from the stem, aiming at a thickness of 3mm and a weight of 0.5g. The samples were placed in test tubes with 3.0ml 0.6% w/v Triphenyl tetrazolium chloride in 0.05M $Na_2HPO_4KH_2PO_4$ buffer (pH 7.4). The material was infiltrated under mains water pressure vacuum until no bubbles were seen (approximately 30 minutes).

The material was incubated at 30C for 15 hours, then drained and rinsed once with distilled water. Samples were then ground individually in a tissue grinder, extracted with 7ml 95% ethanol in boiling water bath for 10 minutes. The test liquid was then made up to 10ml using 95% methanol and absorbance was recorded at 530mu

The assessment was repeated on a further 6 occasions.

Further samples were prepared using preparation techniques practiced in relation to micropropagation. This was carried out in several stages:-

Initial soaking, loosening material for a duration of 10 minutes

Brushing moistened material under a running tap for a duration of 2 mins

Immersion in 20% (softer material) to 40% sodium hypochlorite - preferred to calcium hypochlorite.

The material was rinsed under a running tap 3 times for 1 minute with the last rinse being under distilled water. 5 minutes allowed between each rinsing. Scales were removed, the material excised and recut.

Dye was made up by dilution with a small amount of ethanol (5g/250litres). The pH of the dye solution was 8.9. Dead material was washed through with 1% NaOCl, live material – showing shoots - not. The initial test used a small amount of material of the exterior against material cut from just below the rind and trimmed at the sides. The sample material was cut to a size of approximately 5mm x 2mm.

3.2.9 Assessment of below ground mass

Excavation was carried out at several locations. Underground material was assessed on 17th and 26th March 2009 on the line of a dismantled railway at GR SW 6611 4450 near Trengove, Camborne, Cornwall, using a Kubota mini excavator. Three areas of 1 cubic metre were assessed on each occasion. An area 16 metres by 14 metres had previously been surveyed using GPS equipment. The site was understood to have been used as a tipping area for a number of years and there was evidence that the plant was accidentally imported to the site in excess of 10 years ago and that little subsequent disturbance had occurred. The soil was a medium loam overlying granite, but the depth of excavation did not reveal the bed rock. Concrete and tarmacadam material was revealed during the second excavation, some of the latter being noted with rhizome penetrating it. The pH was recorded at 6.91.

Dry, above ground material was first flattened with a 1 metre bucket using a vertical dropping action and then the dry, above ground material was swept to one side, taking care not to disturb material below ground. An area 3 metres by 1 metre was marked out, entering the site at a tangent from its perimeter. Digging was carried out starting at the extreme outer edge, using a 45 cm bucket and working in towards the centre of the site. Digital images were secured at each stage.

The material was excavated to secure a half bucket load at each dig. Each was shaken over the excavation area to loosen material and then swung over to a deposit area on a membrane where the material was tipped slowly out and rhizome removed by hand. After the deposit of each bucket, the deposited heaped material was again raked through and examined for any material which had been missed in the previous operation. The separated material was put into bags and taken off site for assessment. It was weighed in “as dug” form - basically shaking to remove loose soil from the material before placing in plastic sacks. The assessment made included all *Fallopia* material discovered below ground.

3.2.10 Determination of the period at which rhizome extension occurs

20 growing cases were constructed from clear 4mm Perspex with 4mm plastic spacer strips to maintain a 10mm gap between the two sheets on three sides with a 10mm gap at each end of the base to allow for drainage (Fig. 3.8). The cases were secured on three sides with steel bolts through the spacer strip, two through each strip. The cases were filled with Levington peat free compost, knocking the base regularly on a solid surface to ensure adequate consolidation, to within 50mm of the top. The frames were the thoroughly watered to point of run off, topped up with compost and watered again. A section of prepared rhizome was then placed horizontally on the surface and covered with 20 mm of moist compost. The planting took place on 23rd April 2006.

Rhizome of the previous year’s growth with an outer surface of light brown lignifying tissue and two nodes was selected, washed in tap water after digging and dried with paper tissue. Each sample was approximately 50mm in length with a diameter of approximately 5 mm. The mean weight of each sample was 1.19 +/- 0.30g SD the variance of the samples was 0.9g.

Fig.3.8 Growing case

The growing cases were set upright into a pallet box, separated by 50mm by 25 mm batten so the top of the cases was level with the top of the pallet box and the cases were kept in dark conditions, with the exception of the top of the growing case.

The material was maintained in a moist condition, but no further fertiliser was added during the trial period. The trial was continued through three growing seasons.

3.2.11 Observations in relation to the progressive necrosis of rhizome

Rhizome ranging from 3mm to 35mm in diameter was removed from a number of sites and allowed to desiccate in the open. Some material showed signs of linear desiccation, but other material, generally between 3 and 5mm in diameter, showed horizontal breaks in the cortex at internodal points. This has the physical effect of disruption of connection of the living tissue, with the potential result of focus of regeneration solely within the nodes. To test this hypothesis, the partially desiccated material was cut, at the points of breaks in the cortex, into individual sections. The individual sections were placed on moistened filter paper in Petri dishes and observed. The abscised material produced shoots from the nodal areas.

3.2.12 Orientation of rhizome extension

30 square containers of notched timber (designed for compost container construction, with a gap of 75mm between each timber) were established on heavy duty plastic ground sheets orientated for each face to accord with principal compass points and filled with a well mixed soil sourced from Redruth GR SW 7206 4420. Standardised pot grown plants (from material propagated at the Watering Lane nursery facility of the Eden Project were planted in these containers and maintained in a moist condition. The direction of orientation of shoots coming out of the open areas of the sides of these containers was noted on 16th July 2006.

3.2.13 Moisture content of rhizome

Rhizome has been observed to range in form from white extension tissue, typically 3 to 4 mm in diameter, through to material of several years’ maturity with a dark brown, leathery cortex surrounding woody tissue with a central core of varying yellow/orange colour. Work was carried out to determine the moisture content of such different types of rhizome at different times of year.

Fig. 3.9 Samples of rhizome for drying

Rhizome was sourced from a roadside site at GR SW 7649 3239, near Argal reservoir, Penryn, Falmouth, at monthly intervals from 5th October 2003 to 29th September 2004. The material was dug, brought back to the laboratory, washed in tap water, dried on paper towels and divided into thick <3mm diameter and thin >3mm diameter material and some rough classification of its qualities made e.g. white thin material through stages of development to thick mature rhizome. The material was then cut into approximately 5 cm long sections, individually weighed, to an accuracy of 0.1 gram or greater (dependent on equipment availability), put individually in open foil dishes and placed in a drying oven with the thermostat set at 108 degrees Centigrade for approximately 15 hours. The material was then reweighed. The first sample was replaced in the oven after the assessment the following morning and reassessed 24 hours after the start of the experiment. No significant differences were noted after this further drying period and therefore the shorter drying period was considered satisfactory and adopted. Ten samples were deployed in this first trial but twenty were used in each subsequent assessment.

The usual time scale deployed the placing of the samples in the oven at the end of an afternoon, typically towards 17.00 hours and removal and reweighing the following morning at approximately 09.00.

3.2.14 Regenerative ability of a range of material and provision of standardised material for future use.

Much of the available data on Japanese knotweed is reliant on assessments of material in the field. In order to provide material for further experimental work, it was considered necessary to establish material grown in relatively standardised conditions to establish true tests of comparability. The opportunity was also taken to assess the regenerative capacity of different types of material, including rhizome material with no defined bud material. The opportunity was also taken to assess the form of growth from the material regarding its photosynthesising ability.

Rhizomes were sourced from a stand at Coverack (GR SW 774 180) on 25th February 2002. It was washed, and cut with secateurs into sections ranging in weight between 4.0g and 6.5g, (weighed in the Highways laboratory) sorted into multi-nodal, single nodal and undifferentiated material. Material was graded in two size ranges, 4 to 8 mm diameter and 8 to 12 mm diameter. Much of the larger material had only a single node. Some material had signs of developing buds. The prepared material was placed in polythene bags in cool storage overnight and placed in standard seed trays, with 24 pieces in each tray and placed in an unheated 4.2metre wide polytunnel with netting doors at each end, on a double thickness of Mypex sheet at Watering Lane Nursery of the Eden Project near St Austell. The material was watered to full soil capacity and the house closed overnight and opened during the day. When rooted, the material was potted into 9cmx9cmx10 cm square pots using peat free compost and placed back in the unheated 4.2metre wide polytunnel on a double thickness of Mypex sheet. The material was watered to the point of run off and the house closed. The process was repeated through the growing season and regeneration judged by the presence or absence of above ground material. The material from this trial was finally potted on into 3 litre pots in order to provide reasonably standardised material for future testing purposes.

Some observations on physiology from field sampling:

- **i) Identification of the last points of viability in adverse conditions.** Rhizome material was observed as it dried and samples were taken as desiccation progressed. The material was observed for three months and any signs of turgid tissue were noted to identify how the material dried and thus where the material might remain viable
- **ii) Rhizome dormancy.** Regeneration of established plants after herbicide control treatment was monitored and recorded on 200 field sites adjacent to the highway over a period of 2 years between 2007 and 2009.
- **iii) Rhizome survival in water** 10 samples of rhizome were retained and observed in a 50 litre container of fresh water for a period of six months. Any signs of growth during the period were noted.

iv) **Rhizome survival in low nutrient conditions.** A plant which colonised a piece of polystyrene isolated from its environment was monitored for five years to assess its ability to survive.

v) **Hybridisation.** An area where *Fallopia japonica*, *Fallopia sachalinensis* and *Fallopia* **x** *bohemica* were growing within 20 metres of each other was monitored for a period of three years in order to test if hybridisation could occur and viable seedlings could be produced.

vi) **Depth of rhizome**

Various suppositions have been made in relation to the depth at which rhizome may be found. Reliable information in this respect is very necessary in order that specifications can be appropriately detailed. The opportunity has been taken, when sites are being excavated, to record the depth to which rhizome has been found.

vii) **Rhizome reaction to disturbance** Reaction to disturbance was particularly recorded during operation in May/June 2001 at the site at Veryan and is detailed in Chapter 4.

3.3 Results

3.3.1 Growth rate and timing of above ground shoots

Measurements in Cornwall suggested that growth rates might be higher than had previously been recorded. Field observations discovered a shoot of the current season's growth 1.65 metres tall on 20th April 2006 near Crows-an-wra GR SW.394 270. A 2 metre tall shoot was measured on 25th April 2006 at College, Penryn GR SW 7703 3369.

The pH readings for the site used for the assessment were 5.5, 5.6, 5.6 and 5.7.

<u>Experimental period 1</u>

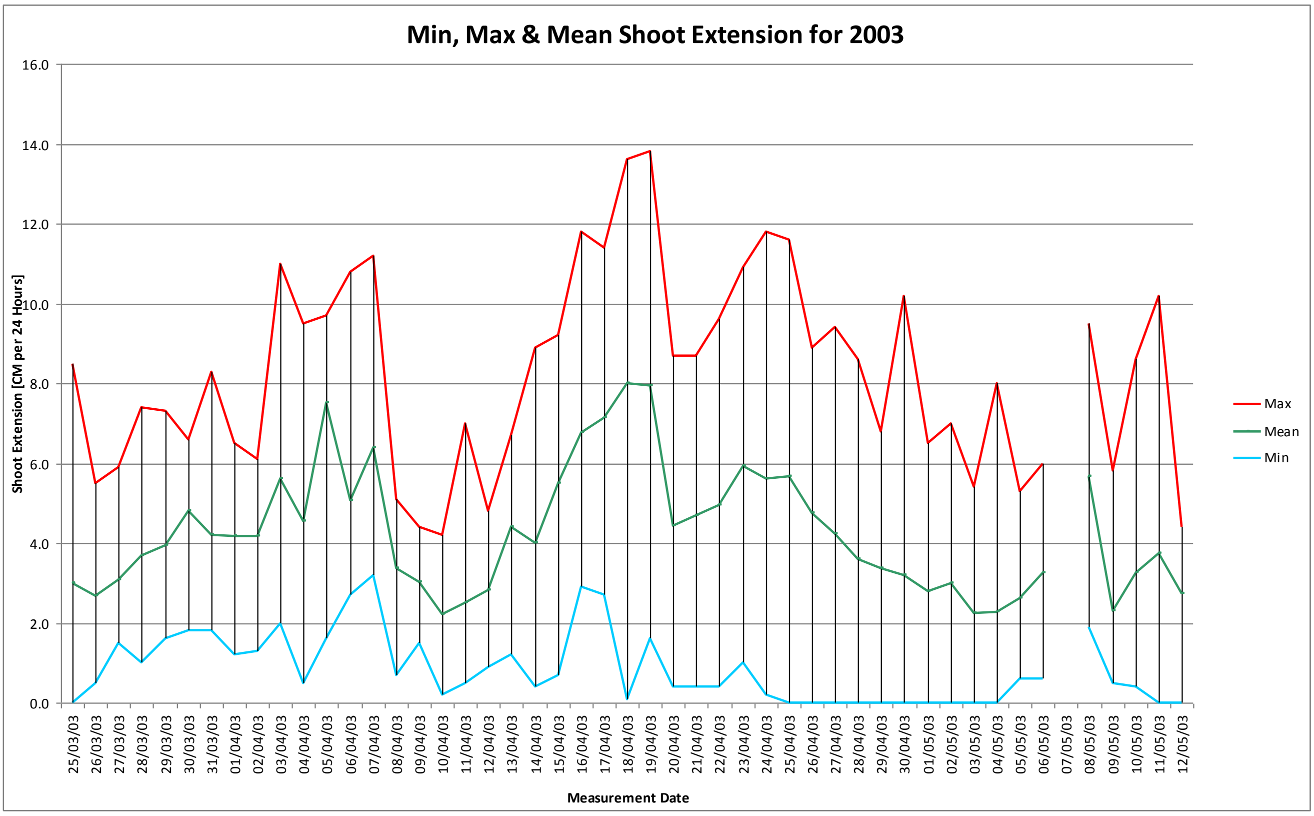


Fig. 3.10 Min, max and mean shoot extension for 2003

Extension of shoots of Japanese knotweed measured in 2003 showing maximum extension, minimum extension and mean extension (n=10 25/3 to 11/4 then n=20 to 22/5)

The greatest extension recorded was that of 13.8 cm of a 65.2 cm shoot over a 23.25 hour period between 07.10 on 2003.04.18 and 07.25 on 2003.04.19.

Experimental period 2

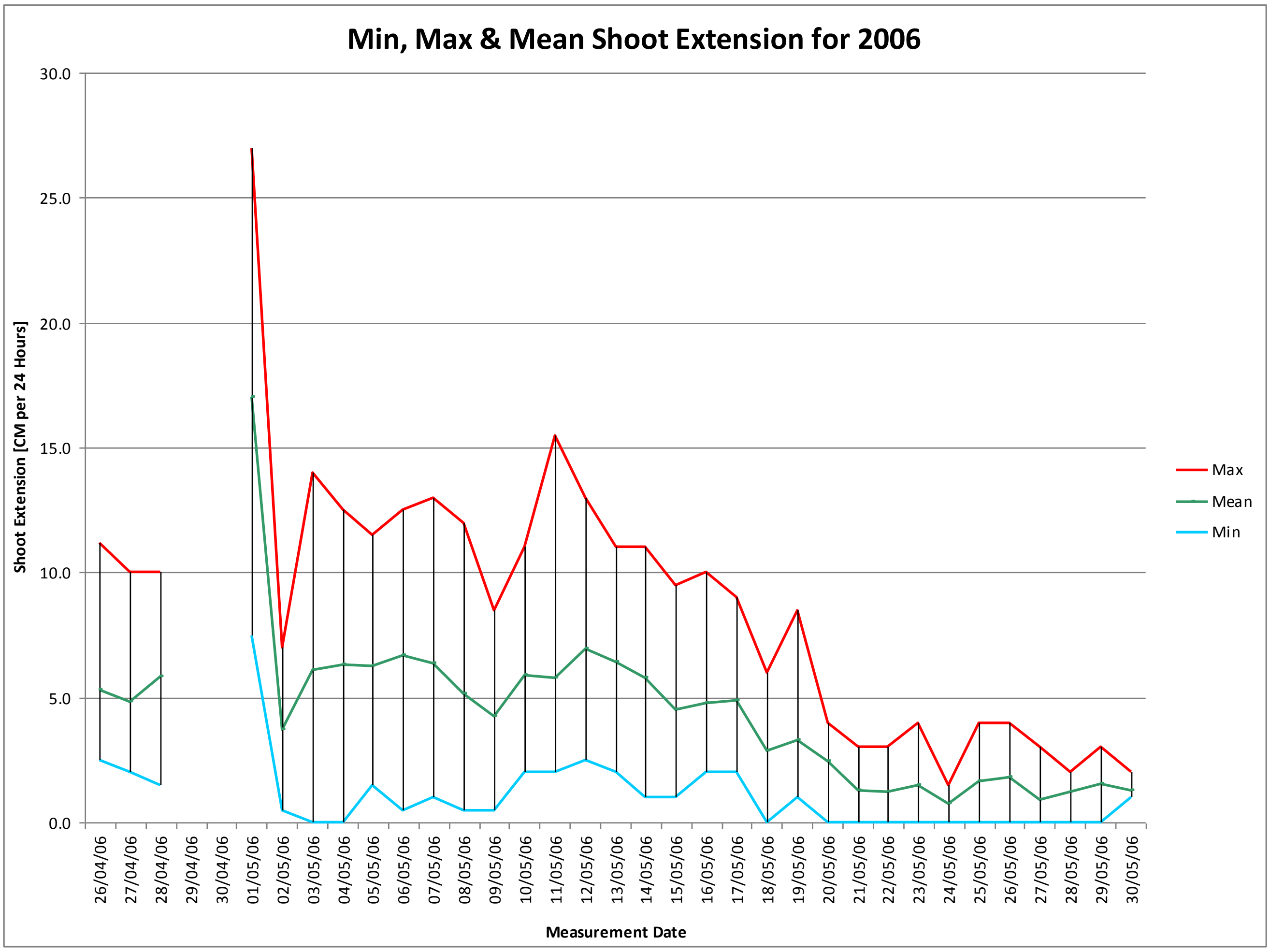


Fig. 3.11 Min, max and mean shoot extension for 2006

Extension of shoots of Japanese knotweed measured in 2006 showing maximum extension, minimum extension and mean extension (<u>n=20)</u>

Work was continued from 2006.04.25 till 2006.05.30, again at 24 hour intervals with 10 shoots. The maximum extension recorded was that of 15.5 cm of a 138.5 cm shoot between 07.10 on 2006.05.10 and 06.55 on 2006.05.11.

<u>Experimental period 3</u>

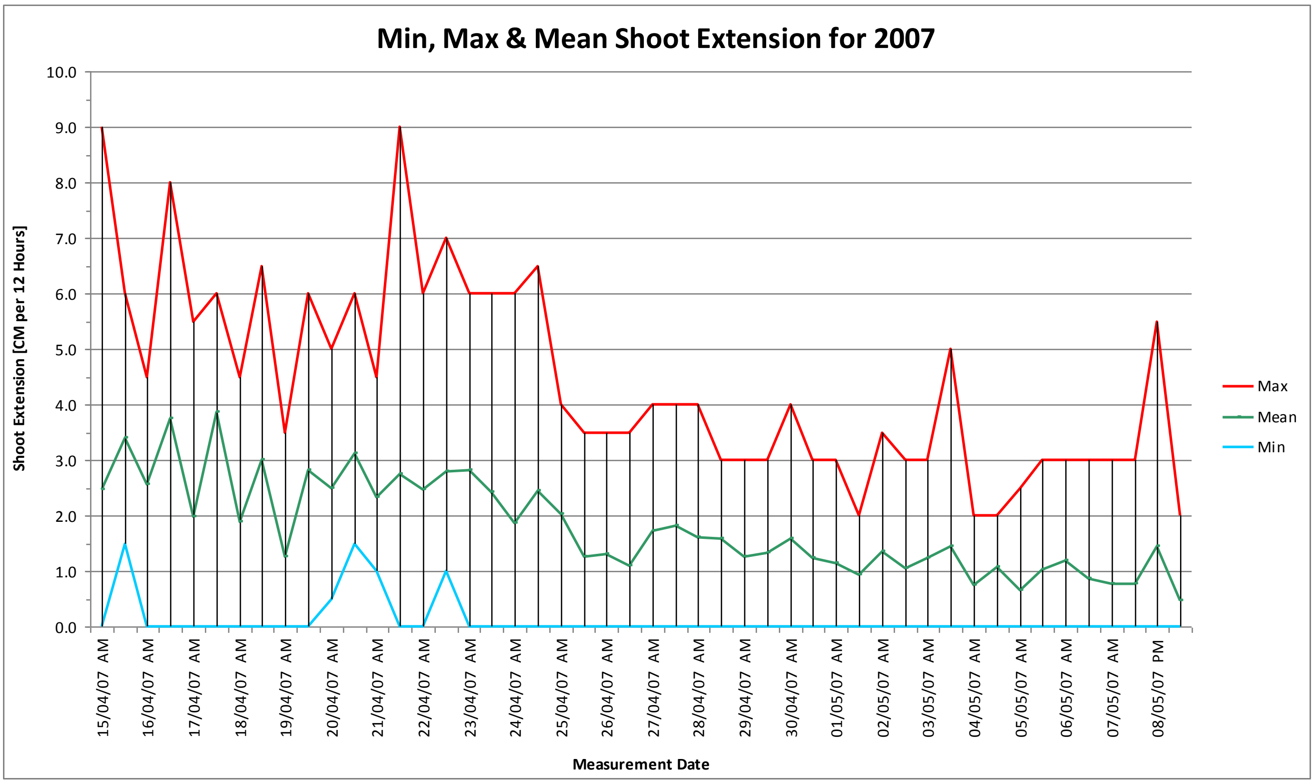


Fig. 3.12 Min, max and mean shoot extension for 2007

Extension of shoots of Japanese knotweed measured in 2007 showing maximum extension, minimum extension and mean extension (n=20)

In 2007 work was carried out between 2007.04.14 and 2007.05.09 at 12 hour intervals. The greatest extension recorded was that of 9cm of a 90.5 cm shoot between 19.00 on 2007.04.14 and 07.10 on 2007.04.15 and of the same amount of a 63cm shoot between 07.10 on 2007.04.21 and 19.10 on 2007.04.21.

Experimental period 4

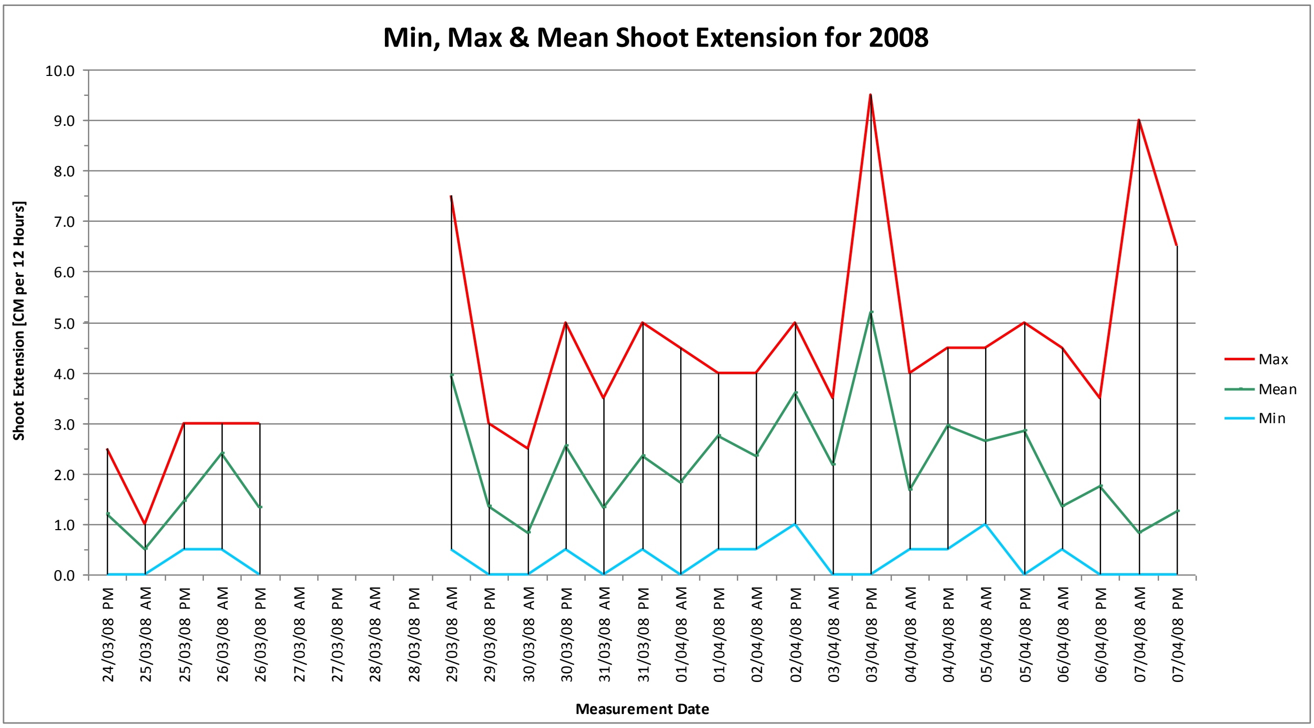


Fig. 3.13 Min, max and mean shoot extension for 2008

Extension of shoots of Japanese knotweed measured in 2008 showing maximum extension, minimum extension and mean extension (n=20)

In 2008 work was carried out between 2008.03.24 and 2008.04.07, measuring 10 shoots at 12 hour intervals with a second tranche of measurement of 10 shoots initiated on 2008.03.29. Both trials continued until 2008.04.07. The maximum rate of growth recorded was 9.5 cm of an 80 cm shoot between 07.15 on 2008.04.03 and 19.00 on the same day. Aggregated figures of preceding and succeeding periods did not exceed 2006 figures.

The maximum extension recorded in a 24 hour period was 15.5cm between 07.10 on 10th and 06.55 on 11th May 2006.

In the 12 hour period assessment, the maximum growth recorded was 9 cm, twice, between 19.00 on 14th April and 07.10 on 15th April 2007 and between 07.10 on 21st April and 19.10 on the same day. . Neither of these shoots, when considered over either the preceding or following periods to aggregate to 24 hours, exceeded the rate of growth in 24 hours recorded in 2006

The four graphs suggest that despite extreme variability in growth rates of individual shoots there is a fairly fast rate of growth in March leading to a peak in early April followed by a decline. Since the growth rates are likely to be highly influenced by temperature and moisture and by the starting height of the samples it was decided to compare relative growth rates of the samples with temperature and rainfall to see whether any correlation could be found. Relative growth rates for the samples were calculated as described in the Methods and rainfall and temperature for the time periods were obtained from the nearby Naval base at RNAS Culdrose which was less than 5 miles from the site.

YEAR 2003

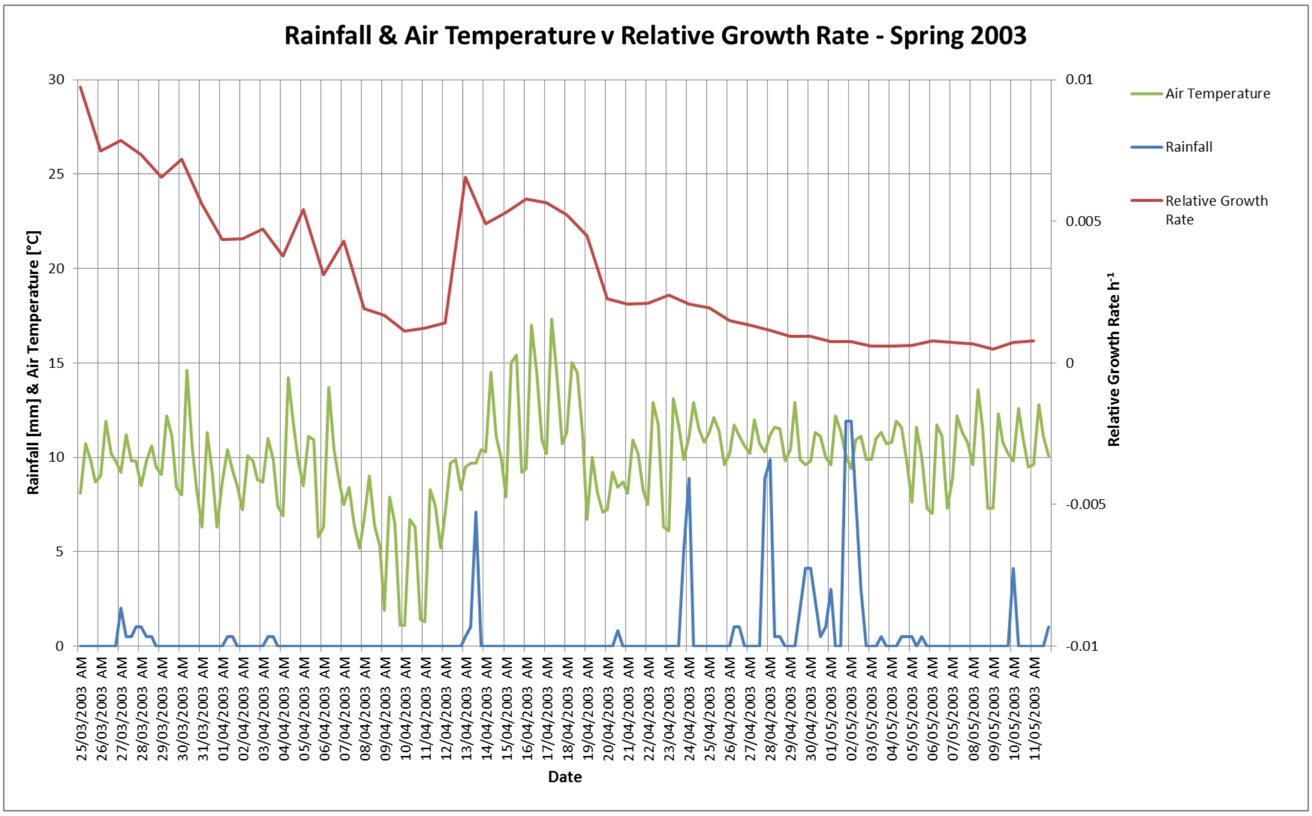


Fig.3.14 Rainfall, air temperature and relative growth rate (RGR) of *Fallopia japonica* 2003 (n=10 plants 25/3 to 11/4 then n=20 plants to 22/5; growth measured at 24 hour intervals)

In 2003 relative growth rate declined from the end of March some of which may be due to cold temperatures in early April. A subsequent rise in temperature at the same time as high rainfall in mid-April appears to have stimulated a growth spurt in the plants. Large rainfall events in late April which were not accompanied by temperature increases did not result in a stimulation of growth rate.

YEAR 2006

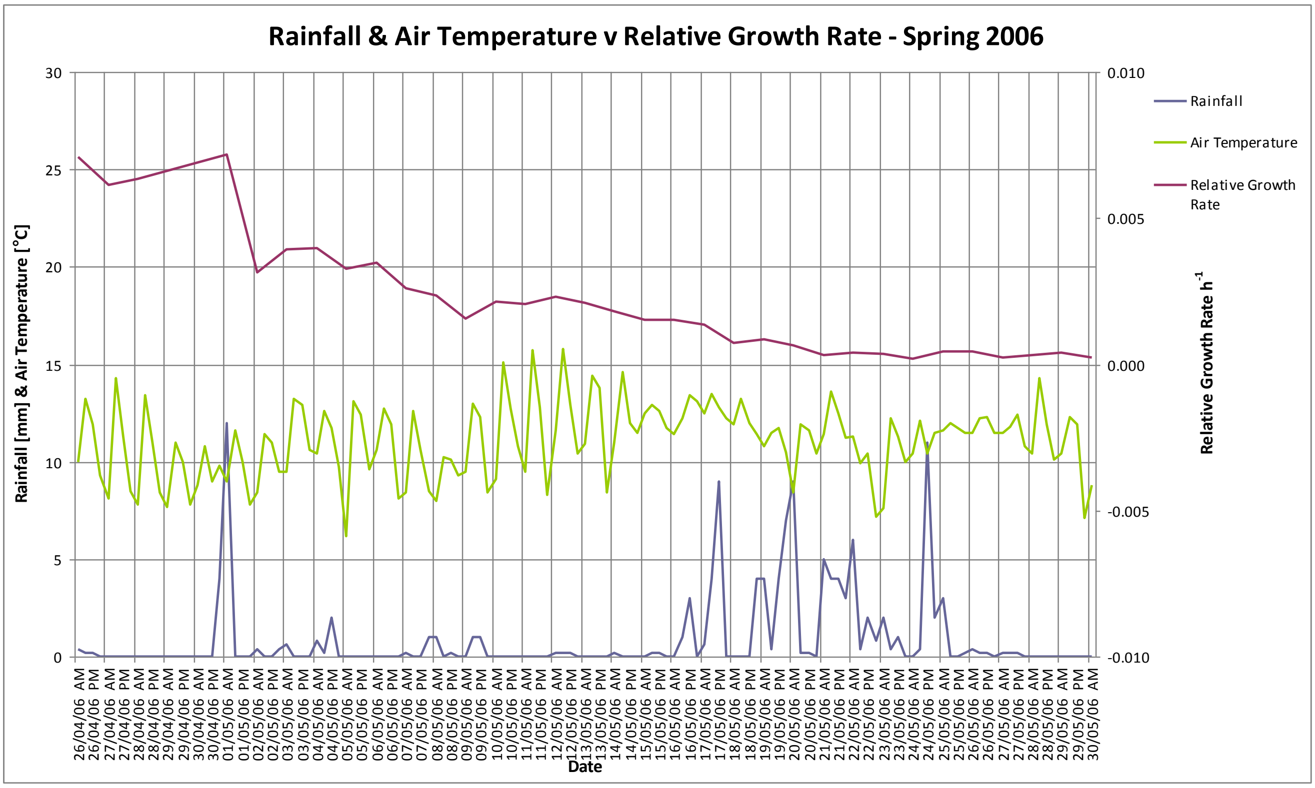


Fig.3.15 Rainfall, air temperature and relative growth rate of *Fallopia japonica* 2006 (n = 20 plants, growth measured at 12 hour intervals)

In 2006 temperatures were fairly constant during the experimental period which was slightly later in the year than in 2003. This is reflected in the even decline in relative growth rate between early and late May. It is possible that the rainfall peak at the start of May could have caused a slight stimulus in growth rate but this is probably not significant. Later peaks in rainfall appear to have no effect.

YEAR 2007

In 2007 temperature was again relatively stable during the experimental period from mid April until mid May. There were two significant rainfall events which did not appear to influence growth rate. The rapid increase growth around the 20th April is only recorded during one 12 hour time period and although correlated with a fluctuating and slightly rising temperature must be considered as an outlier and therefore not significant.

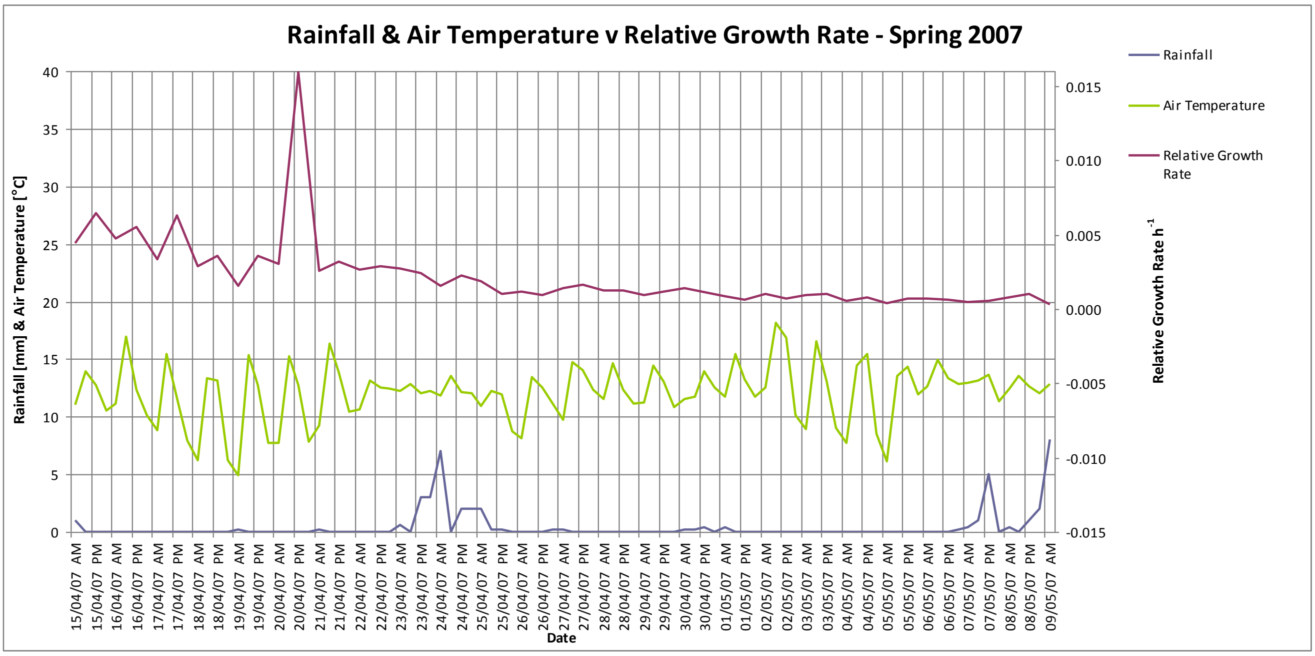


Fig.3.16 Rainfall, air temperature and relative growth rate of *Fallopia japonica* 2007 (n = 20 plants, growth measured at 12 hour intervals)

YEAR 2008

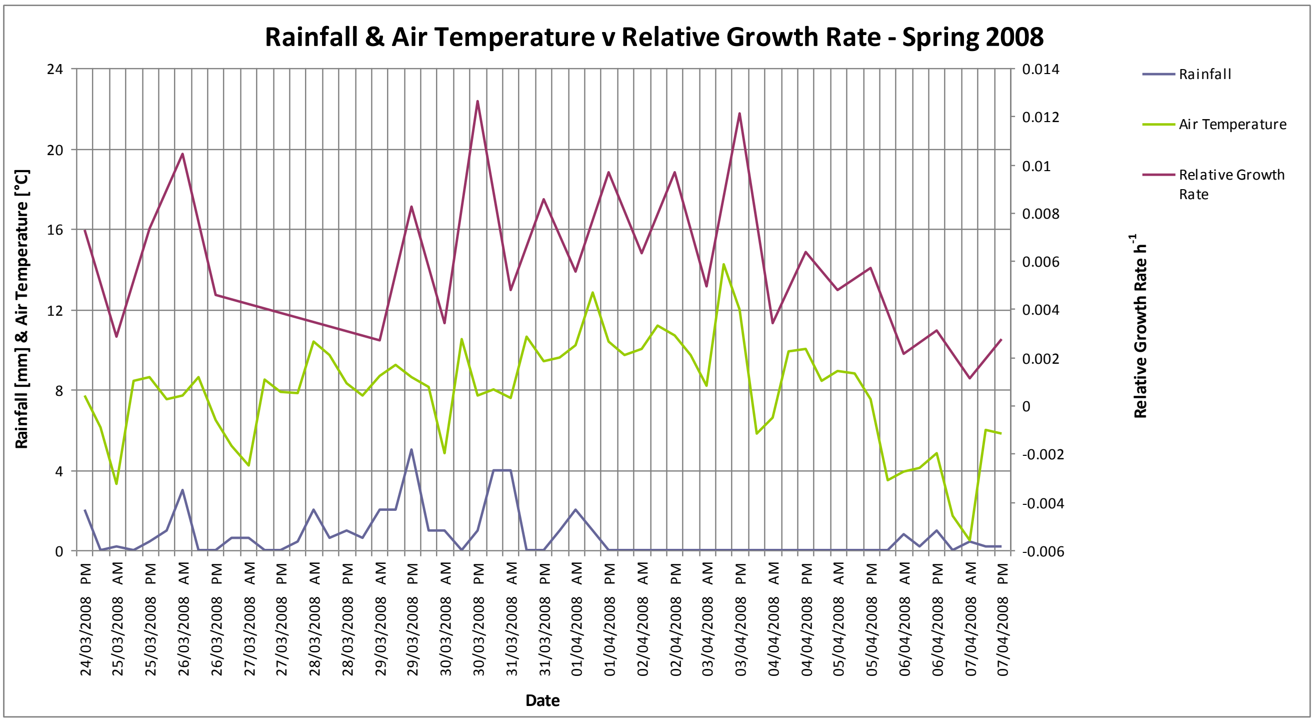


Fig.3.17 Rainfall, air temperature and relative growth rate of *Fallopia japonica* 2008 (n = 20 plants, growth measured at 12 hour intervals)

In 2008 the experimental period extended from late March to early April. From previous years measurements this was expected to be the period of greatest growth. The growth rate fluctuated in line with temperature with only a possible minor influence from rainfall in the early part of the experiment. Rapid decline in temperature at the start of April correlated with a similar decline in growth rate however it is also possible that the growth rate was past its peak anyway.

The 4 years of monitoring would appear to indicate that the period of maximum extension on *Fallopia japonica* in Cornwall is between late March and mid-April and that the rate of growth will be influenced by the temperature during this period. In the spring in Cornwall there appears to be little limitation due to moisture deficit and increased moisture levels do not appear to have a significant effect except possibly in the early part of the initial growth spurt.

3.3.2 Regeneration from leaf material

The leaves remained green and turgid for a period into the autumn.
The material was removed from the warm bench on 27th April 2005. Two of the stem cuttings were observed to have produced shoots, but there was no growth apparent from any of the leaf samples. It was decided that, if growth was going to be initiated, it would have occurred by this time as temperature and seasonal parameters would appear to have been fulfilled for an adequate period.

Fig. 3.18 Stem material with flowering shoots

As previous observations had indicated growth initiation after a fall in temperature (personal observation) it was decided then to leave the material outside for a further period of one month prior to destructive assessment. The material was assessed on 29th May 2005, removed from the growing medium and individually washed.

One leaf had previously been observed on the material with the attached stems. When removed from the growing medium, 10 heavily callused sections and apparently viable portions were found with roots attached, 4 with visible pink buds. 7 callused but apparently dead sections were also removed.

9 heavily callused portions were removed from the trays where simply the petiole and attached lamina had been inserted. Roots (and specifically young white roots on two of the samples) were observed.

The material was placed in closed Petri dishes on moistened filter paper for further observation and maintained in moist conditions in a cold glasshouse. No further regeneration was observed.

3.2.3 Stem counts per square metre

Table 3.1 Assessment of typical number of canes per m^2 on an undisturbed site

Quadrat number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**Population Standard Deviation**
Site 1 (no/ m^2)	6	10	15	4	17	3	13	12	9	3	9.2	
Site 2 (no/ m^2)	23	18	11	9	8	15	3	8	7	7	10.9	
Mean across both sites											**10.5**	**5.35**

Fig. 3.19 Example of site with dense foliage cover with low stem count <6 m^2

3.2.4 Assessment of impact on *Fallopia japonica* of stimulation by cutting

The principal objective of this procedure was to assess whether cutting would stimulate underground extension of the rhizome system. The initial assessment was indicated no underground extension, but the number of shoots which regenerated resulted in the quantification of these in subsequent work. In all cases the a similar sample was treated in an identical way with the exclusion of the cutting.

In each case, cutting of the above ground material resulted in growth of an increased quantity of above ground shoots compared with the controls. These shoots appeared to emanate from buds on the remaining part of the existing shoots, or from buds at their bases, but not from below ground level. The 2006 sample (Batch A) was quite variable but there was an increase in the cut batch post cutting but no change in the controls. The 2007 data appear to suggest a slight increase in shoot growth after cutting but not, statistically, of significance. The data for 2008 show a statistically significant increase in shoot growth after cutting. No increase of extension of underground rhizome was noted in both controls and cut material.   The shoots in the pots which were cut were noted to retain their foliage for a longer period than those left uncut. Leaf material was noted as late as the 26th November on the regrowth material.

Table 3.2 Assessment of impact on *Fallopia japonica* of stimulation by cutting

Pot number	Number of canes per pot. Pre Cut 2006 Batch A	Number of canes per pot Post cut 2006	Increase + - = 2006	Number of canes per pot. Pre Cut 2007 Batch B	Number of canes per pot. Post Cut 2007	Increase + - = 2007	Number of canes per pot. Pre Cut 2008 Batch C	Number of canes per pot. Post Cut 2008	Increase + - = 2008
1 control	4	4	=	2	2	=	2	2	=
2 control	10	10	=	1	1	=	2	2	=
3 control	16	16	=	1	1	=	2	2	=
4 control	9	9	=	3	3	=	3	4	+
5 control	4	4	=	3	3	=	2	3	+
6 control	9	9	=	4	4	=	2	3	+
7 control	3	3	=	4	4	=	3	5	+
8 control	9	9	=	3	3	=	3	4	+
9 control	6	6	=	2	2	=	3	2	-
10 control	3	3	=	3	3	=	2	2	-
Mean	**7.3**	**7.3**	**No change**	**2.6**	**2.6**	**No change**	**2.4**	**2.9**	**Slight increase**
Standard deviation	**4.11**	**4.11**		**1.08**	**1.08**		**0.52**	**1.10**	
11 cut	6	9	+	2	5	+	2	4	+
12 cut	3	7	+	4	7	+	2	6	+
13 cut	6	10	+	5	8	+	2	4	+
14 cut	4	8	+	4	6	+	4	6	+
15 cut	4	7	+	3	2	-	3	6	+
16 cut	5	8	+	4	5	+	3	5	+
17 cut	8	died	N/A	3	died	N/A	5	7	+
18 cut	5	7	+	5	5	=	4	6	+
19 cut	4	6	+	6	9	+	2	7	+
20 cut	6	died	N/A	8	died	N/A	2	died	N/A
Mean	**5.1**	**7.8**	**increase**	**4.4**	**5.9**	**increase**	**2.9**	**5.7**	**increase**
Standard deviation	**1.45**	**1.28**		**1.71**	**2.17**		**1.10**	**1.12**	

3.2.5 Determination of the size of rhizome capable of regeneration

Field observations by the author – such as the observation of very small detached rhizome initiating a leaf in the vicinity of a watercourse near St Erth GR SW 549 348 and at St Agnes GR SW 732 508 (Fig. 3.20), where material weighing 0.2 grams was observed to be producing shoots and roots – suggested that far smaller material could, in suitable conditions, be capable of regeneration. The material collected from the St Agnes area established in potting compost in a pot. The material from St Erth was observed, but not collected.

Fig. 3.20 Regenerating material found at St Agnes

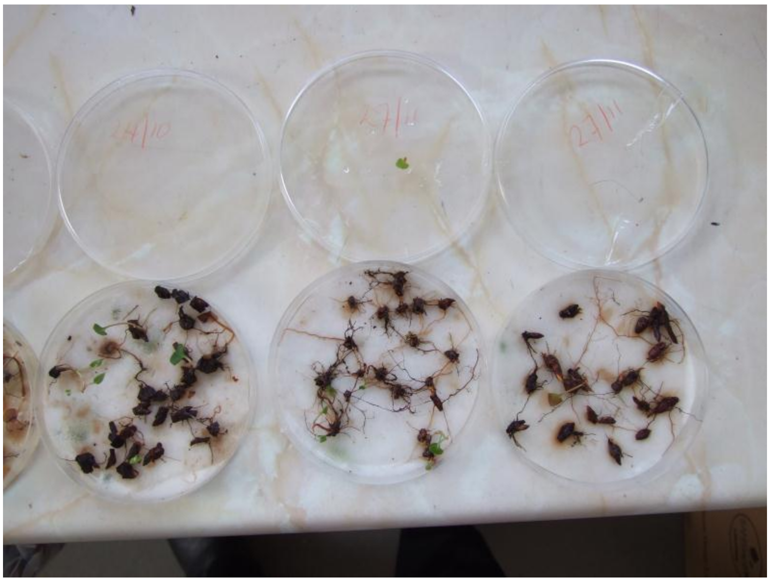


Fig. 3.21 Regenerating rhizome in Petri dishes

The material was assessed for viability on 31st March 2009. The batch methodology did not permit precise individual sample determination, due to the weight of the growth but did allow for relatively close definition between individual samples.

Roots were noted on 93% of the samples. A number of the samples consisting of a bud and shield were showing signs of regeneration in that bud extension was noted.

Criteria for assessment of viability were determined as the presence of roots and of leaf growth.

Fig. 3.22 Rhizome weighing

The smallest material recorded as regenerating according to the determined viability criteria weighed 0.0109. (Fig 3.22)This was smaller than the smallest material initially weighed, and the assumption is that some dieback and desiccation may have occurred before the new shoot was initiated. 9 samples of less than 0.1g were noted as regenerating.:-

A detached bud shield weighing 0.1005g produced a shoot and another weighing 0.12158g showed stem extension, but both subsequently succumbed to fungal infection. Roots were observed on material prepared by cutting longitudinally, within 6 days. The source of roots was in all cases observed to be from an area of less than 3mm from the centre of the bud initial. In all cases the initial observation was of bud extension rather than of root initiation. In the case of the bud shields all were placed with the cut surface in contact with the filter paper. With the full sections, attempts were made to ensure that the lower cut surface made contact with the filter paper but this appeared to have little effect in relation to bud extension or root production.

The latter three batches were retained for a further period and leaves and buds were noted in August 2009. 32% of this material was still viable in August 2009. the lowest weight of material still viable was 0.0109g and an average of the lowest weight of material surviving from three batches gave a mean weight of 0.0633g. This suggests that there is a good likelihood that fragments of rhizome of this weight or more have the potential to re-establish plants when provided with suitable growing conditions. There is also a risk that even smaller material down to 0.01g may be able to grow in certain situations.

Table 3.3 Regenerative capacity of rhizome

Batch no	**1**	**2**	**3**	**4**	**5**	**Summary**
Date of incubation	**08.10.2008**	**20.10.2008**	**24.10.2008**	**07.11.2008**	**27.11.2008**	
Number of rhizome fragments (n_1)	20	20	20	20	20	**100**
Weights of starting samples (g)	0.0100 0.0291 0.0296 0.0542 0.0628 0.0628 0.0744 0.0768 0.0796 0.0857 0.1191 0.1372 0.1433 0.1528 0.1705 0.1746 0.1819 0.1966 0.2320 0.3323	0.0185 0.0226 0.0346 0.0401 0.0415 0.0428 0.0444 0.0522 0.0561 0.0570 0.0611 0.0796 0.0835 0.0873 0.0876 0.0908 0.0908 0.1005 0.1123 0.1377	0.0174 0.0320 0.0468 0.0473 0.0488 0.0496 0.0552 0.0554 0.0614 0.0636 0.0658 0.0785 0.0788 0.0872 0.0882 0.0985 0.0998 0.1068 0.1208 0.1276	0.0202 0.0222 0.0249 0.0256 0.0272 0.0305 0.0306 0.0307 0.0325 0.0350 0.0377 0.0378 0.0424 0.0469 0.0470 0.0492 0.0495 0.4790 0.4840 0.5450	0.0198 0.0201 0.0261 0.0278 0.0299 0.0303 0.0315 0.0328 0.0341 0.0346 0.0375 0.0458 0.0471 0.0473 0.0475 0.0644 0.0804 0.0867 0.6720 0.6990	**Mean weight (g) (+\- SD)** **0.0939 +\- 0.1237**
Mean weight of samples (+\- SD) (g)	0.1203 +\- 0.0798	0.0671 +\- 0.0315	0.0715 +\- 0.0294	0.1049 +\- 0.1721	0.1057 +\- 0.1993	
Lowest weight (g)	0.0100	0.0185	0.0174	0.0202	0.0198	**Mean lowest weight (g) (+\- SD)** **0.0172 +\- 0.00415**
Number of viable samples March 2009 (s_1)	7	8	7	14	5	
Percentage viability (s_1/ n_1 x100)	35%	40%	35%	75%	25%	**41%**

Number of viable samples at August 2009 (s_2)	Not measured	Not measured	2	12	5	
Weights of viable samples at August 2009 (g)	Not measured	Not measured	0.1470 0.4700	0.0109 0.0356 0.0447 0.0454 0.0517 0.0538 0.0589 0.0605 0.0718 0.0918 0.1321 0.1351	0.0321 0.0571 0.0626 0.1014 0.1302	**Overall mean +\- SD** **0.0944 +\- 0.0989**
Lowest surviving weight (g)	Not measured	Not measured	0.1470	0.0109	0.0321	**Mean lowest weight (g) 0.0633**
Percentage viability (s_2/n_1 x100)	Not measured	Not measured	10%	60%	25%	**31.7%**

The latter three batches were retained for a further period and leaves and buds were noted in August 2009. 32% of this material was still viable in August 2009. the lowest weight of material still viable was 0.0109g and an average of the lowest weight of material surviving from three batches gave a mean weight of 0.0633g. This suggests that there is a good likelihood that fragments of rhizome of this weight or more have the potential to re-establish plants when provided with suitable growing conditions. There is also a risk that even smaller material down to 0.01g may be able to grow in certain situations.

3.2.6 Assessment of sustained temperature regime required to remove viability

The material maintained at 60^{o}C was observed after 7 days and appeared to be softer and showed no shoot extension. The same result was noted at 55^{o}C, 50^{o}C, 45^{o}C and 40^{o}C. None of these samples showed viability after the prescribed period in the growth chamber.

At 35°C, 24 of the 30 samples proved viable with bud extension noted. At 37.5°C 12 samples proved viable and 3 at 38.5°C

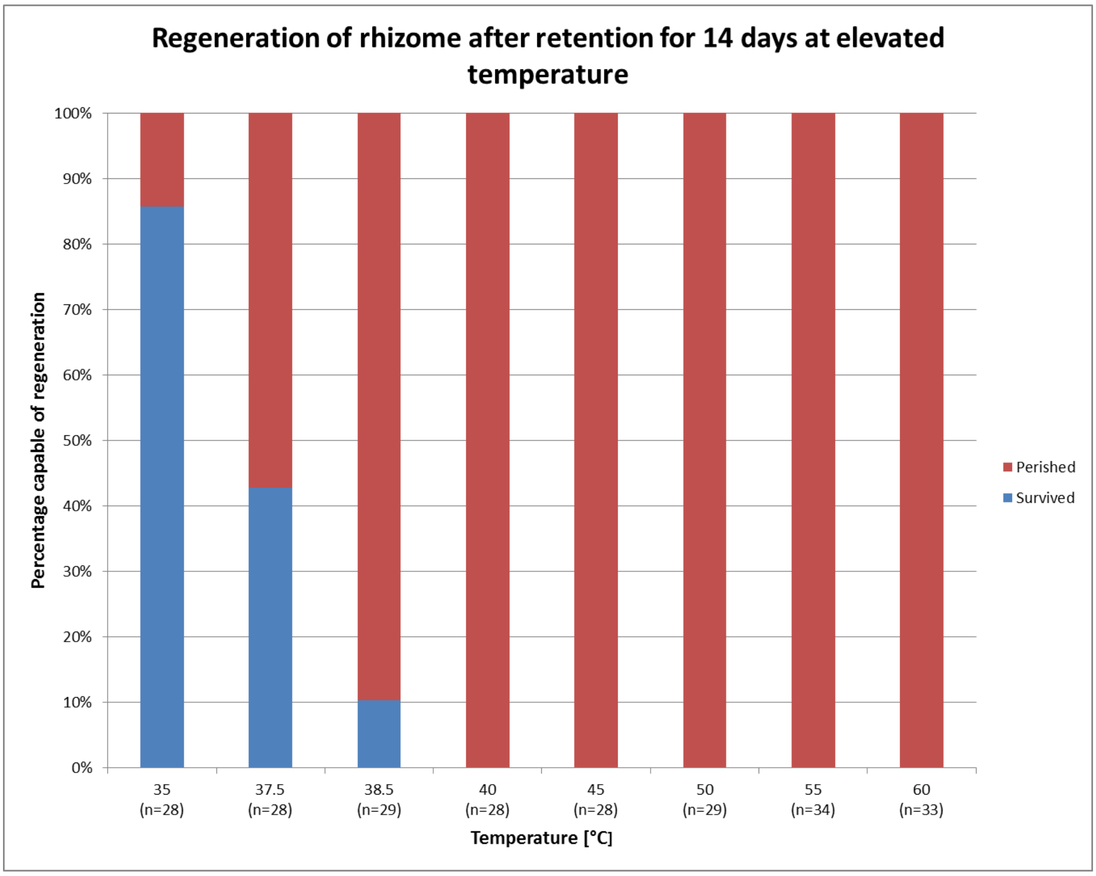


Fig. 3.23 Sustained temperature required to remove viability

3.2.7 Survival of rhizome in saline conditions

Some survey work has been carried out in the vicinity of the Cornish sites where the rivers enter the sea, but there is no clear evidence of colonisation of upper tidal limit areas in their close proximity. This may be due to the fact that these debouchments are generally small, with rocky coastlines on both sides.

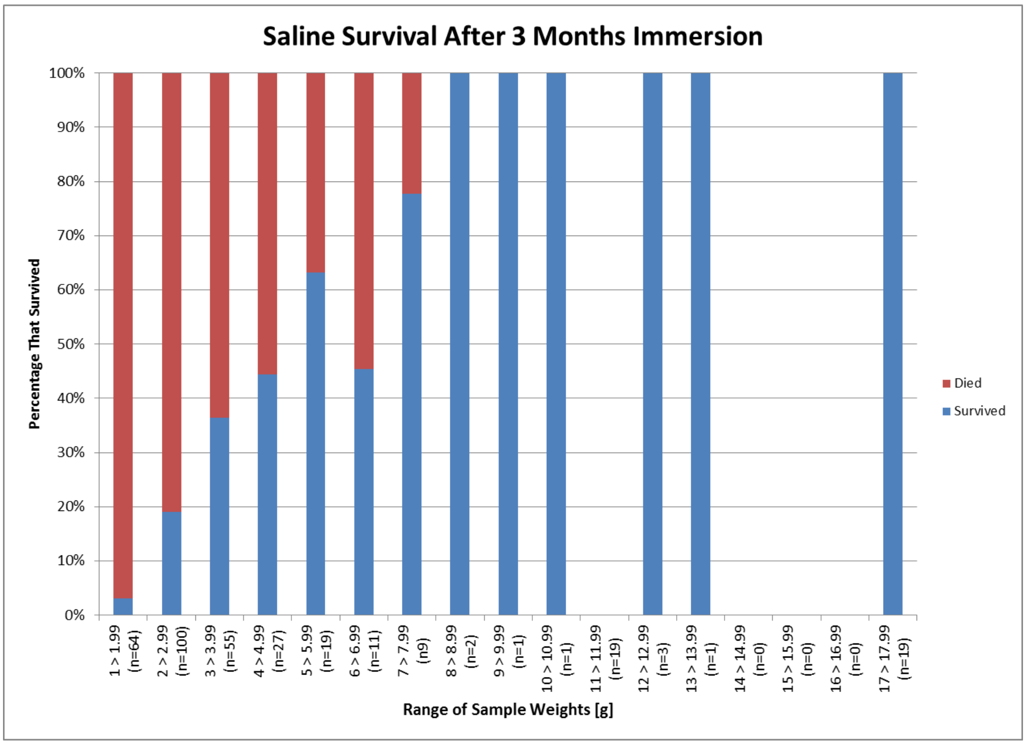


Fig. 3.24 Survival of rhizome in saline conditions

30 samples were placed in seawater (Specific Gravity 1027) on 16th November 2003. 5 samples of rhizome were removed 0n 10th January 2005, weighing 12.6, 15.7, 21.5, 110.4 and 259 grams They were treated as detailed above and maintained in polythene bags as described above. They were observed to be producing shoots on 17th April. 5 further samples were removed on 23rd January weighing 81, 107.7, 110.2, 131.7 and141.8 grams with buds firm and apparently viable. The water had developed a grey slimy covering by this stage.

Further trials were carried out between January and March 2008 at two week intervals. The material demonstrated viability for periods of at least three months.

3.2.8 Viability testing

Rhizome was collected from a number of sites including Tregeseal GR SW 365322 and Mabe GR SW 764323. The material chosen varied between 6 and 15mm in diameter and was of the previous season’s growth with a light to mid brown cortex and bud material visually assessed to be viable. The material was washed thoroughly in tap water, rinsed and dried. Samples were either boiled, steamed or dried for 5 months or left untreated. A vacuum was used to ensure infiltration of the test material with TTC medium was carried out till no bubbles appeared, approximately 30mins. numbers of bubbles were observed, perhaps because the inner section of the pith contains a lot of air. The vacuum was released and the flasks incubated in the dark at a temperature of 30.5°C to 31°C from 18.00 till 10.09 2002-10-12.

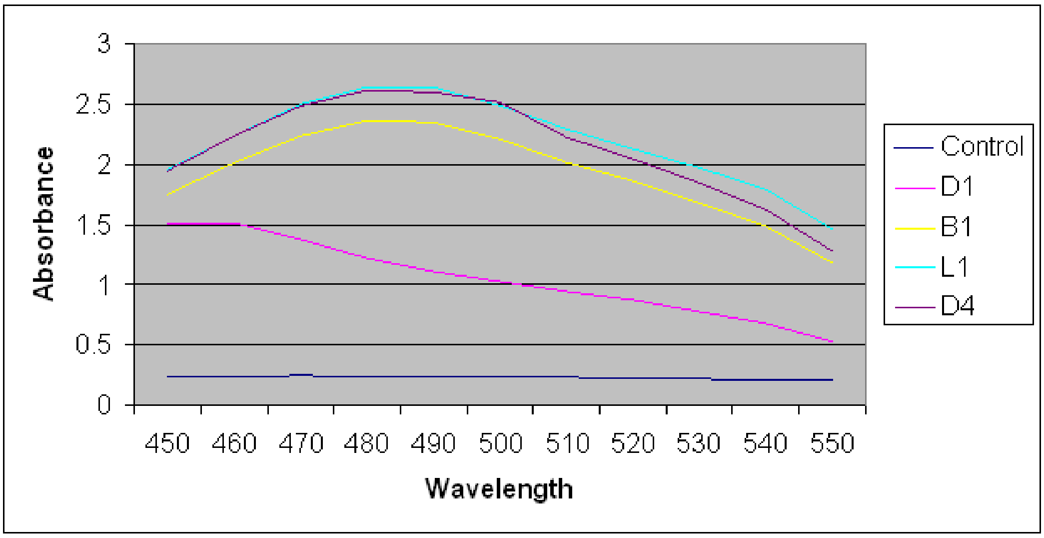


Fig. 3.25 An example of recorded absorbance spectra indicating no clear differentiation of response due to treatment.

Key to rhizome used:-

D1 Dried for 5 months

B1 Steamed to boiling temperature without contact with water

L1 Live material

D4 Boiled in contact with water

C Control, no rhizome

This may indicate either microbial activity or that there is a pigment which has been destroyed by drying. Either of these factors would interfere with spectroscopic analysis. In order to test whether the colouration was due to microbial activity some samples were also frozen in liquid nitrogen. The liquid in the flask with the shoots put in N_2 was orange-brown. The liquid in the flask with the live shoots was clearer and light yellow. Samples N1 (frozen in liquid nitrogen) and L4 (Live) were prepared for microscopic analysis. L4 Under the microscope at 30X under incidental light, the cambial area appeared reddish brown. The internal cortex material was pinkish – this could be through microbial or cell pigments. Live material produced yellowish colouration within 30 seconds. Repetition produced the same result. A colour change was observed only at the cut end of a 5mm length of white shoot. N1 showed some pink staining in the phloem as well as the cortex whereas the cross section of a piece of oven dried material showed no colour change. It is unclear whether either oxidising pigments or microbial activity is producing this colouration but the main conclusion is that this assay is unsuitable for assessing viability of rhizome fragments.

3.2.9 Assessment of below ground mass

Fallopia x *bohemica* which was excavated at Veryan GR SW 9528 4092 where between 29.5 and 32 kg of underground material was discovered in areas 1metre x 1 metre x 750mm. as opposed to 16.5kg of above ground growth in similar area.

On this site it had originally been intended to excavate a cubic metre in each case, but this was compromised by the striking of the slate bedrock. Some small rhizome >5mm in diameter was observed to be penetrating fissures between the laminae of the rock. The equipment which had been available on site did not permit deeper excavation.

The excavation at Trengove produced the following results:-

Each excavation refers to the amount of as dug rhizome encountered in an area of 1 cubic metre.

Excavation 1 17th March 20 kg

Excavation 2 17th March 24kg

Excavation 3 17th March 50kg (centre of clump)

Excavation 4 26th March 23.57kg

Excavation 5 26th March 10.08kg

Excavation 6 26th March 27.95kg

Average 25.93kg/m3 Standard deviation 13.26

The deepest rhizome noted was at 910mm

3.2.10 Determination of the period at which rhizome extension occurs

All the rhizome material planted in the growing cases proved viable, pink shoot extension being noted on 3rd May 2006, with 1 shoot emerging from the top of the case on 5th May. Stem extension by means of white underground shoots was noted only in October and November of each of the following three years. In each of these years the plants produced either 2 or 3 above ground shoots up to 200mm high.

3.2.11 Observations in relation to the progressive necrosis of rhizome

Desiccation was noted from ends and progressively in internodal areas, manifested by reducing of diameter of material followed by ridging and subsequently cracking (Fig. 3.26). The final part of the material to exhibit signs of necrosis was in the immediate vicinity of the lateral buds.

Fig. 3.26 Lateral cracking resulting in separation of growing points

3.2.12 Orientation of shoot emergence

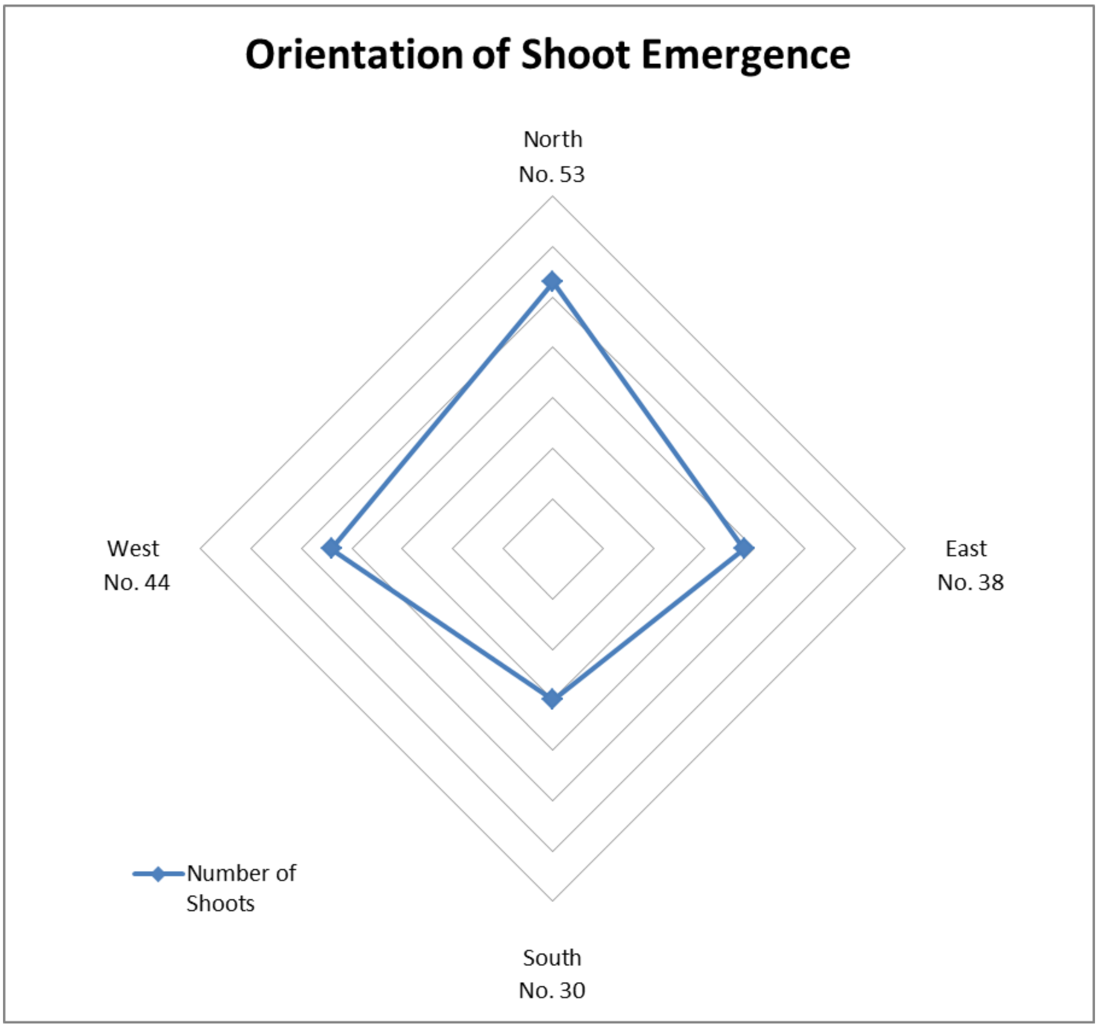


Fig. 3.27 Orientation of shoot emergence

164 shoots were noted in the 30 containers, an average of 5.46 per unit.

32% emerged on the north side of the containers, 18% south 23% east and 27% west.

3.2.13 Moisture content of rhizome

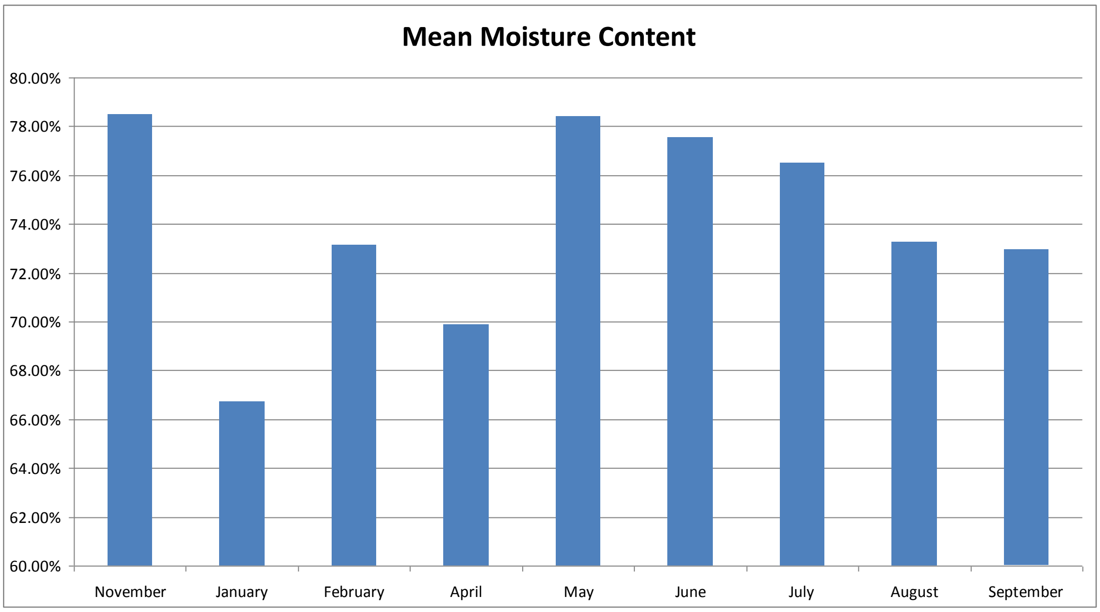


Fig. 3.28 Determination of moisture content of rhizome

n = 20 portions

Moisture content varied from 66% in January to over 78% in May and November. The lowest moisture levels appear to be in the time of maximum growth rate.

3.2.14 Regenerative ability of a range of material and provision of standardised material for future use.

Rhizomes were sourced from a stand at Coverack (GR SW 774 180) on 25th February 2002. It was washed, and cut with secateurs into sections ranging in weight between 4.0g and 6.5g, (weighed in the Highways laboratory) sorted into multi-nodal, single nodal and undifferentiated material. Material was graded in two size ranges, 4 to 8 mm diameter and 8 to 12 mm diameter. Much of the larger material had only a single node. Some material had signs of developing buds. The prepared material was placed in polythene bags in cool storage overnight and placed in standard seed trays, with 24 pieces in each tray and placed in an unheated 4.2metre wide polytunnel with netting doors at each end, on a double thickness of Mypex sheet at Watering Lane Nursery of the Eden Project near St Austell. The material was watered to full soil capacity and the house closed overnight and opened during the day. When rooted, the material was potted into 9cmx9cmx10 cm square pots using peat free compost and placed back in the unheated 4.2metre wide polytunnel on a double thickness of Mypex sheet. The material was watered to the point of run off and the house closed. The process was repeated through the growing season and regeneration judged by the presence or absence of above ground material. The material from this trial was finally potted on into 3 litre pots in order to provide reasonably standardised material for future testing purposes.

The plants were inspected on 4th March when a few red buds were apparent <2%

Table 3.4. Regeneration of cut portions of rhizome

Type of material	Batch 1	Batch 2	Batch 3	Total
Single node (number of portions of rhizome at start)	240	120	48	388
Number producing above ground growth	203	102	35	340
Multi node (number of portions of rhizome at start)	360	864	120	1320
Number producing above ground growth	254	735	96	1085
Undifferentiated material (number of portions of rhizome at start)	24	24	24	72
Number producing above ground growth	1	3	4	8
Number of emergent shoots	2	4	6	12

There would appear to be correlation between size and strength of shoot growth and underground rhizome mass, when the comparison is made with shoots produced from a known and limited weight of rhizome (Fig. 3.29)

Fig. 3.29 Watering Lane material on 14th July 2002 having grown from rhizome of between 4.0g and 6.5g planted on 26th February 2002

Some observations on physiology from field sampling:

i) Last points of viability

Observation by the author of progressive necrosis in adverse conditions e.g. of desiccation, indicate a pattern which may have particular relevance when carrying out assessment on fractured material. A pattern of necrosis has been observed, not only longitudinally from the point of fracture, but also in internodal areas where a pattern of longitudinal cracking has been observed, with the bud retaining signs of viability after active lateral transfer appears to have ceased.

In areas where the three *Fallopia* species are growing in close proximity, less than 100 metres apart, autumnal defoliation has been noted first in *Fallopia sachalinensis*, followed by *Fallopia* x *bohemica* and finally *Fallopia japonica*. The first is generally defoliated by the middle of October, while the last named has been noted with green foliage as late as December, though generally leaf loss occurs on undisturbed material in November. Frost has been noted to cause foliar death.

ii) Rhizome dormancy

Suggestions have been made that material can remain in a viable condition for a period extending to several growing seasons without producing above ground shoots. Observations received from the Highways Agency and Trewidden Garden (GR SW 442 295) have stated that healthy shoots have appeared in areas where material has not been seen for periods varying up to eight years and where no external factors such as stimulation have been noted. Observations from other sources (District councils and private individuals) in 2006 suggested that normal, not epinastic, material was appearing on sites which had not shown any signs of growth for the previous two or three years. The material which was appearing was in all cases at some distance from the noted centre of the previously treated area, leading to the conclusion that the crown of the plant had succumbed to the herbicide treatment and that the connectivity of live tissue has been broken.

The effects of sub lethal applications of herbicide and deep burial of material have both been observed, and appear to be to be factors which appear to lead to such periods of dormancy.

Material failing to produce above ground shoots for a duration of more than a single growing season has been observed at the White River, St Austell (SX 00774 49763), Cot Valley, St Just (SW 35647 30848) and Rocky Valley Tintagel (SX 07251 89465) At these locations monitoring was more straightforward as access was restricted to pedestrian use. On the first site overall spray application had been carried out and there was a total absence of above ground material and the visible vegetation on the previously heavily colonised sites consisted of graminaceous species. No epinastic material was noted on this site. On the other two sites control had been carried out by stem filling, with a follow up by directed spray or weed wiping.

Exposed rhizome was discovered in the White River in areas between minimum and maximum stream flows, where soil had been washed away. When removed it was found to be capable of regeneration. It is postulated that the detachment perhaps stimulated this regeneration.

The most dramatic demonstration of dormant rhizome was observed at Rocky Valley on 13th September 2004, following scouring and damage following the torrential rain in the area of 16th August 2004. The western side of the valley had been treated with the herbicide glyphosate by the National Trust over several years using the stem filling technique. Some small regenerating material had previously been observed on slopes above the river, but a large amount of rhizome of up to 40mm in diameter was exposed and observed. Samples of this were removed to test for regenerative capacity. The site was later observed and weak, normal shoots, but no epinastic shoots were observed. Observation has led to the conclusion that that dormancy of rhizome from sub lethal application of herbicide or displacement into an environment inimical to growth is a major issue. At Veryan (GR SW

9528 4096) areas which were treated in 2001 and produced no above ground material in 2002 produced strong growth in 2003. On the White River rhizome being exposed on slumping bank after 5 years of little or no emergence produced vigorous above ground shoots. Material in treated area of Cot Valley washed by the stream was removed and proved viable when incubated at a temperature of 30^{o}C. Rhizome removed from warm room and left in an unsealed polythene bag in shed was still producing shoots in March 2003. Material on highways which has been treated for up to 5 years has been noted to show no sign of above ground growth, but visually appears alive (plump, moist material).

iii) Rhizome survival in water

Rhizome has been noted below water in a number of situations. A particular example was noted in a lake at Penwithick, St Austell GR SX 034 567 where water levels appeared to remain reasonably constant (Fig. 3.30). There was connectivity to adjacent material on the adjacent bank.

Fig. 3.30 Rhizome below water Penwithick GR SX 034 567

Two pieces of crown material, consisting of material broken off just below – perhaps 100mm - ground level, one of 1200 grammes and one of 650 grammes maintained in water in a bucket were noted to have produced shoot growth after being in situ for 12 months. One of 200 grammes did not produce growth.

iv) Rhizome survival in low nutrient conditions

Evidence of toleration of very low nutrient levels has been observed in a number of circumstances. An extreme example of this was material discovered growing in

Fig. 3.31 Japanese knotweed growing in polystyrene

expanded polystyrene The plant has been moved from its original point of discovery at GR SW 762327, it having been observed that there was no root connection to the soil. It was subsequently positioned on a hard surface with no possibility of contact with a potential growing medium. It has been observed to produce shoot growth in this material for five years with no recordable nutrient source.

v) **Hybridisation**

Hybrid forms of Knotweed have been noted, particularly with *Fallopia baldschuanica*. (Bailey, 1989, 1992, 1994)

Production of apparently viable seed was observed by the author on a plant of *Fallopia japonica* at Sennen GR SW 351 262 (Fig. 3.32). The plant was in close proximity (less than 3 metres) from a specimen of *Fallopia baldschuanica*. Both plants were well established and mature and it would seem reasonable to expect that they had both been in position for a number of years. No hybrid plants were observed within a 5 metre radius of the seed bearing plant.

Fig. 3.32 Apparently viable seed Sennen GR SW 351 262

Spread by seed

Three seedlings have been noted in an area where specimens of *Fallopia japonica, F. sachalinensis* and *F.* x *bohemica* have been grown in close proximity in Coverack (Fig.3.33). The area on which these seedlings were noted to have established was finely ground stone.

Fig 3.33 Seedling observed at Coverack GR SW 743 108

vi) Depth of rhizome

Various suppositions have been made in relation to the depth at which rhizome may be found. Reliable information in this respect is very necessary in order that specifications for physical removal can be appropriately detailed. The opportunity has been taken, when sites are being excavated, to record the depth to which rhizome has been found. In general, the large majority of material has been found within the top metre, but circumstances have discovered material at a depth of 2 metres (Scorrier GR SW 7206 4411). Many of these sites have been disturbed to a greater or lesser extent. In the case cited, the rhizome appears to have descended as far as the clay layer. The soil profile at this site was not even, being somewhat mounded within 2 metres of this measurement point. Heavy clay has been noted to be an inhibiting factor in several circumstances, with the effect of limiting upward or downward progression of rhizome. In contrast to this, rhizome penetration between rock strata has been noted to depths greater than 1 metre.

A particular occurrence was noted at a garden near Loe beach GR SW 825 382 where a 1200mm length of rhizome, less than 4mm in diameter at its thickest point near the surface, was found emanating from material 670mm below ground level in an area where no material had been previously noted, according to the owner who had occupied the property for in excess of 30 years. Such thin material coming from such a depth had not previously been noted and the likelihood of accidental transmission to such a depth in an established garden would seem remote. (Fig. 3.34)

Fig. 3.34 Thin rhizome at depth. Garden near Loe Beach GR SW 825 382

vii) Rhizome reaction to disturbance

A number of instances have been recorded where disturbance of the rhizome system has resulted in stimulation of growth of rhizome. Particular instances which can be cited relate to Talland, GR SX 2226 5160 Tolgullow GR SW 7359 4351 and Veryan GR SW 953 409 (Fig. 3.35)

Fig. 3.35 Disturbed rhizome (<30 days) Veryan GR SW 953 409

This confirmation of the reaction of regrowth to disturbance may be highly relevant to control techniques in that separation of a clump by a root barrier along the line to separate the ownerships could be considered as causing the plant to spread, an offence under the terms of the Wildlife and Countryside Act 1981.

Weight of underground rhizome

The higher figures recorded could conceivably be accounted for by deposition of an accumulation of rhizome in company with the construction materials which were discovered. The quantity of above ground stems observed prior to excavation was not indicative of the presence of this quantity of underground material. (Previous work had suggested a weight ratio of 2:1 between below and above ground material)(Work at Veryan and Brock (1994). Some of the rhizome removed in this area had the appearance of viability (and subsequent tests demonstrated this) but did not have direct connection of above ground shoots. This appears to be a further indication following previous information (Kaye and Semmens, pers. coms) that rhizome may remain in viable but dormant state for several years.

Rhizome has been observed to range from white extension tissue, typically 3 to 4 mm in diameter through to material of several years maturity with a dark brown, leathery cortex surrounding woody tissue and a central core of varying yellow/orange colour (Fig. 3.36).

Fig.3.36 Rhizome of varying maturity

The most mature material has been observed up to 150mm in diameter. On occasion, such material has been observed with deep lateral scarring, perhaps10mm in depth, over much of the surface – typically 5 such scars 200mm in length in material collected near St Austell GR SX 0074 5509. Such scarring would appear to provide evidence of capacity for toleration of a wide range of growing conditions.
On the edges of the clump there is often early growth of shoots which are similar in form to those at the centre, but of lesser size.

If an established clump is disturbed, the reaction of shoot increase is usually concentrated in the area of the area of disturbance and consists of relatively stout shoots.

In areas where occasional mowing is undertaken the shoots are usually dwarf, deep red in the early stages and with a stem diameter of 3 to 5 mm. They may be up to 300 mm tall before the reddening diminishes and the development of green pigmentation indicates that photosynthesis has become a factor in relation to shoot extension.
In less established plantations, the form of growth appears to be proportional to the type, quantity and size of rhizome present and green leaves appear at an earlier growth stage (Fig 3.29).

Where there is large rhizome, this gives rise to thicker shoots – large, but in relatively small numbers (Fig. 3.37).

Fig. 3.37 Shoot emergence from large rhizome

The furled nature of the leaves and the absence of chlorophyll in them lead to the conclusion that initial shoot extension is entirely independent of photosynthetic action.

The delay in leaf expansion may be a genetic factor to get above harsh conditions in its native environment nearer the ground. The leaves themselves are relatively thin and therefore vulnerable to factors such as wind desiccation, but likely to be highly efficient at photosynthesis.
The rapid growth rate and projection of shoots serves to establish the plant above, and thus dominating, surrounding vegetation

Green tissue is prone to rapid desiccation in all but the most favourable conditions for growth. Field observations by the author have noted root formation, heliotropic reaction by the shoot tip and establishment as a discrete plant, in suitable locations, at the interface of the terrestrial and aquatic environments, when shoots have been cut and have fallen into watercourses (Fig. 3.38).

Fig. 3.38 Regenerating stem material in stream Boscastle SX 0989 9110

Fracture of canes at the approach to, or during, the dormant season may result in detachment of part of the crown of the plant, consisting of stem material, which has shown a high capacity for regeneration in the field. Pink basal buds have been frequently noted on this material (Fig. 3.39).

Fig. 3.39 Crown material with pink basal buds

The plant reacts to disturbance of below ground material by the production of vigorous shoots.

Particular attributes of the plant which aid its successful colonisation are its rapid growth, its capacity for rapid vegetative regrowth from small material, the density of the rhizome system which crowds out competition, the density of the shade created by the foliage, capability of survival in biologically challenging habitats, a phrenology which enables shoots to penetrate surrounding vegetation and the fact that it has been imported without its natural predators.

Although it has been demonstrated that regeneration can take place from stem and crown material (Bailey et al. 1995), the principal regenerative base is the massive rhizome system. The size of this underground mass, the phased emergence of shoots and the plant's capability of remaining viable without producing above ground material for some period are likely to appertain to its evolution in volcanic habitats and an ability to penetrate volcanic ash.

The greatest restriction in above ground growth has been recorded in areas of exposure e.g. Goonzion Downs GR SX 175 677, contrasting with the greatest amount within river valleys.

Above ground mass

Fig. 3.40 Crown material Lansallon, St Austell, GR SX 0088 5454

The height of the crown of the plant, defined as agglomeration of material at ground level and above from which shoots emanate, can exceed 1 metre in established plantations e.g. Lansallon, St Austell (Fig. 3.40).

3.4 Discussion

Growth rate of above ground shoots

The rate of maximum extension occurs in the earlier stages of growth before full leaf expansion and is therefore principally driven by utilisation of nutrient reserves in the rhizome system rather than by photosynthetic action. The timing of maximum extension varied between the first week in April and mid May. The data, being gathered over a period of four years, and collated with temperature and rainfall data from a meteorological station less than 12.5 kilometres away, show a reasonably consistent pattern in relation to timing and size of growth at time of greatest increase in size. One particular item of note is the high variability in growth rate in 2008 possibly linked to high rainfall followed by periods of relatively high temperature. There was no clear differentiation between day and night time extension. There are adequate data to indicate likelihood of the maximum growth rate recorded not being an exceptional occurrence. Previous studies had not identified times of greatest growth, maximum growth rate and influence of climate. This work demonstrates that, in Cornwall, the time of maximum rate of growth is generally late March/early April and that growth rate is influenced primarily by temperature where moisture is not limiting. This suggests that Spring is not a good time for effective translocation of glyphosate to and within the rhizome as shoots are actively growing in this period.

Regeneration from leaf material

The nature of the leaf material has few elements in common with those species which are known to be capable of regrowth by this means e.g. begonia. It would seem possible that the leaf regeneration apparently observed may have had some basal bud material and that extension emanated from this source, perhaps drawing resources from the leaf. There do not appear to be records of leaf propagation of closely related members of the Polygonaceae family. The knowledge from earlier work that stem material has an ability to produce root material, the demonstrably small size of the stem in relation to the leaf and the fact that material with a small amount of stem material rooted suggest that some bud or stem material was present in the situation observed. It therefore seems that the leaf and petiole, without any bud material, is not capable of regeneration unlike the suggestion of Brabec.

Stem counts per square metre

The number of stems counted within the site was quite variable. The densest stands of canes were those closest to the stream. It could be considered that the stem count would be greatest in these areas due to the likely disturbance due to the presence of the stream and due to the greater potential for solar interception over the surface of the watercourse without adjacent terrestrial competition. The sample was very limited in size and scope but observations on other sites suggest it provides a reasonable guide to the expectable parameters. It is more desirable to record a larger survey area, an example being 2m by 2m being suggested for large standing material such as *Phragmites* due to the size of material (National Vegetation classification). Field observations on undisturbed sites have indicated that a dense foliage cover can be recorded with comparatively low stem count (Fig. 3.19) when averaged over the area occupied. In the case shown in Fig 3.19 an area of 5 m^2 of visually dense colonisation was considered. It is suggested that this size of quadrat is likely to provide a more holistic and realistic representation.

At the higher counts per square metre, the rate of application of glyphosate, the most commonly used herbicide introduced by stem injection, compared to permitted rates applied by foliar application could be considerable. Legally, the technique of stem injection follows the protocol for stump treatment, for which no maximum permitted rate of application is provided.

Assessment of impact on *Fallopia japonica* of stimulation by cutting

It appears that cutting of above ground growth in this relatively late stage in development does not result in underground extension of rhizome, but of the production of additional above ground shoots. This stimulation of above ground regrowth would appear to have the effect of reduction of underground reserves. It would be useful to replicate the work earlier in the growing season to see whether this results in the underground extension suggested.

Size of rhizome capable of regeneration

The work demonstrates that, in unheated conditions, rhizome of a much smaller size than has previously been noted is capable of regeneration. In these conditions, with a relatively low level of management, between 25% and 70% of the material was noted to have regenerated (average 41%). A further factor worthy of note is the length of time for which rhizome, with no additional nutrient, continued to maintain roots and leaves.

Assessment of sustained temperature regime required to render material unviable.

In view of work that has previously been carried out, (Ward, 2003) a key factor in removing viability would appear to be regulation of the length of trial material as well as consistency in relation to maintenance of the target temperature. The minimum temperature regime required to remove viability appears to be 14 days at 40C. It would appear that Japanese knotweed rhizome, put through an enclosed composting system of the type used for food waste, would have a considerable margin of safety in relation to the normal temperatures and duration required for this process and such equipment as, when used for Japanese knotweed alone it would not require the maintenance of a temperature regime as high as that required for its primary purpose.

Survival of rhizome under saline conditions

The work carried forward observations by Hayward confirming that Japanese knotweed rhizome can survive for periods of several months in saline conditions. There is therefore the potential for such parts of the plant to be carried downstream and out to sea and to re-establish if washed up further down the coast.

Viability testing.

The researchers cited, Steponkus and Lanphear, had carried out tests using aerial shoots of *Hedera*, whereas many other users of this methodology were using it for seed viability assay e.g. Pasha et al. (1982) and Norton (1985). In the cases of both aerial shoots and seeds, for which the majority of viability assessment techniques have been deployed, the level of contamination from microbial or other sources is likely to be lower than that found when dealing with material which has had contact with soil.

Despite careful preparation, which in the later stages as the techniques were refined, followed procedures employed for micropropagation, statistically differences between live and treated material were not demonstrated. A further factor which may have had influence is the presence of yellow dye within the rhizome.

Assessment of underground mass

The nature of the soil and the relatively dry conditions at the time of the excavations were of great assistance in separation of materials and gave a high level of confidence in the efficiency of the procedure.

When the data previously gathered in relation to *Fallopia* x *bohemica* are taken into account and allied with these data, it would appear that the minimum rhizome quantity likely to be present in a cubic metre of soil beneath an established colony of *Fallopia* is likely to be in the order of 26kg.

Determination of the period at which rhizome extension occurs

Although the sample size was small and growth was severely limited by the size of the container and the low nutrient content of the material, the growth pattern in relation to periodicy was comparable with that observed in nearby open ground growing plants and the restricted dimensions of the container were necessary to observe the underground material without physical disturbance. The timing of rhizome growth in such undisturbed circumstances would therefore appear to provide an accurate indication of this facet of growth. Rhizome extension appears to occur during the time of maximum translocation. This is suggestive that the autumn application of a herbicide with the mode of action of glyphosate is likely to be the most effective period.

Observations in relation to the progressive necrosis of rhizome

Although physical connectivity may remain within the rhizome by connection of necrotic tissue, the experiment demonstrates that the plant is capable of regeneration from biologically separated areas. An assessment by a methodology dependent on connectivity to determine the extent of viable material may therefore not provide a reliable indicator of this facet.

Orientation of rhizome extension

The anticipated result of shoot growth on the warmer side did not occur. This may be due to some shading effect by the container.

Determination of moisture content of rhizome

The anticipated differences between younger and more mature rhizome were not conclusively demonstrated. The high November figure may be related to the drawing down of resources at the end of the growing season. This could mean that growth is due to active cell division in early spring followed by stem extension in summer.

Regenerative ability of a range of material and provision of standardised material for future use.

In excess of 10% of the undifferentiated material produced shoots. This seems high as the material was quite carefully inspected before being put into pots.

A number of the plants produced flower initials despite the small size of the initial material and the limited size of the plants in relation to fully grown plants of the species. There may have been some stimulation of this effect by root constriction within the pots. A further point is that the plants produced green leaves from the outset and that these leaves expanded in the early stages of growth. This is in contrast to observations on established plantations where the lack of photosynthetic action is evidenced by the red shoots and delays in leaf expansion, further evidence of the established plant drawing on below ground reserves during early season growth.

Clear evidence of colonisation of the substrate was noted. (Fig.3.41). This demonstrates the ability of the plant to penetrate materials which may be used as barriers.

Fig. 3.41 Detail of underside of barrier material showing root and detail of constraint

Observations in relation to physiology

i) Identification of the last points of viability in adverse conditions

The way in which rhizome reacts in drying conditions was considered, as any methodology reliant on assessment by means of physical connectivity may provide unreliable data if the plant dies back in intermodal areas, leaving isolated viable bud material.

It was apparent that the last points of viability rested with the bud material and that the tissue between them, while providing physical connectivity, had ceased to act as a connection for the transmission of nutrients. This is significant if an assessment of viability of the plant is attempted by the use of electrical apparatus. The lack of connectivity will also prevent translocation of herbicide.

ii) Rhizome dormancy

It would appear that the plant may be able to remain in viable condition without producing above ground growth for periods as yet undetermined, but extending for several growing seasons. Assessment of effectiveness of treatment is frequently predicated on visual observation of apparent viability of above ground stems. This is likely to provide only a limited assessment of viability in the short term in view of the foregoing remarks in relation to underground material. Some of these sites have been treated with glyphosate in the latter part of the growing season, and the epinastic growth noted elsewhere has not been noted, suggesting again that the pattern of distribution of the herbicide within the plant is seasonal, and has different effect at different times of year. This has implications for the requirement of a continuing monitoring programme after the last above ground material has been observed.

iii) Rhizome survival in water

Rhizome has been noted below water in a number of situations. The observations of capacity of detached pieces of rhizome to survive for several months can mean that even in slow moving waters the material can be transported for considerable distances.

iv) Rhizome in low nutrient conditions

Evidence of toleration of very low nutrient levels has been observed in a number of circumstances. Plant material surviving in such conditions is likely to be small, but this may result in the potential for further transfer of the plant as its lack of size may result in it not being observed.

v) Observations in relation to hybridisation

Production of apparently viable seed was observed by the author on a plant of *Fallopia japonica* at Sennen GR SW 351 262 (Fig. 3.21).The plant was in close proximity (less than 3 metres) from a specimen of *Fallopia baldschuanica*.
Three seedlings have been noted in an area where specimens of *Fallopia jap*. *F*. *sachalinensis* and *F*. x *bohemica* have been grown in close proximity. There is therefore the potential for spread to be generated by this means when the species are within pollination distance. The observation of establishment in fine stone dust of low nutritional value and with few competing species is further evidence of the plant's potential in low nutrient conditions.

vii) Depth of rhizome

Viable material has been observed at a depth of 1.7 metres. There would appear to be some association with soil type in that the material had penetrated to but not into a clay substrate.

viii) Rhizome reaction to disturbance

A number of instances have been recorded where disturbance of the rhizome system has resulted in stimulation of growth of rhizome. This confirmation of the reaction of regrowth to disturbance may be highly relevant to control techniques in that separation of a clump by a root barrier along the line to separate the ownerships could be considered as causing the plant to spread, an offence under the terms of the Wildlife and Countryside Act 1981. This appears to be a further indication following previous information (Kaye and Semmens, pers. coms) that rhizome may remain in viable but dormant state for several years.

3.5 Conclusions

The work has clarified the speed with which the plant grows and has indicated that, at the season when the cutting of above ground material was carried out, the plant does not react by the extension of growth underground. Underground disturbance, on the other hand, has been observed to result in extension of the rhizome system. The number of stems in a given area was not recorded as being as great as had been considered likely when bearing in mind the density of the foliage canopy. No regeneration from leaf material was demonstrated, in line with physiological expectations. The size of rhizome capable of regenerating has been shown to be of far smaller size than previously observed. The quantity of underground material which can be anticipated to be discovered was clarified as was the ability of detached rhizome to survive in fresh or saline conditions for periods of several months. The periodicy and direction of rhizome extension and the moisture content of the material were investigated. The methods investigated for the definitive assessment of viability did not produce conclusive results, but the observed way in which rhizome may retain physical viability at nodes with physical but not physiological connectivity may mean that it may be difficult to design a representative sampling methodology. A cautionary note was struck by the discovery of seedlings establishing in a quarried medium. These aspects have direct connection to methods of control which are investigated in the next chapter.

Chapter 4
Methods of Control

4.1 Introduction

The methods used to control plants growing in outdoor conditions can be classed in the categories of physical, chemical, ecological or biological control or a combination of these. Physical control of plants considered to be weeds may be carried out by cutting above ground growth or by the removal of such growth at ground level by methods such as hoeing. Interference below ground level by ploughing or rotovation may be deployed. These techniques are generally most suited to annual plants or, in the case of below ground disturbance, to those species which do not have an underground system likely to regenerate following such interference. Complete removal of the entire target species by means of excavation by digging, forking or otherwise removing all parts considered capable of regeneration may be deployed, particularly in the case of perennial species. This type of advice is well recognised in horticultural circles (Royal Horticultural Society website, 2011). It is likely that physical control may be appropriate for a wide range of plant species, as the continuation of methods which separate any organism from its source of nutrition for a sufficient period of time will result in its demise. The time for which the process needs to be continued can vary considerably depending on the type of plant.

Other physical control techniques for plants considered to be weeds include heat treatment, use of grazing animals and exclusion of light. Heat can be used either in situ (Ascard 1998) or as a post extraction treatment methodology, to remove viability of plant material. It is possible that microwave soil treatments might also be effective (Goodman 2007). Crushing or rolling is an established technique for bracken control, particularly on sensitive sites where herbicide would be inappropriate (Lowday and Marrs 1992). Grazing animals may be used as a control method (Newton et al. 2009). Environmental control may use techniques such as the exclusion of light and thus the prevention of photosynthetic action (Gaisler et al. 2004). This may take the form of the provision of a mulch or by the use of a membrane to cover the area in which growth is anticipated or present using a covering membrane such as black polythene. Mulching is generally a preventative methodology, reliant on a preceding physical methodology to remove any growth. It is generally useable only when the targets for control are yet to appear, are relatively small and/or have a relatively small amount of underground reserves. The use of this methodology is usually confined to annual and short lived perennial species. It is also limited in that it is physically more difficult to exclude light from plants of larger stature.

Physical control of Japanese knotweed has been attempted over many years. The aspects of growth of *Fallopia japonica* described by earlier work (Brock 1992) (Bimova et al. 2001,2004) (Sasik 2006) and further developed by other work in this study, indicate concerns regarding a range of the general physical control methods for plants detailed previously. Physical removal of the above ground parts of the Japanese knotweed plant by means of cutting has not proved adequate (Seiger 1993). The use of mowing or grazing, has been seen to result in a reduction of vigour, but, even when such techniques have been carried through for considerable periods, they have not been demonstrated to result in control of the plant after it has established. Regression analysis has been used to show that a minimum of four cuts a year would be required to deplete rhizome reserves (Seiger and Merchant 1997) but this paper comes to the conclusion that, though cutting may be a useful adjunct to other methods of control, it is unlikely to eradicate the plant as a single technique. Work on the potential of regeneration of above ground stems has indicated that such material is capable of regeneration when left in conditions of sufficient moisture (De Waal 2001). This has been shown to be possible even when the conditions relate to those found in composting conditions (Morris 1999). This has also clarified that bud material of a type likely to be projected by a physical fragmentation method such as strimming, has the potential to regenerate at the points to which it is projected, should moisture levels be suitable. Although cutting has been demonstrated to gain some control, there are issues in relation to the disposal of cut material. Cut material has been demonstrated to have the potential to regenerate (Brock et al. 1995). If material is mown or strimmed there is the concern that material will be projected by the action into areas where it may have the potential to grow. This may be particularly relevant if material is projected into watercourses where it’s potential for further spread will be even wider.

The ability of small parts of less than one gram of the underground system of the plant to regenerate and produce new plants has been demonstrated. (Francis et al. 2008). Increased vigour has been recorded when underground parts of the plant have been disturbed (Child et al. 1998). Pulling of mature stems and rhizomes has been stated to eliminate *Fallopia japonica* in three years (Baker 1988). The removal of shoots early in the growing season could have some value as a control technique as removal of growth at this time must have the effect of some diminution of nutrient reserves. A correspondent has provided data of this technique which indicate substantial diminution, but not elimination, of regrowth (Meneer, R. 2004 pers.com.).

Grazing studies do not appear to have differentiated between different grazing methods of different stock. There would appear to be the potential for further spread of the plant in certain grazing practices. Cutting and grazing may result in reduction of vigour and reduce the below ground biomass, but these are methods of control rather than eradication.

Complete eradication may need to be assessed over a prolonged period of time as this work has shown that material can lie dormant over several years (Chapter 3).

Crushing of the above ground parts of the plant where it is growing is a methodology which has been reported in Cornwall:-

I have trampled knotweed at 3 / 4 times in the summer, one at beginning, and the rest when the stuff has grown to chest height. This year the growth is much reduced in these areas as apposed (sic) *to the control areas where it has been left to get on with it. I would say the knock back is approximately 60-70% and is a surprise I didn't really expect that level of knock back at all (I was hoping for around 30% as a figure) and am delighted. I can only guess that as with other plants crushing releases "don't grow" compounds (straw and grass being good examples of this) has any work been done on* ***crushing*** *– not chopping or rotovating – just either rolling a site or trampling a site? If not it would be worth a try, my experiment suggests it could be an alternative… I will keep you posted.* 11.05.2010

Stem diameters at crushing point would be 2-3 cm, quantity of plant per metre would be (approx) ~10, and area covered would be an area of 12m by 22m again approx. heights would be at crush around 1.5m (on reflection)

I can resupply data on next crush down of new area being tackled. I was very surprised though crush effect reduced plant coverage as shown. 12.05.2010

Andrew Caddy

Crushing and shredding of rhizome removed from the ground has been trialled (Rennocks 2006). The rhizome was rolled to fracture the outer cortex. This technique did appear to kill a number of samples, but the tests require further duplication.

Physical removal of the entire plant, and the surrounding soil which is considered to have the potential to be contaminated, to landfill, has been, and continues to be, a commonly used methodology. Separation of parts of the plant from the accompanying soil after excavation is also attempted (Environment Agency, The Knotweed Code of Practice 2008). Physical removal is dependent on ensuring that all the detached material is dealt with in an appropriate manner. All parts of the plant are considered as controlled waste under the Environmental Protection Act 1990.

Reduction in underground biomass has been demonstrated by the continuing use of cutting techniques (Seiger and Merchant 1997) but it has not been determined how long such treatment needs to be continued in specific circumstances to achieve eradication.

When carrying out excavation procedures, the amount of material which may require to be excavated to ensure adequate removal can result in the requirement for removal of a large quantity of material in proportion to the contaminating plant matter. Prior to this research no work had been carried out to attempt to establish clear criteria as to the minimum size capable of regeneration. In Chapter 3 it was demonstrated that material of 0.06g or less was capable of regeneration. This is an important factor to take into account in relation to any separation methodology.

Some work has been carried out on rhizome extension modelling (Smith, 2006) but there appears to have been little work to indicate the depth and extent of the underground network. One of the main factors for this is that different rooting media and treatment patterns appear to have different effects on rhizome extension. Observations have been made which appear to indicate the likelihood of rhizome following lines of lower resistance e.g. following granular fill in pipelines etc. Material has also been found to penetrate between layers in rock.

Containment of underground growth to prevent root spread can be carried out in some circumstances, often by the use of membranes resistant to root penetration, set vertically in the soil. Such membranes are frequently used in tree planting schemes, in the urban environment, in order to prevent underground parts of the plant becoming entangled with cabling and other services. The technique may also be used to prevent root penetration across property boundaries (Pittenger and Hodel 1999).

Herbicides are well established and commonly deployed for control of plant species considered to be undesirable. The range of action of individual substances can vary widely. There are substances which are selective between monocotyledons and dicotyledons. Some substances may affect only the material with which they come into contact while others are translocated within the plant (Hassall 1982) (Robertson and Kirkwood 1970). The timing of application is often critical. As an example some materials may be effective during the active stages of growth and others as the target species approaches senescence and is returning resources back to an underground storage system, such as rhizomes (Sosbee et al. 1991).

The methods by which chemicals can be applied to plant growth vary. Herbicides are often supplied as concentrates which are diluted with water for application at the specified rate in relation to the target. They may also be applied to cut surfaces or directly injected into stems (Matthews 2008).

Work has been carried out which indicates that *Fallopia japonica* does not translocate quantities of material back to its underground rhizome system until late in the growing season. (Buschmann 1997, Price et al., 2002) This factor is likely to be very relevant in relation to the appropriate timing of use of some of the more commonly used translocated herbicides, e.g. glyphosate (Beerling 1990b). Concern has been expressed regarding cultural and herbicidal control of the plant not being effective and resulting in further spread (Palmer 1990).

Overall herbicide treatment can result in destabilisation of banks of watercourses as non-selective herbicides, which are approved for use in such situations, particularly as the size of the plant can result in off target vegetation damage (Green 2003). More selective herbicide deployment has been explored using the cut and fill technique (Joy 2002) (Ford 2004). Frequently this requires follow up with detailed foliar application as the regenerated stem size may be too small for a repeat of the filling methodology. Leaf wiping with herbicide may be an alternative follow up methodology.

Stem injection systems have been developed where concentrated glyphosate herbicide is injected directly into each individual stem of the plant no more than three nodes above the base (Soll 2003) (Hagen and Dunwiddie 2008). This is based on the stated point that each individual cane produces its own rhizome system (Crockett 2005).

A particular aspect in relation to the efficacy of foliar herbicide application is the relationship of the quantity of plant material above ground in relation to that below the surface. The rate of application of a herbicide is legally defined. When application is being made, particularly to foliage, the point at which maximum application is reached – just before the point at which the liquid reaches the point of run off – can mean that an insufficient quantity of the active ingredient of the herbicide is delivered to remove viability of below ground material in a single application. This is particularly relevant in the case of the *Fallopia*. spp. being considered. Recommendations on the use of glyphosate often state a period of use from May onwards e.g. Environment Agency Code of Practice – though this document does state that later season treatment is preferable. The appearance and size of epinastic material produced after inappropriate herbicide use may mean that such material is overlooked during site assessment. Even if the material is observed, the relatively small leaf area in relation to the quantity of below ground material means that it is difficult to apply an appropriate quantity of herbicide to control the plant due to the extremely limited leaf area in proportion to underground mass. The Environment Agency Code of Practice also advocates the use of picloram at any season of the year, with soil treatment in the winter. Overall application of herbicide may have significant off target effects in relation to a species of the stature of Japanese knotweed. Near water this can result in the loss of bankside cover and therefore result in bank destabilisation. The use of individual stem treatment methodologies is very time consuming. The size of individual stems, particularly at the perimeter of infestations, is often such that such strategies are not achievable overall due to the requirement for adequate capacity in the hollow stems of the smaller canes for receipt of the herbicide. Stem density may be sufficiently high at particular points that the permissible rate of application of herbicide on an area basis may be exceeded.

Ecological control may be a possible option. This utilises the innate competitive nature of one species to the disadvantage of another. An example of this is where vigorous plants are established to physically reduce the potential colonisation area or to reduce light levels for species which are not shade tolerant (Groves 1989). It has been suggested that the introduced greater bindweed *Calystegia sepium* var. *silvaticum* may suppress Japanese knotweed and that the plant's extension is slowed down dramatically once a thick grass cover has established (Gilbert 1989). Work has also been carried out to see whether fast growing rhizomatous grasses can limit the growth of the plant (Wilkins,C. and Mulholland, B. 2003). This form of control has been demonstrated by the authors to limit growth, but the plant will continue to grow, although with reduced vigour.

A variation on ecological control is to release a specific pest species of a plant in order to effect biological control. Enemy release hypothesis (ERH) is the basis of the theory of classic biological control in that the success of invaders in new habitats is due in part to their release from co evolved natural enemies of their natural habitat. When organisms have been introduced to an area in which they are not endemic, biological control may be used by deployment of a predator species known to target the object of control in its native area. The usual methodology is to investigate species which predate the target in the area of origin, and ensure that the species chosen is an exclusive feeder on the target species and is not likely to affect other species in the area of introduction. This control may be termed classical, in which an organism is introduced which reduces the vigour of the target species and which remains as a more or less permanent feature within the environment into which it has been introduced, or inundative in which an organism is introduced which destroys the target organism and, by doing so, causes its own demise (Cruttwell McFadyen 1998). Biological control of Japanese knotweed is presently at the early stages of trial, with the psyllid, *Aphalara itadori*. This sap feeding insect has been the subject of extensive testing and has demonstrated capability of significant reduction in the vigour of *Fallopia japonica* (Djeddour and Shaw 2010)

As biological control is still in its early stages, it is likely to be several years before the effect of the introduced psyllid can be reliably assessed. The plant has been separated from this predator for approximately 150 years and it is not yet known whether endophytic factors within the plant to limit damage by this predator will have reduced to enable more complete control of the plant than in its native environment. Many psyllids have a comparatively weak flight pattern, so distribution may be an issue and individual clumps may escape infestation and therefore control. There are, and will remain many situations, such as in the construction industry, where rapid removal of the plant in its entirety is necessary. It is therefore highly likely that alternative control methodologies will be required for removal for the foreseeable future and that integrated management will be required in the longer term to supplement the psyllid in the aim of eradication.

A combination of techniques has been used for control. Excavation followed by herbicide application to renewed shoot growth has been used (Child et al.,1998). Cutting and herbicide treatment and disturbance and herbicide application has also been studied (Bimova et al., 2001). Other approaches to the improved control of the plant consider the limitations to the presently used herbicide regimes (Bashtanova et al. 2009). A regime of disturbance and herbicide lead to a 95% reduction of visible knotweed above ground after a 12 month period (Child 1998). It was not possible for this study to be continued in the longer term and therefore no investigation was carried out in relation to the possible longer term continuing presence of viable rhizome. This study was carried out on the banks of the River Thames in London where the water table was believed to be very high. Observations have suggested that rhizome is not likely to be found in areas of constant saturation and this would appear to be likely to have a limiting effect on the depth of rhizome in this case.

A consideration of the efficacy of the current techniques used for the control of the plant revealed the lack of robust data and the reliance on anecdotal evidence and literature sources lacking the vigour of peer review (Kabat et al. 2006). This work was reliant on cooperation by all those circulated and the level of responses received in the request for information may raise questions in relation to some of the conclusions reached. In relation to all the methods detailed above, assessment of the success of control is often predicated on the presence or absence of above ground parts. The time span over which such assessment had been carried out in previous work is often limited. Much of the assessment appears to have only been carried out for a period of one or two years. The quantity of material present underground compared to the above ground material is suggestive that this may not be an appropriate methodology to assess the success or otherwise of a control methodology. A further factor is that the period for which viability may remain in underground storage organs in varied areas does not appear to have been assessed in earlier work. A wide variation in relation to stage of establishment has been noted between sites, which is suggestive that a range of control methodologies may be appropriate.

The wide variety of sites and situations in which the plant can grow and the variation in its growth patterns, as well as its robust physiology and response to control attempts, means that a number of methods for control needed to be considered in order to provide solutions to the control of the plant.

4.2 Materials and methods

Advantage was taken of the time scale available to assess regeneration over periods of several years. This was expected to give a greater ability to assess whether control had been successful. The continuing site treatment areas within Cornwall Council responsibility exceeded 1500 at the initiation of the work. These were largely in an ongoing treatment methodology which was reviewed and amended progressively. New sites were taken on during the period of the study and a variety of herbicide methods were deployed. The sites were largely within the road margins, but still provided a wide variety of situations ranging from relatively undisturbed and isolated sites through to areas of regular disturbance. In view of the wide range of requirements regarding time scale, state of establishment of material and danger of wider spread, a number of methodologies for control have been used. Within Cornwall Knotweed Forum, the initial assessment of a site is carried out by considering the risk of spread from it and the timescale available at the specific location to deal with the plant. During the study an assessment was made in relation to what had been done prior to and during the work and changes were implemented in the light of results and of research. Details of these and of the required feedback during the process are included in (Appendices 11 and13) A number of the sites had been subject to various techniques which limited the options of control e.g. low quantity of foliage due to sub lethal herbicide effect limiting the use of foliar acting herbicides.

4.2.1 Physical Control

a) Physical removal

Physical removal of Japanese knotweed, in early stages of establishment, spread by remediation of trenching works A30 trunk road Hayle to Bodmin

It has been postulated that physical removal of the plant may be possible in certain circumstances (Environment Agency Code of Practice, 2009). This is usually founded on gross removal of plant and soil material rather than specific targeting of plant parts. Such gross material removal is extremely costly in supervision, excavation, transport and disposal. The risk of missing or spreading plant material is also great. Work was carried out in 2002 to physically remove Japanese knotweed which had been spread along the A30 by cabling operations in 1999/2000. Topsoil contaminated with Japanese knotweed rhizome had been brought in from a distant site in St Buryan parish and was spread to provide a finishing layer, in some cases less than 50mm deep. Material was noted sporadically over this length, a distance of about 60 km. Some remedial operations had been carried out immediately after the works, but further material was discovered subsequently. The plant material involved was typically dwarf with yellowish foliage and founded on compacted material into which, when excavated, little rhizome penetration was observed.

Fig. 4.1 Small regenerating rhizome A 30 Mitchell GR SW 8497 5423

The specified method was to fork gently round on four sides of each plant at least 100mm away from the above ground material before lifting, one of the main criteria being to ensure that both ends of individual rhizome were sealed and that no orange central rhizome was visible – the latter indicating breakage and the possibility of viable material remaining in the ground. Individual sites were marked by wooden pegs in order to identify them for future monitoring.

Removal by excavation, Church Cove, Lizard GR SW 7144 1274

The objective in this situation was the removal of underground material associated with an apparent single stem of Japanese knotweed in the line of a proposed outfall. It has been suggested that the amount of above ground material may be indicative of what is below ground. However this may not always be the case. A request was received from contractors working for South West Water on a sewerage scheme, to investigate an infestation of Japanese knotweed on the line of their works. The author had previously been called in when Japanese knotweed has been encountered on the A3083 and elsewhere during the course of these works. The site was at Church Cove, adjacent to a public right of way. The site was visited on 23rd December 2004. A considerable infestation of Japanese knotweed was noted along the stream to the west, but this was not affected by the works. The specific problem consisted of a single stem approximately 1.5cm in diameter at the base. It was contained in an apparently excavated area of the cliff – there was certainly visible rock on three sides of the plant and the fourth was open to a car parking area. There was evidence of dumping of vegetative material in the immediate area and the plant appeared to be growing on a mound of such material which may have been deposited over a period of some years. To the western side there was a wall @ 60cm high which bounded the area. The single stem of the plant and its situation and size suggested that it probably originated from the infestation to the west and was not long established. Although there was evidence of dumped *Buddleia* and *Crocosmia* in the adjacent area, the soil in the immediate area surrounding the stem did not appear to have been recently disturbed. The line of excavation passed directly through the area and could not be modified.

The area between the works and the conveying vehicle were covered down with a geotextile barrier. The stone on the site was of a type, serpentine, which has not been noticed to be subject to infiltration, unlike slates. This was therefore removed by hand to a minimum distance of 2 metres from the Japanese knotweed, clear from the area of operations. Hand tools were used to remove all vegetation, except Japanese knotweed, to a height of 75mm above ground level and this was disposed of appropriately. The clump was excavated by machine and loaded directly into a road vehicle for transport to a licensed disposal site (Connon Bridge, Liskeard). The site was checked by hand for any remaining rhizome, starting at the bottom of the excavation and working with hand tools up the slopes of the excavated area. The stone face at the back of the excavation was checked for any fissures in the background cliff face for rhizome and this was removed and loaded for disposal. Once this process was completed, and all material from the excavation loaded onto the transport vehicle, the protective membrane was folded in from the sides, rolled up and placed in the transport vehicle. The site was then inspected to ensure all disturbed material had been placed on the vehicle, which was then securely sheeted down before leaving the site.

Physical removal of material after less than 6 months on site: South Petherwin GR SX 2983 8197 to SX 3067 8179

Soil, unknowingly contaminated with Japanese knotweed rhizome, was taken to this site for verge restoration operations. The deposition depth of the material did not exceed 150mm. It was subsequently discovered to have been contaminated with Japanese knotweed rhizome. 34 occurrences were noted between the two references, approximately three months after material had been brought to site. The material was physically removed by hand by forking carefully around individual shoots. Shoots varied up to approximately 500mm in height.

Excavation and on site desiccation of material at Jillpool, Bosinney GR SX 0664 8872

This area was generally neglected with redundant signage, rubbish and an infestation of Japanese Knotweed. Opportunity was taken of a road closure and the presence of a JCB on site, for drainage work, to implement the clearance. The intention was to clear the infestation of *Fallopia japonica* within a 12 month period. The layby at the southern end was to be formalised and the area to be reprofiled to slope steadily back from the road so that the whole area was completely visible in order to deter dumping. Siding material (topsoil) was to be brought in to improve the fertility of the area prior to the intended planting. This area at the entrance to the village was previously marshland, but had been used as a chipping holding area for highway purposes for a number of years. It was roughly triangular in shape, 50metres on the north to south faces and 25 metres on that from east to west, bounded by a road, a stream and agricultural land.

Fig. 4.2 Jillpool GR SX 0663 8872 Site before commencement of works

The area was perhaps 600mm above the surrounding area, the raising being attributable to residue of chippings and siding material - plus rock, concrete and other materials. Domestic and other rubbish had been dumped from the informal lay – by at the southern end. The soil ranged from a heavy clay through to almost pure chippings, The area had been heavily compacted, but did not show signs of panning, the elevation and the high proportion of chippings perhaps contributing to good drainage on the site. The site was generally level, with a rise of perhaps 800 mm on the northern side where chippings had been piled below some *Salix* spp. and were therefore less accessible. The pH varied within the site, probably due to various importations of material, but was in the acid range in all areas excavated. The northern and eastern sides of the site had heavy infestations of *Fallopia japonica*, the visible extent from 3 metres to 5 metres from the edges of the site. The neighbouring landowner, Mr Dickens, who had knowledge of the area for in excess of 60 years, stated that he could not remember a time when there had not been Japanese Knotweed along the eastern side of the plot, but that the infestation on the northern side was more recent. He considered that movement of materials inside the area could well have led to this spread (Dickens, pers. com. 14.02.2001). The cane material was typically 1 to 2 cm in diameter at a height of 30cm above ground level. On the eastern side there was some evidence of epinastic growth where the material had been sprayed with glyphosate. This dwarfing effect was only visible in a small proportion of the canes (an estimated 10 to 15 %) and no reliable data were available with regard to herbicide treatments which may have been carried out. It would seem likely, as the methodology had previously been current, that treatment with glyphosate had been applied in the early to middle part of the growing season, a phenomenon that had been noted elsewhere to result in such growth. At the north western edge of the site the infestation of *Fallopia* had colonised the Cornish hedge towards the adjacent farmland. The northern area consisted of almost pure stone chippings. The total area of *Fallopia* on the site was difficult to estimate due to the scattered nature of the material. The surrounding vegetation consisted of *Salix cinerea*, *Prunus spinosa* and *Crataegus monogyna* on the Cornish hedge with quantities of *Rubus* spp.and *Hedera helix*. *Acer pseudoplatanus* and *Fraxinus excelsior* were also found in nearby hedges. There were also small quantities of *Rumex* spp, *Urtica dioica*. There was a considerable quantity of *Petasites fragrans* and a small proportion of grass species.

The areas of *Fallopia* were marked out on the ground to ensure proper identification. Excavation was carried out using a wheeled excavator, a JCB, working in towards the plants from a distance of 3 metres from the visible cane and at a depth of 1.5 metres. The direction of excavation was reversed when rhizome was encountered to ensure that it would not be fragmented and drawn outwards. The depth of excavation was also monitored continually for adequacy. Each bucketful of material was rotated in an arc, around a trajectory which could be monitored, and any material which fell from it inspected. At the sorting point, visible rhizome was removed by hand and placed in an adjacent collection vessel. The bucket was then shaken and more material removed as it became visible. The process was then repeated, the cone shaped mound of soil formed, being denser than the rhizome, the latter tended, if missed in the first part or the operation, to be left on the outer surface. Precautions were taken to ensure that material was not replaced in the excavation at greater depth than it had been at at the commencement of operations, by segregation. The process continued through and around the periphery until visual inspection of the vertical faces showed no sign of visible rhizome. The rhizome was transported to a position at the back of the site and piled on the surface to desiccate. Access to this position was restricted by woody material, cut from other parts of the site. In this position it was considered to be unlikely to be disturbed.

Regrowth of the Japanese Knotweed was monitored by shoot count over the area excavated, herbicide (glyphosate) treatment being deployed when necessary when above ground material was observed.

Timetable:

12th February 2001 09.30 to 16.30 JCB on site and used for approximately 3 hours. Rubbish and other uninfected material had already been heaped ready for removal. Approximately three hours were spent working with the digger. Top growth of material was cut down using a long handled slasher to a height of approximately 150mm. This material was put to one side out of the operational area, but within the site. Care was taken during this process not to dislodge any viable crown material. This preparation was considered necessary in order to make subsequent sifting operations easier.

Work started by clearing from the north-western corner, scraping inwards using a 900mm bucket on the digging arm, from the boundaries of the site. The arm was then swung to an accumulation point, with precautions to ensure that no material was lost in transit. At this point the bucket was shaken by the operator under the direction of the person removing the material. Rhizome material was removed by hand to an adjacent deposit area. The nature of the medium produced a generally cone shaped heap whose nature allowed the differentiation of any of the rhizome material which was missed in the first sorting. The process continued around the area in a clockwise direction and all rhizome was deposited on an area of clean chippings at the north western corner. The weather during the operation was wet with almost continuous rain. The scraping was intended to be to a depth and over a sufficient area to remove all rhizome.

14th February 2001 08.20 to 12.45 work was continued according to the above methodology. On this occasion the weather, after a frosty start, was sunny and dry. Rhizome material was deposited on the adjacent road. Once all material had been worked in the method described above, the worked area was again reworked. This secondary working produced a comparatively small amount of material – in the order of 5 to 10 kg. The site was then re-levelled to approximate to the previous profiles. Approximately 20 canes could not be reached on the northern side close to a stream in a substrate consisting principally of chippings and there was a similar situation on the north western corner where 6 to 8 canes were established in a hedge in mineral soil.

The rhizome material was deposited on a pure chippings base at the north western corner of the site, bounded by shrubs on two sides, but demonstrably clear of them. The third side was then blocked by the cut material previously mentioned – largely *Rubus* stems – to deter casual access. The site was visited and assessed for the following seven years, digging of re-arising material being undertaken at the first assessment period and glyphosate treatment being undertaken as required following this inspection.

b) Disturbance

Control using initial removal followed by disturbance.

In line with European Union requirements to reduce the use of pesticides, an expressed desire of a section of the population to avoid the use of herbicides and to provide a methodology that could be applicable in agricultural situations, work was carried out to clarify whether a programme of initial, intensive clearance and removal, followed by a disturbance and desiccation regime could control *Fallopia*.

An area of coastal land of approximately 1 hectare in Veryan parish GR (Centre of largest area) SW 953409 was subject to a major scrub fire in June/ early July 1959. The then landowner, Major Withers, planted *Fallopia* x *bohemica* to stabilise the site in late summer of the same year (Mrs Tisdale pers. com.).

Fig. 4.3 Worker on line of Coast Path at edge of *Fallopia* x *bohemica* area GR SW 9527 4094

The field which was originally planted is bordered on two sides by the Coast Path, a National Trail, and this route was particularly badly affected. There were a number of other outbreaks which were largely confined to access routes through the area, which are mostly public rights of way, though an infestation was noted on the stream running down to Great Perles beach. Apart from these areas, Veryan parish and the adjacent St Michael Caerhayes parish appeared to be virtually free of Japanese knotweed. As this was the case, and all the material noted on the site was the hybrid, *Fallopia* x *bohemica* there are good reasons to believe that all the material noted had spread from the original planting.

The pattern of spread recorded – largely along transport corridors – is a frequently noted distribution. A particular factor in this case is that much of the length recorded is rarely used by vehicles of any description, foot traffic being the major usage. Strimming of the material had been carried out for a number of years, and this would appear to be a likely cause of spread by the distribution of potentially viable material (Bailey et al. 1995). A number of casual references have been noted regarding children who grew up in areas heavily colonised by Japanese knotweed that they used to pull the canes and use them for mock fights, then discarding them (Sherriff pers. com.). It would seem conceivable that this could have been responsible for some of the spread, pulled canes frequently being noted by the author to have viable crown material attached when detached by pulling or when walking through an affected area. The density of the growth may equally have incited those using the route to pull up canes to aid access and to leave them at the end of the worse affected areas, thus increasing spread. A further factor is that the lane was noted to host considerable badger activity. Sett entrances were noted, on the stone and earth banks which border the lane, which cut through rhizome systems. The correlation of badger corridors with recorded spread suggests that some material may have been spread by transport along the corridors as well as physical spread by the sett digging.

Fig. 4.4 Evidence of rhizome disturbance at Veryan by badger excavations GR SW 9520 4103

The main body of knotweed was on a coastal slope of about 30 degrees. The infestation crossed a number of apparently ancient boundary features in the form of Cornish hedges. The area is classified as Heritage Coast and an Area of Outstanding Natural Beauty. None of the area is designated as an SSSI, though the cliffs immediately below have this designation for geological reasons. The soil on the site is a deep, light loam. The site is very prominent and the invasive nature of the plant required that the Coast Path required cutting several times during the growing season. The southerly aspect of the site means that growth was initiated early (shoot extension of up to 50mm was observed on 14th February) and extended well into the autumn.

In a corridor 1km long by 250m wide there were 14 identified sites, 10 by rights of way, 3 by watercourses and one on a hedge boundary. In view of the likelihood of spread from these locations it seemed expedient to treat the area as an entity. A letter was received from English Nature (now Natural England, the statutory nature conservation body, expressing concern regarding the presence of the plant and its treatment. Public monies were being spent on the regularly re-occurring costs of clearance of the coast path. The infestation above Great Perles was considered likely to spread the 150 metres or so down the stream to the sea. There is some evidence that the plant can colonise dune areas, having presumably been washed down a nearby stream and then washed back by the tide (Charter, 2001). The facts that the history of the site were known, that this was probably the largest site of *Fallopia* x *bohemica* in Cornwall, the presence of the South West Coast Path through the site and the designation of the area as an Area of Outstanding Natural Beauty seemed to justify action in combination with the landowners. The likelihood of spread down to the designated geological Site of Special Scientific Interest was a further factor, the plant already having progressed downhill towards this area. In view of the likelihood of spread of the underground material by disturbance, it was considered necessary to use a herbicide regime to prevent incursion into adjacent areas which were not physically suited to disturbance, or whose archaeological or landscape significance was antagonistic to such disturbance. Observation by the author on other sites had noted the danger of transfer of viable plant material on machinery, especially tracked excavators. In order to overcome this problem, the use of wheeled equipment was specified. A survey was made of available excavation tines, but none could be readily sourced which provided sufficient depth of raking effect. As a result special tines were designed and constructed to replace those on the bucket of the machine. The main attributes of these were the curved nature to accord with the bucket profile, the length, 600 mm from base to point and the broad arrow shape of the points, 150 mm across the base and 150 mm from base to point.

Fig. 4.5 Extended tines on excavation machinery

The treatments used were related to specific areas as described below:-

Main area

In the initial phase, stems were cleared by the process of sweeping around with the boom of the excavator, attempting not to disturb below ground material. They were left on site for up to a week to allow them to dry and then gathered for burning on site. Rhizomes were to be excavated during the period March to the end of May by the process of working inwards from the edges of the site and drawing the material up through the soil profile with the extended tines. The excavated rhizome was then removed to designated control areas for desiccation on site and the site further inspected and any apparent rhizome remaining. The rhizome was burned after a period of 7 to 10 days to allow for partial desiccation. The site was disturbed by tractor mounted spring tine harrow in areas showing regeneration. picking and setting rhizome aside for desiccation using the technique described above. The area was to be fenced to prevent disturbance by stock. The disturbance and picking was to be repeated 6 weeks later. Any further treatment method beyond this period was to be determined by level of regrowth, handpicking being the preferred method when little material was apparent. Monitoring was to be carried out for five years from the initiation of the work. Herbicide (glyphosate) was applied where required to the perimeters of the site to prevent material re-colonising the adjacent areas. Consultation was carried out with the Environment Agency regarding treatment programmes adjacent to watercourses i.e. within 1 metre of the bank of the watercourse. In all cases the need to ensure that all plant material stayed on site and that all machinery and equipment was thoroughly cleaned before leaving the treatment areas was emphasised.

Hedge banks

The Japanese knotweed plants were treated with glyphosate when they reached a height of 1.5 metres - provided that there was a good cover of expanded leaves. Retreatment with glyphosate was to be carried out in mid-September prior to die back.

Work was started in May 2001, by the use of glyphosate herbicide treatment along the line of the coast path and bridleway. This was to allow access for machinery and to provide clearance for these routes during the course of the work. Pedestrian brush cutters were deployed at the end of June to cut a swathe around the perimeter without the risk of disturbance that larger machinery could cause, working inwards towards the site to avoid spread of material outside the area. The tined digger, a 12 tonne rubber tyred swing shovel, started work on the site in early July with instructions to cut and disturb all material within the area. Approximately six hawthorn and ten blackthorn shrubs which were totally enclosed by the knotweed were removed during this process as they were of poor quality and would have compromised the work. The part dried cane and rhizome were burned on site. A 5 tonne tracked Kubota was required for this work on the steepest parts of the site. The majority of the large area was disturbed by the middle of July. Randomly selected areas were excavated for assessment of above and below ground mass. Inaccessible areas which were not cultivable were treated with picloram at the recommended rate. This was specifically used on the line of the Coast Path where shoots were reappearing following the early treatment with glyphosate. A further designated area was treated with picloram and then disturbed when the effects of the treatment were noticeable. The main area was spring tine harrowed in early August and was repeated three weeks later and again in mid-September. Rhizome material was hand-picked from the site in October and marginal areas were again treated at this time. After continuing the harrowing treatment on a basis of two occasions per year in the following four years, the practice was discontinued as overall disturbance was not required, the remaining Japanese knotweed plants being sparsely located within the area. Spot treatment with glyphosate was employed in its place.

c) Barrier methods

i) horizontal

Assessment was made of the potential for control of the plant by removal of a limited depth of soil, cover down with a geotextile and reinstatement of soil levels with material free of rhizome material. The chosen site was at Killivose, Camborne (GR SW 6428 3892). This verge site was noted in spring 1998 to be infested with Japanese knotweed. The site was subsequently recorded on the register of highway sites as number 367. The area was approximately 22 metres by 4 metres, facing south east and sloping down slightly towards the carriageway. It was backed by a Cornish hedge on the western side. The soil was removed by excavation machinery (JCB) by the highway contractor to a depth of 150mm over an area 1 metre beyond the affected area – judged by presence of above ground material – and taken to an appropriately licensed waste disposal facility. The lowered area was then covered with a 1200 gauge polythene sheet, a geotextile drainage layer and new topsoil to bring the level back to that of the surrounding ground. The area was then seeded with grass.

ii) vertical

Use of vertical barrier methodology on a property boundary

The site concerned was a highway verge at Jeffries Down, Pendeen (GR SW 3846 3422) (Fig.4.6) adjacent to a Cornish hedge. The site on the inside of the hedge, which was at a level of between 0.5 and 1 metre below the road, had been developed within the last 10 years. The owner of the property wished to demolish the Cornish hedge and replace it with a wall faced with stone on the highway side. The verge at this point was heavily infested with Japanese knotweed. The knotweed had penetrated the wall and was evident on the bungalow side. There was some Japanese knotweed elsewhere on the site, but at some distance from, and not apparently connected to, this infestation.

Fig. 4.6 Material at Jeffries Down GR SW 3846 3422

The presumption was that the Cornish hedge was in the ownership of the adjacent landowner, the highway, and thus public responsibility, extending from the foot of this feature on the highway side to the foot of the equivalent feature on the other side of the road. The opinion of the author was that the maturity of the Japanese knotweed on the verge, the lack of mature Japanese knotweed on the inside of the hedge and the clear evidence of penetration of the wall, led to the conclusion that the knotweed was coming onto private land from the highway. The matter had been discussed with the previous landowner and the conclusion reached that the highway authority had some responsibility in this case.

The suggested course of action involved providing assistance to separate the stone and soil from the knotweed and thus to minimise disposal costs. Following this separation, the verge should be separated from the wall by a root barrier, provided by the highway authority. The following work methodology was produced by the author after site visits on 10th February 2003 and was employed by the builder acting for the property owner and the highway authority in Spring 2003. Loose rock was removed from the inside of wall by hand, inspected for rhizome and piled clear of the working area. The wall was demolished in stages, firstly the material above verge level on the inside, then material above verge on outside face, then the material down to wall foundation level. The excavated material was inspected and any rhizome removed contained in strong plastic sacks for off-site disposal to an appropriate licensed site. The excavated and inspected soil was stacked on a hard surface within the site. The area was excavated to the level required for the concrete foundation of the new structure. There was rock over much of the area. The foundation level was then checked to ensure it was free of rhizome. The root barrier was laid with an allowance of 100mm under the foundation concrete. Allowance was made for the root barrier to extend a minimum of 5 metres beyond the knotweed clump, though this was not possible at the northern, entrance end. The barrier was laid against the vertical face of the verge revealed by the excavation and trimmed so that 75 mm was left exposed above ground level. The Japanese knotweed on the verge had been treated with glyphosate in the preceding autumn and this programme was to be continued. It was agreed that treatment would be continued across the boundary by the Council in the case of material re-arising in the property.

4.2.2 Chemical control

a) Herbicide timing – roadsides

In the majority of cases, application of herbicide has been used as it has been considered the most cost effective means of control of the plant.

The Cornwall County Council Japanese knotweed control project had already been initiated in 1996 prior to the commencement of the research. The methods of treatment and the recording mechanism were altered progressively in line with the research and recording methodologies refined. To this end, this work looked in detail at a number of sites where different control methodologies had been trialled. A particular aspect involved the following up of the importance of the timing of herbicide application, particularly in relation to glyphosate.

i) Initial practice – spring cutting and autumn herbicide application

The initial system which had been advocated was to cut the plant in May/June and then treat regrowth with herbicide (glyphosate) later in the growing season, in August and September. The reasoning for the cutting and earlier spray application was that, if the plant is allowed to grow unchecked for the entire season, it is likely to exceed 2.5 metres in height, with the possibility of impeding visibility on the highway and additionally, there is inherent difficulty of herbicide application to a plant of such stature in a public place.

ii) First modification – spring and autumn herbicide application

The revised practice within the highway was to deliver two sprays of glyphosate per season, one in May/June when plant height was approximately 1.5 metres and there was a good cover of expanded and actively translocating foliage, and the second in September/October immediately prior to senescence. This double treatment regime was based on ADAS advice. Previous work elsewhere had also used this technique (Roblin 1988).

iii) Single autumn herbicide application (2007)

The treatment regime was further modified in 2007 in line with further work, observations and experimental work described in this thesis. Initially the method deployed was to provide a single late season application of glyphosate. Work which has been particularly relevant to this modification was carried out through Camborne School of Mines under the supervision of Dr L.E.T. Jenkin between 1995 and 2007. This assessed the effectiveness of the control which was being carried out by a number of different bodies, which indicated the requirement for a number of treatments over a number of years. Work was carried out on the White River, St Austell (GR SW 7729 1982) (Baker 1998) and at Heamoor, Penzance (GR SW 461 322) in relation to a number of different herbicides and different treatment times. These indicated the benefit, with glyphosate, of late season application (Brown and Jenkin 1999).

Work by Callaghan et al. (1981) noted higher concentrations of starch in rhizome and decreasing soluble concentrates in shoots at the end of the growing season. This was further clarified by Price et al. (2002). This work suggested that consideration of timing of application would appear to be of direct relevance in relation to translocation of herbicide within the plant. The precise timing of this to maximise efficacy was the subject of further consideration.

Work in one area of the highways network was delayed in 2005, and the results were monitored showing that a single late season application of glyphosate appeared, from the viewpoint of re-appearance of above ground material, to be more effective than two applications. This led to field observations at a number of sites to see if treatment success would be more rapid where limited amounts of above ground material were present.

The plants at the sites were all treated with an overall application of glyphosate at the rate of 1:50 when foliar senescence was observed, on 10th October 2005, prior to the first frost. Particular attention was paid to coverage under the leaves. All were observed for the following seven years.

The sites observed were at the following locations:-

SW 7619 1963 Zoar 4 canes

SW 7729 1982 St Keverne Beacon 3 canes

SW 7725 1980 St Keverne Beacon 15 canes

SW 7201 3307 Edgcumbe 26 canes

SW 7629 3481 Treliever 3 canes

iv) Further modifications of practice 2008

Calendar of operations

In order to facilitate access to areas, breaking down the cane, generally by walking through it in boots in February/March, has become a standard practice where clumps of a size deemed difficult to control effectively remain i.e. all parts cannot be reached by a sprayer encircling them. There is a likelihood of rhizome material to be broken off at the same time, so site instructions emphasise the need for all material to be retained on site. Apart from improving access for later operations, the operation may well stimulate growth and increase the amount of material visible for treatment. Stimulation of growth by footfall was observed on a path through a treatment area at Tuckingmill, Camborne (Fig.4.7).

Fig. 4.7 Stimulation of growth by footfall Tuckingmill GR SW 6576 4141

On sites where visibility or access is likely to be compromised in the short term and picloram is not suitable, or where a combined regime is being implemented, use of glyphosate in early season.
On most other sites; use of glyphosate late in the season, post flowering, with an adjuvant, normally Topfilm, accentuating good foliar cover, particularly on the undersides of the leaves.
On sites where overall application cannot be carried out; stem injection using glyphosate late in the season.
Indication of each individual treatment site with a dedicated sign to prevent disturbance and spread of the material by various activities such as flailing, and to inform the public.
Sites are monitored in relation to the criteria set out by the author. (Appendix 14)

b) Sub-lethal effects

Observation on sites where the previous practice of spraying with glyphosate in May/June/July has been carried out has indicated that *Fallopia japonica* may show indicators of epinasty (Fig. 4.8) for more than one season. This growth has an extremely restricted area of foliage and therefore uptake of translocated herbicides is likely to be very limited. The observations suggest that normal growth can recur at some distance from the original application area. This is suggestive that the original application was carried out at the visible centre of the clump and that the glyphosate has lost its effect, being predicated principally on action at growth points (Sansom, Monsanto pers. com.2007.04.18) .Material at some distance is then stimulated into growth when the effect has been exhausted.
Further information was received from Monsanto:-
From radio carbon labelling, it does look as though the glyphosate is concentrated firstly at the apical rhizome internodes, decreasing basipetally ie. from the apex towards the base of the plant.
This is certainly the case in Couch where poor control with glyphosate often leaves dead sections of rhizome a long way from the sprayed shoot and yet some live sections much nearer the shoot. We see this when the rate was too low or it rained soon after application or FYM is applied within 5 days.
This makes it is difficult to choose material for a viability test, since initially timing is so important to the extent of uptake and on top of that the distribution along the rhizome is variable!
As we said the glyphosate does not degrade within the plant to any extent (no more than 5%) but redistribution will depend on the vigour of the remaining plant- hence the epinastic growth can remain for several years with the plant neither recovering nor dying. Finally, the

deciduous nature of the plant means loss of glyphosate through the leaves and dilution to a point where it may start more vigorous re-growth.

(Sansom, Monsanto pers. com.2007.04.18)

Fig. 4.8 Epinastic growth following early season glyphosate treatment Upper Fowey Valley 11.08.2005

The aim of this work was to establish:-

- If rhizome which is producing epinastic growth is removed, whether it will subsequently produce normal growth.
- If epinastic growth is removed, will the remaining rhizome in the ground produce normal growth.
- If clumps which are producing epinastic growth are left undisturbed, will normal growth resume at a later date.

On 2nd August 2004, 10 samples of crown with small epinastic growths were taken from each of three roadside sites which had been subject to early season herbicide treatment. Edgcumbe (GR SW 7206 3310) A394, Mabe (GR SW 7626 3481) A394 Baldhu (GR SW 7694 4349). A further 10 samples each were obtained from stem treatment sites at Tregeseal GR (SW 3598 3238) and Rocky Valley (GR SS 0724 8939). No above ground shoots were observed at any of the sites, though there was some evidence, on close examination, of clustered white epinastic shoot initials <4mm in length. When the crown pieces were broken off, the attached underground material, moist, bright orange rhizome typical of viable Japanese knotweed, was observed. An additional individual sample was taken on 1st October 2004 from GR SW 76196 19628 U6027 Zoar (635.2g), a site where no shoots above ground had been observed for two years. There was no evidence of epinastic shoots on the latter sample, but the attached rhizome appeared similar to the previous samples in relation to potential viability.

In all cases the crown averaged 100mm in diameter and with an average of 100mm length of attached rhizome. The material was incubated and kept moist in individual 150 mm square transparent polythene bags with a handful of moss peat, folded but not sealed in a sheltered position outdoors in natural light. It was decided to retain the material in outdoor conditions over winter and to observe any regrowth in spring. The material was retained for a further year. The sites from the material was obtained were observed in the spring following their collection.

c) Visual effects of various herbicide treatments

A site at Penryn (GR SW 782 346) was treated with a variety of different herbicides as part of an experimental control programme. Digital images were taken of the different foliar symptoms of the plants treated with the different herbicides used for control. This information may be helpful in judging the previous treatments undertaken on other sites.

d) Control of Japanese knotweed by application of herbicide into cut cane stumps

Current work has indicated that Japanese knotweed may be controlled in many situations by overall application of glyphosate based spray to fully developed, mature foliage immediately prior to senescence. However, as the plant may be 3 metres high at this time, there can be considerable operational difficulties using conventional knapsack spraying equipment. Even when equipment such as extending booms is available, if effective overall coverage of the foliage of the knotweed is to be achieved, it will not be possible to avoid spray damage to adjacent vegetation.

In certain situations, such as when the knotweed is growing on a Cornish hedge, on sites with a ground flora considered of particular value, or in a garden situation where the knotweed is growing close to other plants, a stem filling technique may prove a suitable alternative. Although requiring a far higher labour input, the herbicide can be far more accurately directed. The timing of application – late season - should accord with overall foliar application. Epinastic growth has been noted where this technique was deployed earlier in the season.

The National Trust has developed a technique whereby herbicide is inserted directly into the cut stem stumps. The effectiveness of this technique has been assessed through research by Joy (2002) in association with the National Trust in Cornwall with funding from Cornwall

Environmental Trust. This technique has been judged as particularly suitable for use on sites with sensitive associated flora. In view of the heavy labour input required and observation within the a number of areas including Rocky Valley GR SS 0725 8936 and Tregeseal Valley GR SW 3646 3324 that the technique does not appear to give better control than overall foliar application, it would appear to be most appropriately targeted where the potential of damage to associated plant cover is a major concern. Rate of application has been observed by a contractor to be in the order of 10 times longer than that required for a single overall foliar application. (Trickey K. pers. com.2010) The original research was carried out using a variety of herbicides under an Experimental Permission from the Pesticides Safety Directorate (PSD).

The author became involved to formalise the methodologies deployed in order to produce a technique applicable to more wide scale use in field conditions. Application was made by the author to the Pesticides Safety Directorate who confirmed that the technique, as developed, when using the specific herbicide detailed (glyphosate) at a concentration not exceeding that specified, is covered by the general label provisions of the product and did not require a Specific off Label Approval. This approval relates to use in Great Britain. Elsewhere checks should be made with the appropriate authorities responsible for the regulation of pesticides. Reference to specific months relates to British conditions. The most important factor is timing the execution of the technique shortly before senescence is anticipated and this should be related to local conditions. The technique involves the cutting of the mature Japanese knotweed stems and application of a measured dose of dilute herbicide into the hollow stem cavity. The standard methodology used is detailed in full in Appendix 19.

e) Alternatives to glyphosate

i) Testing picloram for use on roadsides (2007)

The herbicide picloram applied early in the growth stages proved effective at Veryan trial sites (see details below) and it was suggested that this material be used on a trial basis in a number of suitable locations (away from water, where there were no plants of particular significance). Grasses and other monocotyledons are not affected by this material, in contrast to glyphosate, and thus bare areas where all green matter is affected are avoided. The rate of application was 5.6 litres/hectare unless brambles (*Rubus* spp.) or bracken were noted to be present on the site intermingled with the *Fallopia* and thus compromising overall treatment. In these cases the label rate appropriate to the control of these species, 11.2 litres/hectare, was deployed. This was implemented as it was considered necessary to ensure that the areas adjacent to the Japanese knotweed could be clear enough for adequate monitoring of any peripheral regrowth of the target species. Advantages of the use of picloram include the fact that application can take place at an earlier date and thus on shorter growth material, easier to target, the aim being to apply when the material was at a height of 600mm, information having been received from Dow Agrosciences (Cawley, A. Pers.com. 2004) that the four to six leaf stage was appropriate for treatment, the worst time for treatment being when the plant was in flower (with the caveat that no specific work had been previously carried out on Japanese knotweed). As the main message appeared to be that application should be carried out during active growth and the fact that leaves often take some considerable period to unfurl completely, a growth height of 600mm was resolved to be a reasonable stage for treatment. Picloram is also soil acting, so the timing was also felt to comply with this parameter.

The area chosen for this work was an area of former mining activity at Scorrier, Redruth, (GR SW 7207 4412) which was noted to be heavily colonised by the plant. Various excavations took place within the site in relation to stability assessment as the area was intended for construction of a waste facility. Following these excavations, the herbicide picloram was applied to the area at the rate of 5.6l/ha, later than would have been deemed desirable, in early August 2007 (Fig.4.9)

Fig. 4.9 Scorrier picloram treatment site 10th August 2007 GR SW 7208 4411

f) Landscape scale control – Whole catchment assessment using photographic monitoring: Tregeseal

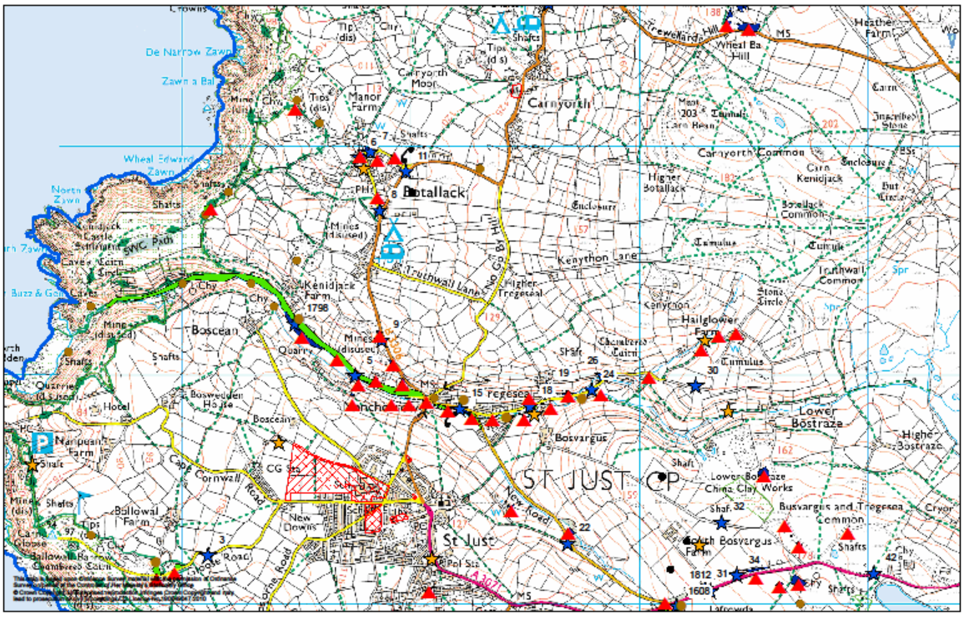


Fig. 4.10 Tregeseal Valley. Symbols in red, green and blue indicate Japanese knotweed

Work in the Tregeseal Valley GR SW 394 323 to GR SW354 321 was initiated due to a combination of factors. *Fallopia japonica* was present in quantity within many areas of the valley, affecting a number of owners and interest groups. The plant was invading not only the semi natural environment, diminishing the quantity of native plant species, but also causing damage in the built environment, including disruption of historic features.

The first stage of the project was to carry out a GPS survey of the sites. This was compromised to some extent by the fact that growth had been suppressed by previous work in the lower part of the valley (north-west of GR SW 3642 3216). It was considered that the remaining and untreated part of the valley would provide sufficient reference to be relevant.

The National Trust owned considerable affected holdings in the lower valley, Penwith District Council had a responsibility in relation to watercourses, Cornwall County Council had responsibility in relation to highway verges, Natural England had interest in the invasive species, particularly on agricultural land, South West Water was undertaking works within the affected area and St Just Town Council was expressing concern on behalf of their parishioners. Individuals, such as allotment holders, were also being directly affected.

The use of herbicide was the chosen technique, other methodologies being shown to be less efficacious or less cost effective. Glyphosate was the active ingredient deployed, due to its relative safety in relation to non-target species. The Trust carried out work by stem injection in close proximity to the watercourse and used knapsack or long lance overall spray application at the recommended concentration in the field between GR SW 3644 3226 and

GR SW 3661 3211, where approximately 4350 square metres were recorded. The other partners in the project used the technique of knapsack or long lance overall spray application of glyphosate at the recommended concentration, except in a small area at GR SW 3773 3191, sufficiently far from the watercourse, where picloram was used.

The National Trust had already carried out very successful work in the nearby Cot Valley using cutting and stem filling and work on the highway, on more than 1800 sites, using overall herbicide application was showing notable success. Work was, therefore, carried out by the partners using the combination of the tested techniques of stem filling and overall herbicide application, according to the requirements of individual areas. Some experimental work had previously been carried out in the lower valley by Camborne School of Mines (University of Exeter).

The valley was monitored during the course of the work, by the use of fixed point photo monitoring. This provided appropriate reference data and demonstrates the effectiveness of the work carried out so far. Digital images were preferably to be secured on all sites on the same day at the nearest convenient date to 1st August, 1st November, 1st May for three years, commencing in May 2006. The intention was to take photographs from the following points which are identified by arrows located as described below and aligned with the direction from which the image should be secured. The image was taken from a height of 1.5m above adjacent ground level or as specified below. The chosen points start from an overview over the lower valley and then proceed inland:-

Site numbers:-

1. **Site 1** GR SW 3567 3260 At junction of track and coast path by quarry. Image taken by way-marker post looking up the valley Ref 1OU (No 1 overview upstream) and date e.g.1OU 20060501.
2. **Site 2** GR SW 3611 3248 Marked on boulder below track above Carn Praunter. Image directly across valley. Image to be referenced 1GS with date e.g.1GS20060501.
3. **Site 3** GR SW 3611 3248 Down valley to sea to be referenced 2GSW with date.
4. **Site 4** GR SW 3 596 3237 Marked on decking on downstream side of footbridge on public right of way in lower valley. Image to be marked 3D with date.
5. **Site 5** GR SW 3596 3237 Marked on decking on upstream side of footbridge. Images to be referenced 4U with date.
6. **Site 6** GR SW 3620 3236 Marked on boulder on knoll on footpath to south of stream, approximately 200m upstream of buildings. Image downstream looking towards footbridge to be referenced 5D with date.
7. **Site 7** GR SW 3620 3236 Taken towards bend in stream looking upstream, camera pointed down, to be referenced 6U with date.

8. **Site 8** GR SW 3263 3240 Marked on boulder on old crossing point below tractor shed. Image downstream to be referenced 7D with date.
9. **Site 9** GR SW 3263 3240 Marked on boulder on old crossing point below tractor shed upstream to be referenced 8U with date.
10. **Site 10** GR SW 3643 3231 Marked on iron rails on each side of foot and vehicular bridge south of Kenidjack Farm. Photograph taken 90cm above marks. Image downstream. Image to be referenced 9D with date.
11. **Site 11** GR SW 3643 3231 Marked on iron rails on each side of foot and vehicular bridge south of Kenidjack Farm. Photograph taken 90cm above marks. Image upstream. Image to be referenced 10U with date.
12. **Site 12** GR SW 3651 3226 On masonry surrounding grid over shaft at Wheal Drea. Image upstream reference 10OU with date.
13. **Site 13** GR SW 3651 3226 On masonry surrounding grid over shaft at Wheal Drea.Across valley. Image referenced 10A with date.
14. **Site 14** GR SW 3651 3226 On masonry surrounding grid over shaft at Wheal Drea. Upstream Image referenced 10ODwith date.
15. **Site 15** GR SW 3668 3205 Marked on stone by road adjacent to former water site offices entrance opposite lower gate post. Images down stream to be referenced 11D with date.
16. **Site 16** GR SW 3668 3205 Marked on stone by road adjacent to former water site offices entrance opposite lower gate post. Image upstream to be referenced 12U with date.
17. **Site 17** GR SW 3672 3202 Marked on decking of footbridge downstream of vehicular access to water treatment works. Image downstream. Image to be referenced 13D
18. **Site 18** GR SW 3672 3202 Marked on decking of footbridge downstream of vehicular access to water treatment works. Image downstream. Image to be referenced and 14U with date.
19. **Site 19** GR SW 3704 3189 Marked on pump house wall. Image to be taken downstream 100cm above mark. Image to be referenced 15D with date.
20. **Site 20** GR SW 3706 3188 Marked on parapet wall of road bridge at bottom of Nancherrow Hill, west side. Image downstream taken 100cm above mark. Image to be referenced 16D with date.
21. **Site 21** GR SW 3707 3188 Marked on parapet of road bridge bottom of Nancherrow Hill, east side. Image upstream to be taken 100cm above mark. Image to be referenced 17U with date.

22. **Site 22** GR SW 3728 3181 Marked on parapet wall of road bridge to north of Rugby Club. Image downstream 60cm above parapet. Image to be referenced 18D with date.
23. **Site 23** GR SW 3746 3184 Marked on footboards on footbridge to south east of Tregeseal Terrace. Image downstream. Image to be referenced 19D with date.
24. **Site 24** GR SW 3746 3184 Marked on footboards on footbridge to south east of Tregeseal Terrace. Image upstream. Image to be referenced 20U with date.
25. **Site 25** GR SW 3755 3187 Marked on stone on road bridge north of Thealby Cottage, west side. Image downstream. Image to be referenced 21D with date
26. **Site 26** GR SW 3756 3187 Marked on safety rail on road bridge to north of Thealby cottage, east side. Image upstream 45cm above rail. Image to be referenced 22U with date.

4.2.3 Combination treatments

a) Herbicide treatment followed by removal to treatment area within site

Barncoose, Redruth GR SW 6854 4174

Herbicide treatment was carried out followed by excavation of the treated material and its placement into bunds at Barncoose, Redruth GR SW 6854 4174. This followed guidelines for on-site treatment practice for soil containing Japanese knotweed. (Environment Agency Code of Practice). The site was visited on 3rd October 2007, following earlier survey and the application by overall foliar application of glyphosate at the rate of 1:500 in the previous week. The area to be excavated was marked out with paint. The area appeared to have been disturbed on one side by trenching operations – small Japanese knotweed plants were discovered at a distance of some metres from the main area noted. The area where the knotweed was previously seen was also noted to have been partially covered with soil and tree detritus. The rhizome systems were excavated with no attempt being made to separate them from the accompanying soil. The material was then transported within site to a designated treatment area, and deposited on a membrane to a maximum depth of 600mm. The criteria for further treatment were that regenerating material were to be treated with glyphosate when the plant was observed to have fully expanded green leaves. Disturbance was to be carried out three weeks after such treatment, using a tined bucket on an excavator pulling from the sides of the site, to draw material up through its profile. The sites from which the excavation took place were required to be inspected at intervals of three weeks and, any material which appeared, treated. The inspection, disturbance and treatment regimes were to be continued as long as deemed necessary. The author attended for excavation operations on 10th October. Soil was excavated from the identified areas, the sides and bottoms of the excavations inspected for rhizome and deemed clear. Excavation was to some extent compromised by the discovery of large lumps of concrete within the ground, but inspection of these did not reveal any rhizome within the rough exteriors. Material was relocated to the specified area within the site for reprofiling into windrows for further treatment as required. There was some concern that the earlier excavations might have fragmented rhizome along the line of the earlier trenching and it was suggested that a watch be kept for possible later emergence of material.

b) Movement of material to treatment areas within site and herbicide treatment of bunded material

St Erth Civic Amenity Site Extension GR SW 5430 3470

As part of works to secure the area purchased by the County Council at St Erth, a bund was placed along the entire length of the site, using material from the western part of the area. It would appear that some of this material was contaminated by Japanese knotweed (an area colonised by this plant within the proposed park and ride area had already been identified and excavated for further treatment within the site). A number of small shoots of Japanese knotweed (<20) had been observed within the bund and three shoots in a cluster in the levelled area approximately 15 metres to the north of it. Works had been carried out on the site in the autumn of 2005 and material was exported within the site to a treatment area. The objective of the operation was the transfer of the imported material back to the western end of the site for further treatment to ensure that viability was removed. The method employed was, starting at the eastern end, to scrape material off to determinable original levels using an excavator. The material was transferred to dumper trucks stationed within the area to be cleared so that any material which might fall from them would be picked up by subsequent excavation. The trucks then used a defined route to the recipient site where the material was deposited in piles to await spreading at the end of the operation by the excavator to a depth not exceeding 300mm on an area covered by geotextile barrier. The operators of the plant were informed of the necessity for thorough cleaning of vehicles and the placement of any potentially contaminated material within the recipient area. The author attended on site, advised and inspected from 08.00 until approximately 12.00 on the 10th July 2007, by which time all the observed shoots had been excavated. Excavation of the small shoots behind the bund was carried out by hand. No rhizome was observed remaining on the sites where it had been observed after the work was carried out. A final scraping of the area was understood to have been carried out after the author had left the site. Excavation had been carried out to investigate drainage at the western end of the site and material had been removed to make access to the site before works commenced. No material had been observed in this area a few days prior to commencement of works. A pavement has been constructed along the roadway and some of the plants, <4, were observed in close proximity to this feature. Excavation was limited in this area.

4.3 Results

4.3.1 Physical Control

a) Physical removal

i) Removal of above ground material

Grazing

Grazing has been proposed as a means of controlling *Fallopia* spp. (Beerling 1991a). A number of observations in Cornwall by the author have noted control to some limited extent by cattle, possibly related to intensity of stocking rate, when the stock are put into the affected area early in the growing season when the plant is less than approximately 300mm high. Where cattle are put into pasture when the plant is more mature there may be some control by physical trampling of the material, related perhaps to gaining access to shade, water or other fodder target areas, but no substantial control. A site at Wendron GR SW 6814 3134 has been observed over a five year period. Intermittent stocking and silage cutting has taken place in this area, but no significant control has been observed (from the boundary of the site).

A field at Lanarth, St Keverne GR SW 7699 2104 adjacent to a garden area, was noted by the author, in autumn 2003, to have sporadic infestation of *Fallopia* over an area approximately 180 metres by 30 metres with plants up to 500mm high, in a field approximately 250 metres by 70 metres. The landowner stated that the field had been subject to grazing by sheep for more than 15 years and that the plant had been reduced considerably. The material was noted to have reduced further by summer 2009, but was still present.

Grazing by horses was noted by the author at Goonzion Downs GR SX174 680. The pasture was largely gorse and heather so the strong grazing noted (Fig. 4.11) may well have been directly related to paucity of alternative pasture. It was not possible to determine the regularity of the grazing pattern at this point.

Fig. 4.11 Grazing , Goonzion Downs GR SX 174 680

Pigs have been suggested as a means of control. Pigs were noted in an enclosure in Maker with Rame GR SX 426 491. Their foraging pattern is predicated on soil disturbance, and quantities of viable rhizome were noted at the peripheries of the enclosure (Fig. 4.12). There was no clarity as to preference by the animals for either the underground or overground parts of the plant and no data were available regarding any supplementary feeding regime, but the presence of rhizome and small shoots is suggestive that this is not likely to be a preferred food target for this species and that there is considerable danger of spread of the plant.

Fig. 4.12 Grazing by pigs Maker with Rame GR SX 426 491

Pulling

A site at Gweek GR SW 706 268 where pulling had been carried out on a regular basis for 15 years was stated as still producing a few shoots (Collins L. pers. com. 2007)

ii) Removal of below ground material

Physical removal of Japanese knotweed, in early stages of establishment, spread by remediation of trenching works A30 trunk road Hayle to Bodmin

The process was quite successful with little reappearance compared to the number of pieces removed, being noted subsequently. Of the sites 29 excavated, 5 produced further growth.

Removal by excavation, Church Cove, Lizard GR SW 7144 1274

The excavation was carried out on 21st January 2005. The wall was removed as specified and vegetation cleared. This vegetation clearance revealed epinastic material in the vicinity of the rock face behind. The discovery of this epinastic material strongly suggested that the area had previously been treated with herbicide. After attempting to delineate the extent of the clump and removal of stone and other material, such as metal, which was observed to be free of rhizome (the site was clearly used for some tipping, excavation was carried out by swing shovel and hand picking was employed. Approximately 3 tonnes of mixed and potentially contaminated material was removed, swung over a Terram™ covered area into Terram™ envelopes in pick ups for transport to the designated landfill site.

Fig. 4.13 Deep rhizome Church Cove GR SW 7144 1274

Rhizome was noted in fissures in the rock and other material to depth of 1.5 metres. (Fig. 4.13) The quantity of rhizome removed was disproportionately high compared with the amount of above ground material and there was no evidence of recent herbicide application (confirmed by comment of a nearby resident). The site has been monitored on an ongoing basis and no above ground material has been noted since the excavation was carried out.

Physical removal of material after less than 6 months on site: South Petherwin GR SX 2983 8197 to SX 3067 8179

Thirty four individual plants were removed. Two shoots were noted following the work. These were removed, but no further material has been discovered. The site continues to be monitored by the author, but no further shoots have been recorded in the six years following the removal.

Excavation and on site desiccation of material at Jillpool, Bosinney GR SS 0664 8872

No rhizome was found more than 2 metres away from previously visible above ground material at the first excavation. The depth at which rhizome was discovered was 600mm to 800mm below soil level. It was observed that the material at lower depth was composed of rhizome with a light brown rind, comparatively smooth in appearance with no visible buds or roots and visually similar to *Iris* spp. rhizome. Particularly in the areas of high chipping content, but also notably elsewhere, the rhizome was noted to be generally less than 8mm in diameter, black in colour and with a large number of black and apparently dead roots. Internal colour varied from a deep orange – particularly in the smaller rhizomes – to a pale yellow, particularly in the larger rhizome. The rhizome removed from site was estimated to weigh approximately 2 tonnes. The nature of the soil meant that little soil adhered to it, the estimate being that the weight of the soil component did not exceed 10% of the total.

24th May 2001 Site visited. Photographs taken. The long interval between visits was due to Foot and Mouth disease restrictions. 4 clumps of 3 to 4 shoots up to 1.5m high were noted along the back hedge in an area which had not been previously noted to be colonised. Undisturbed marginal material was noted to be up to 1.8m in height. In areas in which rhizome had been removed there was a considerable regrowth of shoots up to 400mm high, though 60 to 70% of shoots were considerably smaller than this (Fig.4.14). A clear difference was seen between shoots from large, deep rhizome and smaller, shallower material, the former being redder and slower in expanding their leaves. The smallest rhizome which was seen to be producing root and shoot was 2mm in diameter and 3mm in length. A number of samples were dug and compared. There was considerable confidence that the shoots that were removed were dug in their entirety as considerable care was taken to remove the complete rhizome and no freshly exposed internal material was observed.

Fig. 4.14 Regeneration following rhizome removal Jillpool GR SS 0664 8872

Following treatment with glyphosate, recurrence on the site was very limited - 4 shoots in the disturbance area in the following year. The piled rhizome desiccated in a satisfactory manner with less than 20 pieces showing regrowth.
The site was visited on a minimum of two occasions per year. 16th October 2008 one shoot less than 300mm high noted on disturbed area.

b) Disturbance

i) above ground

Scorrier - A communication has been received which states that a single green shoot has appeared – and been removed - each year at a site in a domestic curtilage since the property was purchased in 1982 at Scorrier, Redruth GR SW 7249 4414 (Price pers. com. 2009).

ii) below ground

Observations on work sites

The author has been called in to a number of sites where Japanese knotweed has been noted to be present and has made observations on work methods being deployed on them. In a number of cases, disturbance of the plant had already occurred and material had been distributed within the site to unknown locations and depths. Even when a period of time had elapsed, the observation has been made that rhizome can remain below soil level without producing above ground shoots. There are contentions that this can remain the case for a number of years. The author saw material emerging from a soil pile at Scorrier GR SW 7157 4399 where the top was taken off a pile of soil. *Fallopia* emerged from lower areas which had previously been covered with perhaps in excess of 2 metres of soil. It was suggested by those who had long term knowledge of the site that the material could have remained undisturbed for ten years (Semmens, pers. com. 2011)
A site where Japanese knotweed had been noted in specific area was East Hill, Pool. GR SW 6621 4133 .The material was spread from the margins of the site over almost the complete area during mine capping operations, resulting in the discovery of viable rhizome at a depth of two metres at least three years after the re-profiling operations. Above ground material had not been noted at this position during the intervening period (Fig. 4.15).

Fig. 4.15 Viable rhizome at depth due to deposition of material GR SW 6621 4133

On another site in the area, the plant had been noted within structures as well as outside them. (Fig. 4.16). The demolition methodology, however, did not make allowance for this and, instead of pushing the walls down onto the concrete floor area, the site was bulldozed. The result was that rhizome which was colonising the underside of the concrete was mixed with all the other uncontaminated material, resulting a far greater mass of contaminated matter. The result was that the material ended up by having to be sorted by hand to physically remove rhizome at significantly increased cost.

Fig. 4.16 Japanese knotweed inside building GR SW 6564 4012

A site near Dolsdon, GR SX 275 947 was visited on 14th October 2004. The landowner had been resident on the site for many years and stated that the plant was not on the site until the last 10 years. There are badgers on site and the spread of the plant appeared to concur with sett entrances and transport corridors.

Control using initial removal followed by disturbance.

Fig. 4.17 Area following initial removal treatment at Veryan GR SW 9529 4095. Image courtesy of R.N.A.S. Culdrose

Rhizome weighing produced results ranging from 16.5 to 25kg of underground material in areas of 1m x 1m x 750 mm. Above ground material in these situations ranged from 12 kg to 16kg/m^2.

30 days after the disturbance shoots 350 – 450mm high with @ 5 to 6 expanded green leaves were noted over the work area. Underground extension growth from the disturbed rhizome was noted in disturbed material during hand picking operations less than 30 days after initial disturbance, extensions noted ranged to more than 100mm in length.

Fig.4.18 Weighing of above ground material

Where the herbicide picloram was used, the attempt was made to reduce its long term effects by carrying out disturbance a month after application of the material. The result of this activity was stimulated regrowth. Other areas which had been treated at the same time, but which were not disturbed, did not produce such growth. The effects of epinasty were still noted at one particular area within the lane in 2009 despite the discontinuation of early application of glyphosate some three years previous to this date. The overall result has been a reduction of over 98% of the cover of the plant, but continued treatment is still required.

iii) Climatic effects

Observations in Cornwall have suggested that plant growth may be stimulated by periods of cold weather. Tim Burgess of Cornwall Council has commented:

"I mentioned after last year's short spell of cold weather (snow and frost) we noticed that in areas where knotweed had been mainly cleared the year before or certainly growth had been substantially knocked back the few plants that were re-growing appeared to have quite vigorous strong growth. It's just a general observation we have made and nothing scientific about the findings.

We have just starting the control for this year and have noticed in Tregeseal, St Just that the same results appear to be happening this year and that the few plants that are returning are producing very strong, early growth following an exceptionally cold winter for West Cornwall which had prolonged spells of frost and/or snow than the year before. I don't know if this is actually happening, is due to a lack of competitive plants which may have also been effected or even killed off by the cold, the animals that germinate them or if the weather has somehow stimulated this vigorous growth, but given that this is the second year we have noticed this and the only changes from previous years appears to be these cold winters, feel that the weather is certainly effecting (sic) *things?"* (Burgess Pers. com. 2010)

c) Barrier methods

i) horizontal

There was some localised regrowth in the season following the work at the back of the site by the Cornish hedge and at the point at which the verge met the road, due to the difficulty of getting a proper seal at these points. This was treated with herbicide (glyphosate). This treatment was followed up the following year (1999), but no further regrowth has subsequently been recorded. The site was disturbed by trenching operations in 2006, but no further growth was noted following this disturbance. The final site assessment was carried out in 2011 and no above ground material was observed.

ii) vertical

Use of vertical barrier methodology on a property boundary

The disturbance of the rhizome resulted in the production of an observed denser canopy of growth on the verge side. The normal verge treatment process was continued and the site was last treated in 2008 when less than 10 shoots were observed. The site is now in the period of five years of monitoring following the last observed above ground material. On the internal face the digging and removal did not result in the appearance of further shoot growth.

4.3.2 Chemical control

a) Herbicide timing – roadsides

i) Initial practice – spring cutting and autumn herbicide application

The anticipated result was that the plant would produce new growth by the due time for autumn application. The usual form of subsequent growth consisted of vigorous and usually non flowering shoots which tended to retain their foliage longer than uncut material e.g. observations near Three Burrows (GR SW 7515 4670). The physiology of these shoots was therefore at variance with material that had grown without intervention and therefore might not react in the same way in relation to nutrient translocation as that used in the research quoted (Buschmann 1997). Field observations confirmed this.

ii) First modification – spring and autumn herbicide application

The application of the herbicide glyphosate early in the season resulted in a reduction of material above ground, but the production of epinastic shoots in many locations e.g. Padstow (GR SW 9118 7472). This shoot material produced stems generally less than 300mm in height and very limited quantities of foliage with leaves less than 10mm across. This reduced foliar area reduces the potential target area for translocated herbicide and thus the lower amount of such herbicide which can be applied to the plant.

iii) Single autumn herbicide application (2007)

These sites have been monitored at least twice a year during the growing season since the application was carried out and no above ground material has been observed to date (2012). Additional evidence of the effectiveness of the methodology is that the site at Treliever was physically disturbed in spring 2007. Such stimulation could, in view of other observations, be expected to result in growth of above ground shoots, but none have been noted to regenerate (2009). Other sites have been observed where such later treatment, where the foliage has started to yellow, have also shown very effective control. It should be noted that, while the five sites cited had been noted for several years and were therefore classifiable as established, with canes in excess of 1.5 metres, the number of canes present did not exceed

50 in each case and, therefore, the anticipated quantity of below ground material was believed to be limited. Apart from the aspect of timing, the other area accentuated from this work was the desirability to get good herbicide cover on the undersides of the leaves.
An informal trial was carried out comparing application to the upper surfaces of leaves with application to both upper and underside of leaf surfaces. When the herbicide was applied to the underside of leaves as well as upper surface more complete above ground cane death was noted. This technique therefore appeared to provide more effective control and thus has formed part of the instructions to those carrying out the spraying since 2007.

iv) Methods in use on roadsides by Cornwall County Council from 2008

Of a sample of 1654 sites treated by Cornwall Council within the highway and analysed by the author, in 2009, 714 have no noted above ground growth, 686 have less than 10 shoots, 160 have between 10 and 20 shoots and 94 more than 20. (Fig 4.19).

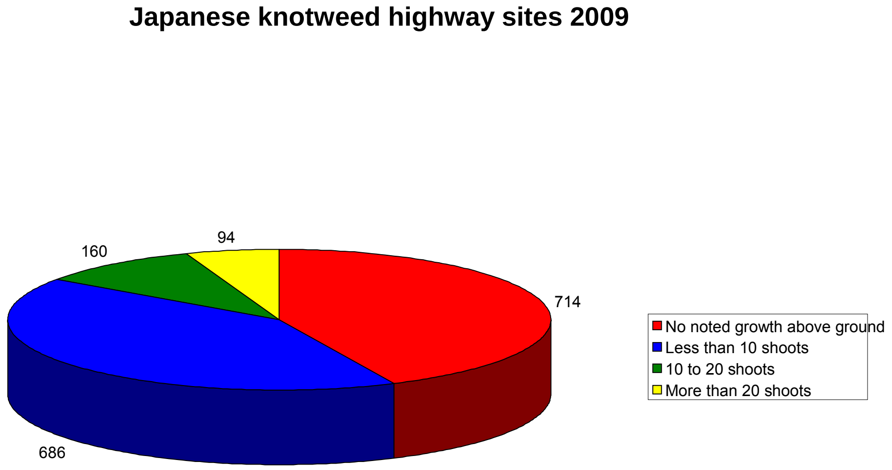


Fig . 4.19 Proportions of highway sites 2009 showing effectiveness of control treatment in 2008

b) Sub-lethal effects

Fig 4.20 Regrowth of detached epinastic material

When the 30 samples taken in August were inspected on 1st October 2004, some extension of the epinastic shoots (up to 8mm) was observed on all the samples and removal of small sections of cortex revealed apparently viable tissue beneath. The retained rhizome, including the sample taken in October 2004, produced a further flush of epinastic shoots the following growing season, but not normal growth (Fig 4.20). Leaf retention was noted on epinastic material later in the growing season than on untreated material. Some pieces of rhizome were noted with green epinastic leaves on 24th November 2006 after normally growing plants in the vicinity has lost their leaves.

100% of the detached rhizome showed continuation of appearance of viability (buds (but clustered in epinastic form)), after a further 12 months, but did not produce normal shoots. No normal growth was noted in the immediate vicinity, less than 0.5 metre from the foci of the points on the sites where the material had been removed. Normal growth though less vigorous than from untreated was noted in May 2005.

c) Visual effects of various herbicide treatments

Images were secured from a number of positions to provide information as to the appearance of the plant following the application of a range of herbicides.

Picloram (Fig 4.21) usually showed considerable distortion of growth and arching of stems with some desiccation at the point of bending and foliar distortion. This contrasted with notable stunting and reddening of growth by Imazapyr (Fig 4.22). Triclopyr usually showed more marked reddening of stems than picloram but less foliar distortion (Fig 4.23).

Fig. 4.21 Picloram foliar effect

Fig. 4.22 Imazapyr foliar effect

Fig. 4.23 Triclopyr foliar effect

d) Control of Japanese knotweed by application of herbicide into cut cane stumps

The graph below shows the reducing labour input required for control in Cot Valley. There is significant early reduction, but still some requirement twelve years after the start of the project.

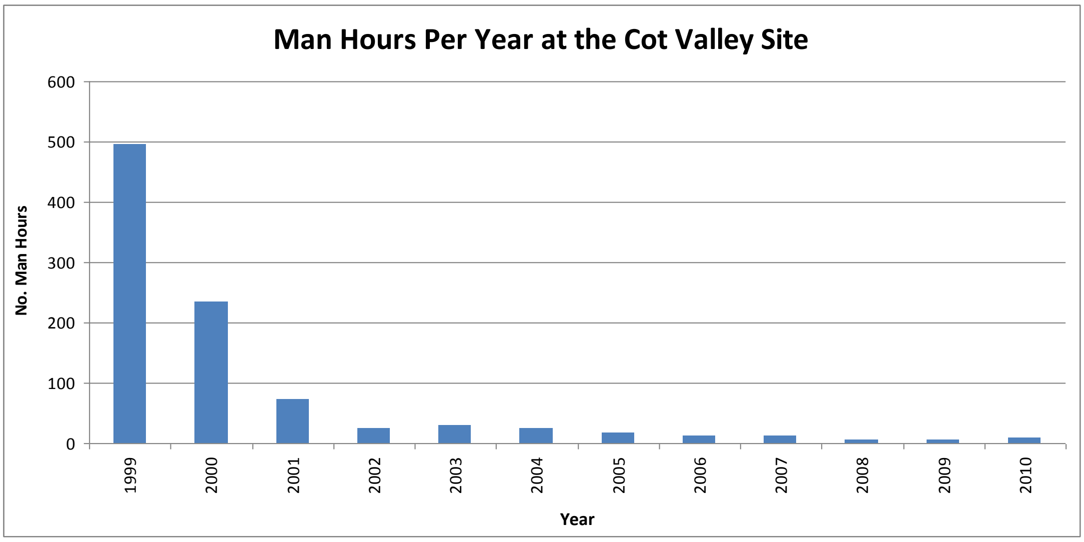


Fig. 4.24 Working hours required for control of Japanese knotweed using stem filling methodology at Cot Valley, St Just (Information courtesy of K. Trickey, site contractor)

e) Alternatives to glyphosate

i) Testing picloram for use on roadsides (2007)

Application at the site at Scorrier was considered necessary the following spring, when the material was approximately 600m high. In 2009, though no shoot growth had been observed, a small amount of rhizome material was observed which appeared viable. Monitoring continued with <200 stems noted in 2010 with a further decrease in 2011. A concern in relation to this though, was the continuation of the presence of small shoot growth (Fig.4.25). 10 random samples of rhizome were also inspected from the area and apparent areas of viability were noted in three cases. When considered by the criterion of decrease in above ground material, with a reduction on this site of more than 95%, the operation could be considered successful, but such a method fails to take into account the potential from viable material remaining underground.

Fig. 4.25 Scorrier site GR SW 7207 4412 summer 2011. Small viable growth in treated area

ii) Observations

Manure application

Seleggan, Redruth GR SW 693 401. This site was visited on 15th September 2005. The field was previously part of a mining complex. Japanese knotweed is frequently noted in the surrounding area. Waste mined material from previous activity was piled on the site before being removed for reprocessing in the 1980s. Reinstatement which took place following this activity consisted of the spreading of a shallow layer of soil and seeding with grass. Following this, Japanese knotweed sprang up over the area. The knotweed had presumably been imported with the topsoil. The area with the knotweed was covered with straw and pig dung when it was about 350mm (1 foot) high, using a dung spreader at a rate which apparently killed the knotweed but not the grass. The area has not subsequently been disturbed by ploughing or other earth movement. When the site was inspected, knotweed was noted round the edge, but not in the body of the field. This technique of manure application was also mentioned to have been carried out at Glenstal Abbey, Eire. (Personal com. Keane 2005).

"Faced here with an extensive tangle old stone walls, valuable trees and Fallopia, we see, after three years of mechanical, manual, non-chemical campaign, the weed is on the runfrom its last few remote and inaccessible strongholds, having already ceded vast territories on the plains.

We generally attacked in three waves:

1) Disruption, comminution and sometimes burial of the root system by big, skillfully operated tracked excavator.

2) Spreading (by tractor trailer and excavator) a 600mm layer of fresh farmyard manure. A heavy guage(sic) black plastic silage cover may also be used as an addition or as an alternative.

3) Moping up of survivors by infantry.

Notes: 1) In areas of strong competition for light, selective cutting and plucking with or without some manual digging say three or four times a year for three years may be sufficient for total elimination. Broken roots, kept without access to light in the ground for one year, rot.

2) Manure and plastic may both help to generate soil conditions of anerobic quality and methane toxicity to which fallopia, with its marked aereal(sic) or surficial roots may be particularly vulnerable. Both also keep the plant on the desired side of the compensation point, allowing the plant more easily to be broken at a distance down from the light when the plant is plucked. After the manure has broken down a bit, monitoring and rapid reaction is necessary to prevent an explosion of new fallopia roots from upcoming stems at the surface. 'Heavy guage' silage cover (NB not wrap) in this market area keeps things only just under the compensation point when used singly in full light and may require two or three years to be 99.9% effective; in semi shade it may do the job in one year. Where the first shoots of the first Spring lift the plastic, the plastic may be folded back the shoots cut and the plastic restored. The second shoots will not be so strong.

3) Fallopia is a brave plant, always ready to show the flag wherever the root is present. Once victory has become possible through the catastrophic interventions described above, the pleasures of the chase and a growing totemic relationship with this remarkable *plant allow one to recognise it at a hundred paces and purue(sic) it with manic energy and zeal. One misses it when it is gone."*

Ammonium sulphamate

Messack: - A site at Messack SW 647 418 was reported to have had *Fallopia japonica* successfully treated by the landowner. He reported that previously there was material 1.2m in height over an area of approximately 30 square meters. He had cut a slot in each stem at 300mm above ground level sufficient for an oil can to be inserted. Amcide (ammonium sulphamate) was injected at 400g/litre. 2 to 3 squirts were put in each in spring – before May/June. Any new shoots produced after this treatment had normal foliage and were not epinastic. The treatment was carried out in spring 1994. No shoots were noted until 1998. 1 subsequent treatment was carried out in 2001 when 2 to 3 shoots appeared in the composting area. No subsequent reappearancewas noted. The site was visited on 1st October 2004. The site was noted as woodland, with beech, evergreen oak, cherry, hawthorn and light/medium shade. The previous house was built about 1926 with the gardens believed to have been laid out by a local landscaping firm.

Cadgwith: - October 2004 Treatment of *Fallopia* was carried out below Long Loft, Cadgwith GR SW 7213 1446. A variety of methods were used, including glyphosate stem filling, overall glyphosate spraying and stem filling with ammonium sulphamate at the rate of 454g in 1.135litres water injected at the rate of 10ml per stem. Observations suggested that the ammonium sulphate treatment was as successful as that using glyphosate.

f) Landscape scale control – Whole catchment assessment using photographic monitoring: Tregeseal

After 3 years of treatment the following observations were made.

Former CSM research site GR SW 3590 3234 up to iron railed vehicular bridge. GR SW 3642 3231

Epinastic shoots were observed in a number of locations, particularly in the pasture below the cottage. The size of this material and the fact that regrowth of other vegetation was obscuring this made it difficult to quantify. This was the area which had been subject to previous herbicide treatment. There were also normal shoots, at up to twenty locations, but each consisted of less than 5 shoots.

Iron railed bridge GR SW 3642 3231 to water treatment works GR SW 3678 3197

Overall spraying in agricultural land appeared to be more effective than cut and fill though overall spraying seemed less effective on the back hedge. Control within the verge which had been carried out by overall application was not good, with growth on all the recorded sites.

By water treatment works GR SW 3678 3197

Control by stem filling was generally effective, with only 3 sets of growth noted, each with less than 5 shoots.

Water treatment works GR SW 3678 3197 to Nancherrow Hill Bridge GR SW 3706 3189

The area opposite the workshop on the field hedge treated by overall application had 3 shoots. The area treated early by the Environment Agency appeared comparatively clear. Significant reduction was noted in the double treated area below the road bridge (Figs. 4.26,27,28,29). No epinastic growth was noted. This was an area of overall late season spraying.

Fig. 4.26 Site 22 at start of project May 2006
Shows vigorous undisturbed dense growth

Fig. 4.27 Site 22 Year 1 monitoring August 2007
Shows inadequate treatment with branching regrowth

Fig. 4.28 Site 22 Year 2 monitoring August 2008 Shows absence of above ground knotweed apart from small shoot on far left.

Fig. 4.29 Site 22 Year 3 monitoring August 2009 Shows effective control with strong growth of native species.

Above Nancherrow Hill Bridge GR SW 3706 3189 to south of Blackberry Stamps GR SW 3783 3192

Treatment appeared very poor on the south eastern side of road and it was little better on the bank by the road. In both cases there had been limited ability to carry out control

Moderate reduction in density of Japanese knotweed was noted up to the rugby club. Significant height reduction of stems was noted immediately below the road bridge. Generally good control was observed up to the footbridge. Excellent control with <12 small shoots was noted immediately above. Approximately ten shoots remained in the previously heavy infestation by the *Gunnera*. 2 small shoots were noted in the upstream wall. Other material was cut and left on the bank by stream by a third party. Good control was seen by the milk stand and very good control in the quarry. Material has been noted in one specific situation where above ground material was absent for more than one growing season.

g) Combination treatments

a) Herbicide treatment followed by removal to treatment area within site

The site was visited on a number of occasions in 2008 and 2009. Regenerating material was noted on the bunded area in 2008 and treated. A single shoot was discovered in 2009 within the bund. No material was discovered on the sites from which material had been removed.

b) Translocation of material to treatment areas within site and continued herbicide treatment of bunded material

St Erth Civic Amenity Site Extension GR SW 5430 3470

The Japanese knotweed deposited on the material regenerated following the treatment (Fig. 4.30) and was treated with glyphosate at the rate of 1:500 in September 2007. The deposited material was and turned by machinery during Spring 2008 , the considerably reduced material treated in September 2008. The process was repeated in 2009 and 2010. Less than 20 shoots were noted in 2009 and 11 in 2009. 2 were noted in 2010.

Fig. 4.30 St Erth material fall from barrier membrane GR SW 5430 3470

4.4 Discussion

4.4.1 Physical Control

a) Physical removal

i) Removal of above ground material

Grazing

Though there may be some control by grazing, most shoot reduction will take place during the time of greatest palatability. Above ground shoots of the previous year's growth may act as a barrier to access. There is also the danger that movement of material by stock may result in further distribution of viable material. Even in situations where the grazing is thorough, for example by sheep, the noted effect is reduction of above ground material rather than eradication. There is also the danger that some types of stock may spread the plant more widely e.g. pigs.

Pulling

Observations suggest reduction in plant vigour if this is carried out assiduously. There is no evidence of eradication by this means.

Removal of below ground material

Physical removal of Japanese knotweed, in early stages of establishment, spread by remediation of trenching works A30 trunk road Hayle to Bodmin

As individual plants were removed without the accompanying soil mass, disposal costs were minimised. More material of similar type was later observed in the Mitchell area. As this area was closely surveyed prior to the earlier removal operations, and there was some variation in depth of burial, this gives additional credence to the belief that the rhizome can remain dormant for considerable periods. The compacted layer below the plants, particularly in clay areas, appeared to have considerable resistance to penetration by the rhizome and this aided removal. Material at greater depth may take a considerable time to produce above ground shoots so this is not a single stage process. The stage of establishment of material may be material to the degree of success that may be anticipated. Considerable costs were incurred in relation to traffic management as well as operative time in relation to the removal, but this would have been several fold greater if gross excavation had been carried out. If this early intervention had not been carried out removal costs would have increased exponentially.

Removal by excavation, Church Cove, Lizard GR SW 7144 1274

The results appear to confirm previous observations regarding the potential of rhizome to remain dormant for considerable periods of time. It was not possible, due to operational requirements to separate out the rhizome from the excavated material, but the quantities removed were recorded as being higher than would have been anticipated from a visual inspection of above ground material during the previous growing season. It also indicated that visual assessment of stems may not be a reliable method of determination of quantity of viable subterranean material, particularly when the site history is unknown.

Physical removal of material after less than 6 months on site: South Petherwin GR SX 2983 8197 to SX 3067 8179

This site provides further evidence of the ease of transfer of the plant and also shows that properly executed removal of individual shoots can be effective, but that rapid action and continued monitoring is necessary. There was little limitation to downward progress of the material as the subsoil was not compacted, and the growth noted was vigorous. This cases appears to confirm that complete removal within the growing season following deposition, provided that the material is within approximately 300mm of the soil surface, may be possible.

Excavation and on site desiccation of material at Jillpool, Bosinney GR SS 0664 8872

The timing of the work, which was constrained by coordination with the other work and the road closure during the dormant season, made the positive delineation of the infestation more complicated as the identification relied on recognition of dead above ground material in an area of disturbance.
In view of the apparent low nutrient status of the medium, and of reports of the depth at which rhizome has been reported to have been found, the depth of colonisation appeared to be a relatively shallow. Work on this site was compromised by the continual disturbance and it was unclear as to the limits of the Japanese knotweed infestation. There may well have been buried material which did not produce any above ground shoots which was invigorated by adjacent disturbance. The quality of the selection process when the author was not on site on the second day of works may have been of a different standard. In consideration of the amount of rhizome removed compared with that which subsequently regenerated, on a sampling basis, well in excess of 90% by weight was removed. Despite this level of removal, regeneration in the season following disturbance, though of a far less vigorous nature than that previously present, required further control by herbicide. Once this control had been carried out, regrowth was minimal in nature. The observation of a single shoot at the end of the growing season in 2008 after a period when no growth had been observed, places emphasis on the need for continuation of monitoring.

Fig. 4.31 Small regenerating material at Jillpool

Material appeared from areas which were apparently clear at the time of the first assessment. This may be attributable to a history of progressive deposition of material which was covered to a depth which inhibited above ground growth, while material below ground remained viable. Reappearance of above ground material following the initial herbicide retreatment was indicative of phased regeneration, the treatment of the regenerated material appearing to be successful when rhizome was inspected, the criteria being breaking of the material to examine for any areas of potential viability, assessed visually by yellow colouration and moisture content. The work indicated the potential for regeneration of very small material (Fig. 4.31). The work also emphasised the need for close supervision when such operations are being undertaken.

b) Disturbance

i) above ground – the report of diminished vigour following the repeated damage by treading to above ground growth is a similar mechanism to the removal of above ground growth in that it may progressively reduce vigour, but it is not a demonstrable method of eradication.

ii) below ground

Observations on work sites

Early inspection on foot is vital before any machinery entry onto site. Site history is an important factor, particularly where it is suspected that a control regime for Japanese knotweed has been undertaken as above ground shoots of the plant may be very much reduced in size or not be present. Any demolition methodology on a site where Japanese knotweed is anticipated to be present in foundation material needs to ensure segregation of contaminated from non-contaminated material.

Control using initial removal followed by disturbance.

The required timing of the start of the operation on the specific site was May 2001. As the stand consisted of almost no plant species apart from the knotweed, therefore there was virtually no risk of disturbing nesting birds which would normally be a concern at this treatment time. Further, the monotypical stand meant that there would be likely to be a greatly diminished general level of wildlife interest in contrast to that in the varied surrounding native vegetation. Though there was risk of disturbing underground material by the use of machinery rather than hand techniques at the initiation of the work, the area of the site and the density of material precluded manual work except in very limited areas, generally around the periphery. Excavation was planned for the following stage of the work and therefore an element of disturbance was not considered to cause problems by spreading rhizome material more widely.

Access was somewhat compromised, as clearance progressed, by the discovery of banks and pits and features which were considered to have possible archaeological significance. It had not been possible to identify these potential hazards before the start of the work due to the density of the growth. The depth of the leaf mulch observed at the initiation of the work, more than 100mm in more than 20 measured situations, combined with the substantial shading effect of the knotweed when in full leaf, would appear to give strong reason for the absence of other plant species in the centre parts of the stand.

If clearance in the first instance is sufficiently thorough and subsequent herbicide application is limited, this should allow for more localised further treatment and regeneration from the seed bank. The spring tine regime still required to be used over substantial areas of the site, which somewhat compromised establishment of some growth from the adjacent seed bank to give cover to the slope during the winter. The use of overall disturbance ceased in favour of spot treatment with glyphosate as a range of species colonised the site and the knotweed was focussed on small material in restricted areas. Herbicide treatment without disturbance would have needed to be repeated for a period of several years and the most effective herbicides for JK control are not selective, leaving the site bare and thus liable to erosion. Assessment of weight of above ground material at 14.5 kg is suggestive that the cut weight of above ground material is approximately half that of below ground as dug wet weight material at peak of growth.

There was some evidence of induced dormancy from repeated herbicide use and it was believed that this dormancy could be broken by further disturbance of the site. The areas treated with picloram produced very limited regeneration material. Where the picloram treated areas were intentionally disturbed as foliar symptoms occurred, however, regrowth was strong. Although substantial reduction in growth can be demonstrated by the work carried out, quantities of material remained and material was present on the site in 2009. The excavation methodology was compromised by the comparatively shallow depth of soil above rock. The laminae of this rock had been penetrated by rhizome and this factor compromised the effectiveness of the method. It also limited the ability to excavate underground material for assessment, as this rock was found at less than 1 metre below the surface. This phenomenon was also noted at Charlestown (Fig.4.32). The laminaceous, shillet bedrock was subject to colonisation and extraction of rhizome was compromised by this. There has been a substantial diminution of material under the continuing disturbance regime, but a small amount of live material was observed on site in 2011.

iii) Climatic effects

There would appear to be some evidence of resumption of growth from dormant material after particularly cold winters.

c) Barrier methods

i) horizontal

This work showed that removal followed by the use of a membrane may be a worthwhile method provided that the cover is adequate and that the site is clearly marked to ensure subsequent disturbance does not occur. The material in the case cited appears to have been at relatively shallow depth and not fully established. The disturbance seven years after the last treatment of the site which did not result in further regrowth of material is suggestive of successful control at this site.

ii) vertical

Use of vertical barrier methodology on a property boundary

It was not possible to numerically quantify the increased density of canopy as the area had not been specifically assessed, apart from visually, in the growing season before work was required. The material immediately adjacent to the cut area appeared particularly vigorous. This may be particularly relevant where material on a property boundary is disturbed and divided when an operation such as barrier installation is been carried out. It emphasises the desirability of cooperation when Japanese knotweed is on both sides of a property boundary.

As granite is a relatively unfissured material, it was not anticipated that rhizome material would be found attached to it and this proved to be the case with the granite, of which the wall was built, so the inspection and removal was relatively straightforward. The process was aided by the proximity of bedrock relatively close to the soil surface. The soil on the site, being a fine loam, allowed relatively easy separation of rhizome. The fact that the infestation was at a higher level aided the process of excavation.

Barriers may provide a physical prevention of rhizome entering an area. They are often used at or near property boundaries, but the act of cutting rhizome has been demonstrated to result in regrowth which will in the presence of an impenetrable barrier, invade the area adjacent area. The use of a barrier to contain rhizome by cover or encapsulation should take account of the fact that it is not known how long rhizome may remain viable in such conditions.

4.4.2 Chemical control

a) Herbicide timing – roadsides

i) initial practice – spring cutting and autumn herbicide application

This methodology was amended due to the difficulties of dealing with the cut material with a demonstrated high regenerative capacity (Brock et al. 1995) and, additionally, the requirement that, if material were to be removed from site, it must be treated as contaminated waste for the purposes of disposal. An additional factor was the suggestion that cutting appeared to promote extension growth from the underground system at the periphery of the clump, which could promote its spread into adjacent land, perhaps in different ownership. A further complication was that the cutting method had the potential to further spread the plant, particularly on uneven sites where it is possible that the crown material – with the previously cited potential to regenerate very easily -could be struck and thus scattered.

ii) first modification – spring and autumn herbicide application

The optimum time for transfer back to the rhizome system has been demonstrated to occur at the end of the growing season (Price, A.C. et al. 2002; Buschmann 1997). The early treatment detailed above appeared to have the disadvantage of promoting the epinastic growth mentioned elsewhere. Additionally, work by Price et al. (2002) has suggested that little material may be stored in the rhizome system until later in the year. This is very suggestive that earlier application of the herbicide may have very limited effect and result in poor control. In view of the study carried out by Hirose (1984) in relation to nitrogen utilisation, the provision of a fertiliser at the appropriate growth stage may stimulate growth and be appropriate prior to further treatment. Observations have led to the conclusion that, in certain circumstances, herbicide treatment may mean that the central part of the plant system is destroyed, that connectivity of viable tissue between radiating rhizome is therefore lost and shoots observed at the presumed outer limits of the clump are therefore biologically discreet individuals although genetically identical. After herbicide treatment, there may be a period, extending to more than one growing season, when above ground shoots may be absent. When shoots reappear they are frequently at the anticipated fringes of the clump and/or they are at places where disturbance occurs, such as at the interface with a watercourse (Fig. 4.32).

Fig. 4.32 Emergent shoots at red bud stage White River, St Austell GR SX 0081 5013

iii) Single autumn herbicide application (2007)

Late season herbicide application with glyphosate has demonstrated increased effectiveness, though on new sites the size of the material at the time of initial application may mean that the operation is physically difficult to undertake.

iv) Methods in use on roadsides by Cornwall County Council from 2008

The collation and development of a comprehensive database has been central to the development of the control methodology. There is a clear need for assurance of continuity of uniformity of treatment. In cases where there has been discontinuity, control has been less effective as well as more protracted. Maintenance of visibility has been a key issue when control has had to be a compromise between cutting and herbicide where a residual material cannot be used. The herbicide used must be appropriate to the individual site and site circumstances. There is a correlation between the sites where continuation of treatment is necessary and material on adjacent land. In 41% of cases where treatment is continuing, there is material on adjacent land. Clearly there are difficulties in delivering sufficient herbicide to the material above ground to gain effective control through such an extensive underground mass. The normal rate of application of glyphosate for Japanese knotweed control is 5litres product (360g/litre active ingredient) diluted in 200 litres of water applied per hectare. Monsanto, the product manufacturer, has stated that the optimum concentration of active ingredient of glyphosate is as above and there is no benefit of increased concentration. (Sansom pers. com. 2008) The label gives a range of application rates for the product which can permit a higher concentration on herbaceous material. Glyphosate use in the early season has been noted in many circumstances to be counterproductive. Due to the observations of incomplete control after single application in this thesis further clarification on translocation of glyphosate within the plant was sought from the manufacturer of the product (Sansom pers.com. 2012). Cited below.

Subject: Limitation of anticipated control of Japanese knotweed due to proportion of above ground growth available for targeting in relation to that underground

I understand that the translocation pattern of glyphosate is to the growing points.

"Movement is always source to sink with the loading sink delivering first to the closest sinks and then successively away. The big problem is that a very low dose of glyphosate delivered to the most active sinks almost immediately upsets the metabolic processes which then decreases the metabolism of the primary assimilant (usually sucrose) and the increase in concentration results in decreased phloem delivery and so a "self-limitation". As a result it is very beneficial to deliver a large dose suddenly and like a tidal wave it moves to all the reaches of the phloem."

Is this always to the furthest points, with the possibility of diminished effectiveness nearer the crown if the quantity of active ingredient is not sufficient to ensure eradication?

"It depends on what is respiring and consuming or storing sucrose. Mature tissue is often bypassed. Mature stem tissue, rhizomes etc houses dormant meristems. So after glyphosate is delivered to the growing point, bypassing the mature points near the crown, then these dormant meristems will break given the right hormone or seasonal stimulus and then if glyphosate is remaining in the local tissue it will remobilize to the new growing sink. The trick then is to have a sustained tidal wave so that when delivery stops to the growing points the phloem is "full" and the glyphosate then leaches out to the neighbouring tissues. If the concentration is insufficient to kill the new local meristem then although damaged it continues to grow."

The logic would appear to be that at the optimum time of application, in autumn, the areas of greatest activity are at the periphery as the reserves in the above ground mass are transferred for storage.

My observations suggest that treatment can be effective at the centre of the treated clump, but that material may appear at some distance in the following season.

Yes the optimum period is just after flowering. It is during this period that excess assimilant will be redirected to the roots and the rhizome development that occurs after vegetative growth stops. At bloom a glyphosate application will certainly sterilize flowers and result in very low fecundity (for a plant that is not sterile of *course). The trick at this treatment point is to optimize delivery. But very high doses delivered as a foliar application can kill the source leaf and so limit loading and translocation- especially with some formulations of glyphosate e.g Tallowamine based products like the original Roundup. Stem injection bypasses this problem so should be more efficient, but our UK Biactive formulations are much better and as we don't see much difference between injection/stem filling, I don't think this is a big factor in your observations. There is a second but rarely discussed improvement obtained by following a foliar glyphosate spray, usually 30 minutes but as late as a day with 0.5% silwet alone it will often double the uptake reactivating the loading sites. I haven't tried this on perennials but it is very potent on herbaceous weeds. I am not aware of any work with this technique in Europe, so if you wanted to have a look you would be the first!*

Allowing mature tissues to form is equivalent to allowing dormant meristems to set and they can only be killed when they start to grow. I have not been successful stimulating bud breakage with hormones in annuals but maybe perennials are different.

There can also be differences between leaves in different positions on the stem. Cotton for instance has two kinds of source leaves, those actively delivering sucrose and those waiting to senesce. The latter are not good loading sights. So then we can deduce that source leaf position is critical in the developmental status so leaving foliar application until some leaves are senescing will restrict uptake."

I would presume that this may be due to the foliar area available for targeting in relation to the below ground reserves. Is there any data in relation to the effectiveness of the herbicide in relation to anticipated underground mass of rhizome? I.e even with a full mature canopy, the target area will not be sufficient to allow the application of sufficient active ingredient to ensure eradication?

"Maybe, it really depends on how much dormant tissue the plant supports or allows, if it is only one season then it shouldn't be a problem but if lots of dormant rhizomes are strung around from multiple years of storage just waiting for a catastrophe to rescue the plant then you are right and they will have to be killed sequentially."

Is the targeting of the product to the more active growing points, meaning that the less active buds on the way to the terminals may remain viable?

"Yes as I said above."

Would it be reasonable, in view of the observations of peripheral regrowth, to assume that there may remain physical connectivity, but breaks in the translocating tissues, meaning that one has biological individuals?

"Maybe. Phloem delivery has several theoretical forms. At the sink the mesophyll cells may load the phloem directly through plasmadesmata and the companion cell. Alternatively it can be exported to the apoplast and then loaded actively into the companion cell and phloem. Similarly unloading can be direct symplastic or unloaded into the apoplast and then reloaded. I think I have data supporting all four types and like in soybean two types can be in one plant. Apical meristem delivery is symplastic and suffers from self limitation but the same source leaf shows no limitation delivering to roots suggesting root unloading is apoplastic. Hence your notion that once a mature rhizome is setup and allowed to go dormant it may be disconnected however the phloem moving through to the next node must still operate. I doubt they are fully disconnected if the rhizomes are very long. My only experience in this regard is with Johnsongrass and glyphosate is very good at getting all the rhizomes."

This is not in any way criticising the effectiveness of glyphosate, which we use at the most effective time, but to demonstrate that the great quantity of below ground material with the potential for regeneration means that a programme for several years can be needed.

"I have tried adding an auxin to the mix due to its longevity - it doesn't antagonize glyphosate and will provide residual root inhibition. But it can damage other trees and shrubs so be careful."

Is there any benefit in repeated doses of glyphosate at any specific time period in the autumn?

"Covered above."

These comments support the findings that an effective first treatment of a site is vital and treatment may have to continue for several years on previously inadequately treated sites or where significant volumes of rhizome are present.

b) Sub-lethal effects

On roadside sites, glyphosate had originally been used by Cornwall County Council on a biannual basis, the first application being in May/June and the second in September. This would appear to be of questionable validity when consideration of remobilisation of nutrients within the plant system is taken into account (Price et al.

2003). In contrast with this, single late autumn applications of glyphosate at SW 7743 1081, SW 7730 1983 and SW 7724 1981 near Coverack have resulted in the appearance of only a few normal – though weak – shoots in the growing season following application, but no epinastic growth. The reasoning for the use of glyphosate in May/June was to control the plant in situations where visibility may be compromised by letting it attain its full height and where a residual compound is not appropriate. Sites have been observed by the author over three growing seasons and, while the epinastic shoots prove that the plant is still viable, the absence of normal growth over such a period raises the question as to whether these effects can be overcome over time or whether removal of the centres of epinastic growth may result in the restoration of normal growth.

When an area has been treated with a sub-lethal dose of glyphosate the regrowth often consists of a proliferation of dwarf shoots with distorted foliage. If the plant is then disturbed and the rhizome fragmented, a reversion to typical but weak growth patterns has been noted in some areas. This would suggest that the concentration of remaining glyphosate is at the visible growth points and that the separated plant parts resulting from disturbance are stimulated by the disturbance to produce shoots. The assessment methodology, by removing material, will affect future growth. The removal of the crown, with evidence of residual glyphosate – whose mode of action is understood to be centred on growth points, may have the effect of reducing growth inhibition in the surrounding rhizome area on site and thus stimulate the resumption of normal growth. The theory on which the work was carried out was that any residual effect of the herbicide would be concentrated in the areas demonstrating epinastic growth and that removal of such material could have the effect of stimulation of normal growth elsewhere within the plant system. None of the removed sampled material produced normal growth, even after two seasons.

In areas away from the points at which the epinastic material was removed at Tregeseal and Rocky Valley, normal growth patterns, albeit of small material have been noted, especially in close proximity to the watercourses after up to 5 years. It is understood that all material had been treated in these areas, but it has not been possible to determine whether direct conductivity existed between these points and those from which the material was removed.

The effects of the herbicide would appear to be limited when glyphosate is applied at stages of growth before material is translocated to below ground sections of the plant (ie early in the growing season). There may be a period when normal growth may reappear at a distance from the original treatment point due to re-emergence of previously dormant buds. The implications for management are that visual observation of above ground growth after such a treatment regime, may not provide a reliable assessment of below ground mass, particularly because the presence of epinastic material which is far less apparent than normal growth. A control programme may be compromised by the development of epinasty as the target area for foliar acting herbicides will be physically limited. The size of above ground material may make site assessment difficult. A continuing monitoring regime will be needed as normal growth may well reoccur after a period of several years. During this time frame it is likely that other species will have recolonised the area and that a renewed herbicide regime may inhibit this recolonisation process.

c) Control of Japanese knotweed by application of herbicide into cut cane stumps

This method is very labour intensive when compared to overall foliar application. It is very targeted and avoids surrounding vegetation and features such as watercourses. When considered in a general fashion by photographic monitoring in the work in Tregeseal, the technique appears to be questionable in its effectiveness in contrast to overall foliar treatment. The disposal of the cut material has the potential for further spread, particularly near watercourses, and this may be particularly relevant in areas of high footfall. The technique does have the advantage, and may be advantageously used, on the edges of large stands where there are particular sensitivities in relation to adjacent vegetation or watercourses. Fig. 4.24 indicates that although a significant reduction in time taken, effort and financial input occurs over the first two years of treatment there will be a requirement for continuation of control, over at least a twelve year period in this case. The fluctuation of time input required over this continuing period is indicative of occasional reappearance of material which may be a result of herbicide induced dormancy.

Following the initial treatment, the stem regeneration is generally too small to permit further injection and weed wiping or spot spraying is required. Such material can be difficult to find in recolonising vegetation.

d) Alternatives to glyphosate

The use of a residual herbicide such as picloram may occasionally be effective on appropriate sites (see case study regarding Scorrier treatment site) but on a site where material is disturbed within a short period of application its effectiveness may be much reduced (observations in the Veryan case study). Ammonium sulphamate did show some promise but has now been withdrawn from use as a herbicide. Manure and its creation of anaerobic conditions may have some control value but this is unlikely to be approved by the Environment Agency in most conditions due to risks of ammonia and nitrate entering watercourses.

e) Landscape scale control – Whole catchment assessment using photographic monitoring: Tregeseal

The photographic monitoring has given a good overview of progress over the scope of the project. This visual information has been extremely useful to demonstrate effective control to partners and the public. It has also provided evidence of incursion by other species as the Japanese knotweed has declined. These do include another invasive alien species - *Impatiens glandulifera*.

Because of the physical size of the stems, stem filling is only appropriate on stems more than 8ml in diameter. The methodology developed by the National Trust and submitted for approval by Cornwall Council to the Pesticide Safety Directorate is an extrapolation from that already approved for stump treatment. This knotweed cut stem process was found to meet the previously approved process for stump treatment. In foliar application the maximum statutory approved rate of glyphosate application at label concentration for forestry is 10 litre/ha. However for stump treatment there is no limit to the number of times an area can be treated per year and no guidance on the maximum number of stems permitted to be treated in a given area. There was some concern that where knotweed stems were treated by this method their density could mean that an amount of herbicide far in excess of that permitted for foliar application might be applied. Therefore work was carried out to determine the number of stems likely to be encountered in a given area. The work showed that in most circumstances the stem density should not result in over-heavy herbicide application. The stem injection methodology did not appear to give better results in comparison with overall application. This accords with work previously carried out on the White River, St Austell (Brown et. al 1999). The method is very specific in its delivery and may be appropriate where particularly sensitive areas have been colonised by Japanese knotweed or where the plant is growing among other desirable plants. The time taken for application is, however, in the order of ten times that for foliar application (Trickey pers. com.2010) and may be difficult to deliver in many locations e.g. the steep banks of a watercourse. Early season delivery by this means also seems to have a likelihood of resulting in epinastic growth. On one site mentioned within Tregeseal valley which was inadvertently treated twice by overall foliar application within a period of three days above ground growth was significantly reduced. One area was noted within the photographic monitoring which did not produce any above ground material for a complete growing season.

4.4.3 Combination treatments

a) Herbicide treatment followed by removal to treatment area within site

The methodology was effective, but emphasised the requirement for the continuation of monitoring and treatment to be included in the terms of contract for works. The material may need to be turned to ensure stimulation of material and to avoid the possibility of material at depth within the bund remaining viable, but not producing above ground shoots.

b) Translocation of material to treatment areas within site and continued herbicide treatment of bunded material

St Erth Civic Amenity Site Extension GR SW 5430 3470

This was a remedial operation after works had been initiated and material had therefore been spread. The site engineer was fully cooperative, but works were compromised by the presence of trees and of an archaeological site. This emphasises the need for a comprehensive consideration of the site prior to any intervention activities. If this is not undertaken the result is likely to be compromise of the usability of the site and increased costs. The material which had previously been subject to a treatment regime using herbicide was marginally compromised by being drawn off the membrane (Fig. 4.30). The depth of material on the membrane exceeded that requested and this may be a factor in the lack of appearance of shoots from the more deeply covered material. Turning material by machinery on a membrane carries the inherent risk of material falling onto the surrounding area, and has the potential to rupture the membrane which could result in material colonising beneath the material.

General Discussion

There are a number of observations which record the absence of above ground material for more than a single growing season, but where material has subsequently reappeared, often following disturbance. There is also some evidence of reappearance after particularly cold preceding winters.

Physical removal techniques have proved effective in some circumstances, with a success rate in excess of 90% when assessed by number of canes before and after treatment. Penetration between layers in slate beds has been observed (Fig.4.33). Where such rock layers are close to the surface of the soil the efficacy of excavation techniques is likely to be compromised. Integration with the rough undersurface of poured concrete and penetration of tarmacadam have also been observed to be subject to colonisation by rhizome Figs. 4.34,4.35) .

Physical separation, on suitable, generally fibrous soils where some sifting process is possible, with sufficient concern in relation to the method of operation and to the care with which the separation process is undertaken, has been demonstrated to provide a high level of control, albeit requiring follow up control operations and/or the requirement for an alternative disposal system for soil material which has the potential to remain contaminated. Where structures are within such a clearance area and are the subject of demolition, it has been observed that rhizome has become established in the rough undersurfaces of concrete and that due precautions are necessary to ensure that above ground parts of the building, which are demonstrably uncontaminated by the plant, should be removed as a separate operation. Where demolition is carried out as a single operation, the amount of contaminated material will be increased considerably.

Geological conditions also need to be taken into account in view of the noted penetration of rhizome between strata in slate beds.

Fig. 4.33 Rhizome penetrating rock strata Charlestown GR SW 6943 2492

Fig.4.34 Rhizome penetrating tarmacadam

Fig 4.35 Wider view of colonisation of tarmacadam

These facts indicate the difficulty of work methodologies whose objective is to guarantee that any medium is capable of being guaranteed to be free of any Japanese knotweed material with the potential to regenerate.

Early season use of the herbicide, glyphosate, has been observed to result in epinastic growth. This has been observed to continue for more than a single growing season. Rhizome material removed in such situations has shown capability of production of normal shoot growth. Very late season use of glyphosate on sites where less than 40 above ground shoots have been recorded has resulted in no recorded renewed above ground growth after six years of observation. Disturbance in the short term following application of picloram, has been observed to result in the renewal of active growth. Cutting and stem filling with glyphosate has been found to be no more effective than overall herbicide application with the chemical. It has been recorded that any renewed growth after treatment is often at a metre or more from the original treatment.

The range of conditions in which the plant is found and the varying time requirements in relation to the required completion of works make it very difficult to determine a single methodology which would be appropriate for all circumstances. In most case a late autumn foliar application of glyphosate will give the most effective results but in some cases a number of methods will need to be combined to produce the desired result. For example in urgent cases physical removal followed by monitoring and glyphosate spot treatment as necessary will be required.

The work has given indication of the amount of material which is likely to be found below ground. The proportion of underground stem, in relation to root material, can be high, as is the quantity of underground material in total in comparison with that above ground. These facts mean that it may well be difficult to apply an adequate dose of herbicide to the plant in a single operation to provide sufficient active ingredient to achieve eradication. The late season use of the herbicide, glyphosate has been found to be effective and is licensed for use in the widest range of circumstances, but full control is very rarely gained in a single year and monitoring and treatment may be required for over 12 years.

The observation of renewed growth after treatment, often at a metre or more from the original treatment, is suggestive that the herbicide may be not be translocated to all the growing points. It is also suggestive that the centre part of the plant may be dead, that viable connectivity is broken and that a number of individual plants are present rather than a single entity. This will compromise any conductivity testing method in relation to the plant when in situ.

The use, during the active growing phase, of herbicides based on the active ingredient, picloram, may be appropriate in certain situations where further disturbance of the ground is unlikely The areas in which this product can be used are limited as it is not approved for use in or near water and it can affect nearby dicotyledonous growth.

One of the particular problems is that a sub lethal dose of herbicide may result in the loss of all above ground growth for a period of more than one growing season. As the criteria for assessment of the success of a methodology are often predicated on the presence or absence of above ground stems, this may result in an assessment of an area being considered to be free of the plant when this is not the case. Further disturbance of material is almost certain to lead to further fragmentation of the rhizome, leading to regeneration from those parts less affected by any previous herbicide activity e.g. bud material which was not active at the time of herbicide application.

Appropriate timing in relation to the use of particular herbicides has been shown to be of considerable importance, the problems with early season use of glyphosate being a particular case. Advice to take “immediate action” by gardening writers without caveats can result in the use of what is one of the most commonly available herbicides, based on glyphosate at an inappropriate time resulting in the production of epinastic shoots and a false belief that the plant is controlled. It has been observed that material connected to such shoots can return to normal growth after a period of time which can exceed a year.

The targeting of the undersides of the leaves has been observed to enhance results in relation to foliar applied herbicides. This may be due to the fact that the upper side of the leaves has a coating which protects the leaves from a range of environmental factors, while the underside does not have such protection.

4.5 Conclusions

The range of available methods of control needs to be related to the individual site and the time available for the process. Consideration of an area during the dormant season or without any knowledge of the history of a site is unlikely to provide a reliable assessment and can result in increased costs to deal with subsequent recolonisation. The costs associated with delays in development or other factors which require the immediate use of a site, mean there is likely to be little alternative to excavation. Immediate removal off site of all potentially infected material requires appropriately licensed operators for such off site transport of material and the material itself is required to be sent to an appropriately licensed facility and requires the payment of landfill tax as well as the physical removal costs. Costs may vary widely according to the distance the material is required to be conveyed. Separation methodologies can be appropriate provided that they are carried out with adequate care. Relocation of excavated material within the site boundaries for further treatment can be possible if space permits. In all of these removal processes, there is further cost for import of materials to restore levels. On site burial to a depth of 5 metres, or 2 metres if the material is fully encapsulated is a method which avoids transportation costs, but an adequate record of such activity should be maintained as a developed site is likely to be disturbed and/or redeveloped at some stage in the future. Appropriate herbicide methodologies may be the least expensive and indeed the only practical methodology in many circumstances provided there is no short term removal requirement. Even in the case of herbicide application, although the material costs may be relatively straightforward to determine, the application costs may vary widely, from straightforward access available to vehicular transport through to extremes which may require the use of specialist access methodologies. Herbicide may be of limited efficacy in situations where the target area for the material may be limited in proportion to that underground. Regardless of the methodology deployed, there is a need to incorporate an ongoing monitoring cost for at least five years.

Chapter 5

Discussion and Conclusions

This work was initiated in view of the observed spread of *Fallopia* in Cornwall, which was noted as an issue within the Biodiversity Action Plan for the county, as well as on a wider national and international scale. The demonstrable increase in costs due to delays in taking action for control, particularly on development sites was, also a factor, as was the variation and uncertainty in methodologies being employed for the control of the plant. The aims of the work were to determine key gaps in knowledge by understanding more of the physiology of the plant and to consider workable methodologies for control, sampling and assessment of the efficacy of the control. The role of human activities in the spread of the plant led to development of educational methodologies to increase knowledge for the target audiences.

The Cornwall Knotweed Forum, of which the author is chair, has raised awareness of the plant and has attempted to demonstrate a reasoned approach to its control, placing priority for most immediate action in areas where there is the highest likelihood of spread.

In order to extend this knowledge and to gain a breadth of information the author in conjunction with others, has undertaken public awareness exercises such as attendance at shows and the production of guidance material (Appendix 15). This has been an effective means of communicating with the general public and local organisations. It is believed that this approach has assisted in reducing the concealment of the presence of the plant, which is a likely consequence of adverse publicity about it and, particularly, its effect on property values. Records of the plant in situations where it cannot be seen require permission from the landowner concerned. There has only been one instance when, having been invited to a site, the landowner has refused such permission. In view of the number of occasions when such visits have been requested, this is felt to be some measure of success. The currently declining number of records being received in relation to new sites, particularly those resulting from fly tipping, is considered as indicative of the success of this initiative.

The data produced emphasise the correlation between transport corridors and the likely presence of the plant. The recorded distribution within watercourses is a specific example. In contrast, the absence of the plant in areas such as the high moorland, where there is a far lower level of human activity, is notable. The danger of linear activities promoting further spread, as an example, trenching within highways, also demonstrates the significance of the database to provide a record to check before the commencement of works. There did not appear to be an association with geological conditions. As an example of this the area cited near Bolventor on a granite substrate has no noted occurrences, while the area around Camborne and Redruth has a high number of occurrences in a geologically similar situation. The principal differentiating factor is the presence and interference of man in the latter situation. Further confirmation that the plant can grow in such upland conditions is witnessed by records on the in relatively undisturbed conditions at the summit of Carn Brea, where fly tipping was probably its means of introduction. The data obtained from the site at Veryan, where there is good record of the original area of planting of a variety of the plant not present in the near area and with a clear knowledge of its time and area of planting, (Chapter 4) provide further information regarding likely methods of spread. The role of human activities in dispersal is demonstrable in many of the recorded situations. Further evidence of the role of disturbance in spread is afforded by the relatively slow rate of increase recorded over a period of eight years at Coverack.

The work has extended and refined the surveying methodology carried through by BSBI to provide a greater level of information on sites in Cornwall than is available in any area of equivalent size. Examples of this are the refinement to survey by polygon rather than point data and to clarify the physical situation of individual infestations. A particular point is the number of additional sites in areas within settlements, such areas being likely to be under recorded, particularly when introduced plants, and plants considered to be garden subjects, are the target.

The development of the Cornwall and Isles of Scilly database has provided a firm starting point from which priorities for action can be determined. The use of GPS surveying methodology has provided an accurate definition of sites, though its use may be somewhat limited in areas of poor reception such as deep valleys. The database provides information in relation to the type and sensitivity of habitat and an assessment of the options for control based on accessibility, density of cover and vigour of growth. The requirement for reports of the plant to be verified by trained operators has reduced misrecording. The set parameters in relation to maintenance of entries on the database reflect the unknown period for which rhizomatous material may remain viable. The work carried out within this provides a groundbase for a wide variety of interest groups. It provides some initial guidance, but, particularly where works are intended, the benefits of an appropriate and timely survey are further emphasised by field observations.

Brock and Wade demonstrated that material of 0.7 of a gram of rhizome of the plant can be viable. This work has shown that material of 0.0109 of a gram can regenerate. The work was further developed to show that even such small material is capable of maintaining its viability in moist conditions for more than 9 months. This has implications for long term management of sites, particularly those that have been disturbed. The fact that rhizome of such a small size can regenerate means that any physical separation method for rhizome in soil cannot be guaranteed to pick up all viable material on a site. Disturbance and fragmentation of the rhizome into small pieces could result in increased potential infection and spread across the site. It also has implications for any sampling methodology. If such small material is present within a construction site, it is difficult to see how a legally meaningful sampling methodology can be devised to account for such small material in an area which may extend to several hectares. Observations of rhizome failing to produce above ground shoots for more than a growing season and communications indicating that deeply buried rhizome may remain viable for a number of years are additional complicating factors for any assessment methodology.

The work did not reveal a conclusive chemical testing methodology to demonstrate viability. The majority of testing procedures are used for material where external contamination is at a low level e.g. above ground material or seeds. The testing of rhizome therefore becomes difficult at an initial stage. A further factor could be the range of potentially activating material within the rhizome. Material treated in a number of ways, such as baking and boiling, when tested against material demonstrably viable – by the growing of associated and previously attached material – did not demonstrate significantly demonstrable differences when recorded graphically.

A viability test will only provide an individual assessment and, apart from giving an assessment of an individual item, its effect cannot be used for extrapolation on a wider scale as it could, for example when testing representatives of batches of, say coniferous seedlings for quality and potential for survival. When the individual sample is being tested, the position on the sample from which material is acquired is also of relevance. The generally observed pattern of progressive desiccation is for the thinner material to dry out first. Instances have been recorded, within the work, of lateral cracking of rhizome, with apparently viable bud material remaining between necrotic sections. Even if testing is predicated on bud material, the growth from apparently undifferentiated material, observed in the production trials carried out, adds a further complicating factor. This has implications for a number of land management operations, and leads to the conclusion that a cautionary attitude should be taken in relation to burial of the rhizome both from the type of material showing capacity for regeneration and because of its as yet undetermined period of retention of viability.

Cane count or percentage cover before and after control operations has been the most frequently used methodology when assessing the success of a control methodology. Such use of above ground material for assessment of any control methodology is also called into question in view of observations which indicate the capacity of the plant to regenerate from material which has not shown above ground growth for several seasons. In the case of epinasty, the work suggests that material can remain in this state for more than one growing season. This was particularly relevant on the site detailed at Church Cove (Chapter 4) where the single noted cane gave poor indication of the quantity of material underground. Many assessment methodologies not only rely on the quantity of above ground material as the criterion for assessment of the efficacy of a treatment regime, but are frequently carried out on only a single occasion, and a site may be considered free of the plant when it is not. The size of epinastic shoots which may occur after sublethal herbicide application means that they may not be observed when assessment is being undertaken. It also means that herbicide uptake by foliar action is severely limited and that there may be the potential for regrowth at the outer margins of the plant once the effect of the herbicide has diminished. Above ground monitoring may indicate numerical success, but practical difficulties of treating material in regenerating vegetation remain, particularly when the small amounts of targetable foliage compared with the likely quantity of remaining viable underground material are taken into consideration.

This thesis, following observations by Hayward of the likelihood of spread of the plant within the sea, has demonstrated that rhizome can survive in saline conditions for periods of up to three months (Chapter 3). The implications of this for control and management are that, during flood conditions, rhizome can be washed down and may be able to spread along the coast. Further evidence of the spread of rhizome under flood conditions within watercourses was observed at Boscastle (Chapter 3). The survival of rhizome material for several months in fully saturated conditions has additional concerns for the management of the plant in the vicinity of watercourses.

Earlier work has suggested that rhizome may remain viable in conditions analogous to composting (Morris 1999) (Ward 2003). This work has shown that maintenance of a temperature of 40C or over maintained constantly for 14 days removed viability in all samples tested. This means that is theoretically possible to envisage a composting system which could treat Japanese knotweed and remove rhizome viability. However, even segmentation of material and reliable temperature control would be essential and open composting systems cannot maintain the precise temperature control throughout the heap necessary to ensure complete removal of viability from various sized rhizome. The implications for Japanese knotweed disposal are that only in vessel composting systems should be considered, the material to be processed should be prepared to a consistent standard, that accurate temperature monitoring throughout the material should be undertaken and the residence time for the material within the vessel should not be less than 14 days.

The work has provided further guidance as to the quantity of material expected to be found below ground. This appears to vary somewhat and stem density was not found to provide reliable indication of the quantity of material to be found below ground. This was particularly apparent in the case of the excavations at Trengrove and Church Cove, where the substantial quantity of below ground provided further evidence of the capability of rhizome to remain in a viable condition, but not to produce above ground stem material.

The recording of the rate of growth clarifies and extends work by Child (1999) as it covers four years and is collated with temperature and rainfall records. Particularly relevant factors include the recording of a rate of growth of 15.5 cm in a 24 hour period and connection between stem extension timing and temperature. This could have predictive significance regarding anticipated changes in climatic patterns as well as a present use in determining optimisation of timing in relation to control operations, particularly by more closely determining the application timing for herbicide whose optimal functioning is at the time of most rapid growth.

The size of material demonstrated to be capable of regeneration, the maintenance of viability in material which is physically connected but which has necrotic material between individual centres of viability and the likelihood of previous disturbance of any test site (Chapter 3) all call into question the value of a viability testing procedure in the field situation.

The first criterion in relation to the validity of viability testing should rest within the appropriate methodology to gather a representative sample from the site.
On the field scale, note has been made of sites where the crown of the plant appears to have been killed by herbicide or other action and shoots which have been observed at some distance presumed to be the periphery of the original infestation, may maintain physical connection but lack biologically viable connectivity. On a more simplistic scale, in the light of the many sites observed, the phenomenon of the “undisturbed site” is an extremely rare occurrence. Occasions have been noted where a machine has been used to “tidy” a site where Japanese knotweed has been dumped at the entrance, resulting in widespread dispersal of viable material to random positions and at random depth. The area cited at Jillpool would appear to have had material within it which was not producing above ground shoots. Any sampling procedure is therefore likely to be questionable in relation to its representational reliability.

In view of the demonstrated size of material which has shown capability of regeneration, it seems that the likelihood of producing a meaningful strategy to demonstrate, conclusively, legal and/or biological assurance that no viable material is present in the volume of soil which may be affected seems low. It would seem likely that, in the case of rhizome at least, the size of material is in direct relation to the time for which it may remain viable without production of shoot growth.

Penetration of rock strata by rhizome in a coastal location, and particularly on one of the field treatment sites has been noted (Chapter 4). This phenomenon, which is also recorded in the built environment, has management implications when separation of the rhizome from the soil mass is being undertaken in that, particularly in the case of inclined slates, penetration may be to a considerable depth and there is the danger of leaving viable material on site. Within the built environment, the colonisation by rhizome of the rough undersurface of concrete or tarmacadam causes problems in management in that, even when put through crushing machinery, rhizome of a size demonstrated in this work to be capable of regeneration may remain adhered to the material with the potential for further transmission. If a demolition methodology on a site where Japanese knotweed is noted in close association to buildings to be removed does not take this factor into account, and utilises a wholesale rather than a separation methodology to keep demonstrably uncontaminated material separate, this potential for further spread is greatly increased. In situations where the plant is growing in condition where the rhizome has not colonised substrates, particularly where laminaceous rocks are close to the surface, and the soil does not contain material with the potential for colonisation e.g. rough, as poured concrete, excavation methodologies, carried out with adequate care, have resulted in a reduction of observed regrowth of between 95 and 100%. This assessment could be criticised for the use of assessment by determination of above ground material (see above) but the difference between assessment by this methodology, rather than its use when herbicide control is being assessed, is that the use of herbicide may have the effect of suppressing growth, while the disturbance by excavation has been shown, by work at Veryan, to result in stimulation of the rhizome.

Testing has indicated that the cutting of above ground material does not appear to result in stimulation of underground rhizome (Chapter 3) but that underground disturbance results in further below ground extension (Fig. 3.35). There may have some seasonal influence in that material disturbed early in the growing season at Jilpool produced above ground shoots, whereas that at Veryan where the plant was in leaf, resulted in underground extension of rhizome. Stimulation of growth by pressure and movement of the action of walking has been observed. (Fig. 4.7). This should be considered as a caution, for those managing access routes, in relation to the possibility of encouragement of spread of the plant onto neighbouring land.

The work has clarified that a number of different techniques may be applicable for the control of Japanese knotweed dependent on the situation and a variety of other factors. One of the key factors is whether the plant is entirely on one property. A large percentage of highway sites where continuing treatment is required are on sites where the plant crosses onto the highway from adjacent land. An additional factor is that a percentage of the population are unwilling to use herbicides.

Herbicide treatment has been demonstrated by the field work to be effective, but the product used must be deployed at the appropriate season to optimise its mode of action and a realistic time scale taken into account, depending on the size of the infestation. The use of glyphosate immediately prior to senescence has been recorded in the work to result in control by the use of a single application in cases when less than twenty stems are present. The use of this material, earlier in the season, has been noted to result in epinastic growth and a poor standard of control. Larger stands of the plant require late season application, using this material, to be continued for at least three years, but this time period will depend on the degree of establishment of the plant and the quantity of material on site. Treatment with picloram earlier in the season has been shown to be effective, but its area of use is more restricted, it not being permitted for use near water or sensitive plants. In either case site monitoring needs to be continued for a period of at least five years after the last above ground material has been noted.

Grazing has been observed to have some limiting effect on stand extension. From the viewpoint of management, however, there is risk of spread of the plant from animal foraging activities. There is a presumption that this may have been the case in the positioning of some of the outbreaks at Veryan, it seeming possible that underground material could have been pulled up by the grazing animal with above ground material and dropped when the more palatable above ground part had been consumed. The varying methods of grazing by different species are also relevant in relation to control or possibility of spread. Even when carried out in a most effective manner, with grazing by sheep whose feeding pattern is to graze closely with the minimal disturbance of below ground material, grazing can at best be regarded as a method of control rather than eradication, as noted by the continuing presence of the plant in a situation where grazing had been continued by this species for more than fifteen years.

The excavation methodologies deployed in Chapter 4 provide some evidence that, though statistically a large percentage of viable material may be removed, taken in combination with soil structure, potentially contaminated colonised material such as fissured concrete within the soil body and the size of rhizome shown to be capable of regeneration, its efficiency is at least variable and heavily dependent on capability and motivation of site operatives. In all circumstances an ongoing monitoring programme is essential. The duration of such a monitoring period requires further work, but it is considered it should be at least five years. The deep burial of underground material can be an effective methodology, with the caveat that the period for which rhizome may remain viable in such conditions has not been fully determined. The fully enclosed burial permitted at 2 metres below ground level permitted in the Environment Agency methodology (Environment Agency Code of Practice) may be of concern in relation to the rate of redevelopment of many non residential premises, such concerns being related to possible alteration of levels or the use of piling in relation to construction. Such actions could have the potential to rupture the enclosed root barrier and could result in the regeneration of the plant. The use of a barrier, when the underground mass is disturbed, appears to result in directed, invigorated growth.

This thesis has demonstrated, by reference to the range of highway sites which have been part of the treatment programme, that the use of herbicides at inappropriate seasons can lead to suppression of growth or the development of growth patterns which compromise and delay further control. The major example of this relates to the use of glyphosate in the early season where the effect has been to restrict growth and compromise future control. One of the principal benefits of the use of herbicides can be, when adequate time is available, to treat without disturbance of the underground mass. Assessment of success in such circumstances is generally predicated on presence or absence of above ground material. The absence of above ground growth for a period of one or more growing seasons should not be regarded as a satisfactory indicator that no viable material is present below ground.

Disturbance techniques may, in specific cases, be a valid management technique, dependent on the depth of rhizome within the soil. If the rhizome is at considerable depth, as an example on a site where progressive tipping has been carried out over a prolonged period, viable material may be left at a depth where above ground shoots are not produced by the stimulation and therefore there is no above ground material to monitor and treat and the false assumption may be made that the site is clear of infestation. This is also a concern if the action of disturbance means that material is put down lower in the soil profile rather than lifted to nearer the surface. If rhizome is fragmented, the ratio of above ground to below ground material will be increased. As the segments of such separated material are smaller, the requirement for photosynthetic action to be initiated by the plant at an earlier stage to promulgate further growth is increased and the efficacy of subsequent herbicide dependent on such material for satisfactory uptake will also be improved.

The varying time requirements for control and the demand of, particularly, the construction industry, for some form of guarantee of eradication are questionable in relation to their achievability in practical, botanical or legal terms.

The number of highway sites which are producing growth has fallen progressively, but small, weak material continues to appear on a considerable proportion of sites. It has not been demonstrated what quantity of viable rhizome remains underground and whether the herbicide is having an inhibiting effect largely centred on the above ground material. Certainly the target area for herbicide is reducing. One particularly important issue is the demonstration of the disappearance of above ground growth for more than one growing season. The highway treatment programme in Cornwall, with its considerable number of inactive and probably eradicated sites, provides evidence that appropriate and correctly timed herbicide application remains the most appropriate treatment methodology in the majority of cases where the timescale permits. Observations have emphasised the need for a continuation of monitoring for at least the time period of five years after above ground growth is last seen, as presently used. Where there is Japanese knotweed adjacent to, and probably connected to, the material under treatment within the highway, the proportion of sites which require continuing treatment is high, indicating the limitation in relation to the translocation of the herbicide and the requirement for application to the whole area colonised by the plant, to maximise effect.

There is a concern that biological control methods could be seen as providing “the answer” in relation to control of *Fallopia*. This assumption could be highly counter productive if it results in the withdrawal of current control methods. In the first instance the efficacy is not yet known in relation to widespread control and it is likely to take several years to gain data in this respect, secondly it is likely to, at best, result in diminution of vigour of the plant rather than eradication. Images from Japan (Watanabe, K. Pers. com. 1996) indicate strong regrowth of Japanese knotweed following disturbance in its native environment. It will therefore be necessary to find integrated control methods to take advantage of biological control, and to complement it. Where control has already been established, continuation of the current programme to eradication would seem the appropriate objective. It is therefore strongly suggested that the point be reinforced that biological control may assist greatly, but that it should be integrated with other control methods to maximise effect.

The use of any form of below ground disturbance technique has legal implications, particularly when carried out close to ownership boundaries.

There are fundamental problems in relation to the Wildlife and Countryside Act 1981 which is the main statute regarding Japanese knotweed.

The Act states:-

if any person plants or otherwise causes to grow in the wild any plant which is-

(a) included in Part II of Schedule 9 he shall be guilty of an offence

The schedule includes *Fallopia japonica* under the name, in the original Act, of *Polygonum cuspidatum*, with the caveat that the common name, Japanese knotweed, which is commonly used to describe all the species cited, is for guidance only. This was very restrictive in that *Fallopia sachalinensis* was not covered by the legislation, nor was the hybrid *Fallopia* x *bohemica* until the relevant Schedule was amended in 2010.

The Act relies on an act of commission for an offence to have occurred. Thus failure to take action to prevent spread is not an offence.

There is no definition of "the wild" in the Act. If property is of uncultivated nature, it could be construed to be "the wild" as set out by the Act, but without guidance each case would need to be considered individually. From the viewpoint of a caged, imported animal species covered by the Act, release from a cage, even in the centre of a city, could well be considered to be release into the wild. The same is far more difficult to apply to a plant in a landscape where some form of cultivation, even on a widely periodic and minimal basis, is demonstrable. The lack of cases brought under this section of the legislation during the thirty years which it has been in force, compared with the number of occasions when there is strong evidence of the plant being spread, is evidence of the ineffectiveness of the legislation.

From the viewpoint of common law, the issue of disturbance and the reaction of the plant to it, calls into question, when the plant extends across the boundary of two properties, the actions of an individual establishing a vertical root barrier demonstrably impervious to rhizome penetration, to prevent ingress into the property. The installation of such a feature will cut the rhizome and the barrier will effectively prevent the extension back into the property and thus direct its growth, demonstrated by this work to be stimulated by such action, into the adjacent property. If the

adjacent area is considered to be “the wild” within the terms of the Wildlife and Countryside Act, action could conceivably be taken by the relevant statutory body against the installer of the barrier as the action of such installation could be considered an act of commission, causing the plant to spread. Even if this is not the case, action for nuisance under common law might be considered as a possible course of action for the aggrieved party.
Such use of root barriers at the boundaries of sites when the plant is established on both sides has the potential to raise a number of issues. Apart from the points raised above, there is also the operational fact that the barrier is unlikely to coincide with the exact property line, and its position is therefore likely to be a compromise, perhaps resulting in the continued presence of the plant along the property boundary in a position which may be operationally difficult for control by either party..

This situation emphasises the desirability for cooperation between the affected parties and the requirement for adequate, recorded communication between them when the plant crosses boundaries. Recorded communication and offers of cooperation can aid in the demonstration that, if one party has taken action and this has resulted in spread, all reasonable actions had been taken and offers of cooperation had been made, prior to the action, to the other party.

In the highway network in Cornwall, about 40% of the sites undergoing continuing treatment have connected material into the off highway part which is not being treated. This could result in progression towards pursuit of action under public nuisance on the grounds that control of the plant can be demonstrated, damage is caused by the plant and a continuation of public expenditure is required to maintain control. The pragmatic stance taken by Cornwall Council of assessment of the likelihood that the infestation started within land in the Council’s responsibility and offering, in such cases, to use a herbicide regime to treat the entirety of the stand has resulted in more effective control at little additional cost as the operative would be present on the site to deal with the plant on the Council’s ownership as a matter of routine.

Key issues in the consideration of control methodologies include the wide variety of sites on which the plant has been discovered. The widest range of control options are likely to be when there is no danger of interference by any agencies likely to disturb the plant, the plant is physically easily accessible, within a single ownership, isolated from valued surrounding growth and water, there are no hard materials in the close proximity (>10metres from any part), no legal constraints on operations and there is no time restriction on the operation. The number of circumstances in which all these parameters are fulfilled is likely to be low. The attached spreadsheet (Appendix 20) attempts to provide some summary to take into account these factors.

Appropriate and timely planning of operations is particularly important, the field observations having noted a number of occasions where the site has been disturbed in an inappropriate way immediately prior to activities such as construction, making it virtually impossible, in line with the small size of material demonstrated to be capable of regeneration, to determine the location of viable material. Small quantities of material in the early stages of establishment have been successfully treated in a single season when appropriate herbicide has been properly applied at the appropriate time, but at least three years may be required in the case of well established material. The process can be shortened by disturbance, but the concern of leaving viable material at depth needs to be considered. Physical removal, when carried out with adequate thoroughness can be successful, but, if separation procedures are being employed, the nature of the soil and surrounding material needs to be taken into account e.g. where rhizome has colonised concrete or other hard material.

It remains necessary to allow for a continuing monitoring and follow up methodology in all circumstances to deal with any material which may rearise after treatment has been carried out. It is not clear how long this period is required to be, but a minimum of five years after the last above ground growth has been noted, would seem to be a minimum to suggest until a more definitive answer in relation to the time for which rhizome may be viable but not produce above ground shoots is more clearly determined.

Conclusions

The wide range of sites and situations which have been encountered during the course of this work have provided a background to give breadth of consideration to the stated aim of development of strategies for the control and eradication of Japanese knotweed. This has included requirements to provide workable solutions in circumstances as varied as remote areas with little risk of disturbance through to sites where development is scheduled within days, and between sites where material has been recently deposited to those where the plant has been in situation for many years.

One of the most important points is that a full and non interventionist survey is the primary requirement before any activities take place on a site. Sites such as those detailed where disturbance has taken place prior to the identification of the plant, have resulted in greatly increased costs compared to those which would have been incurred if early recognition and planning had been deployed.

In order to avoid this, a flow chart (Appendix 20) has been produced. The intention of this is to direct the reader to an appropriate course of action. To complement this, a sketch plan has also been produced (Appendix 21) to indicate the type and size of material which may be anticipated to be on site at a particular period and suggestions for appropriate methods of herbicide treatment.

One of the most concerning issues is situations where the plant crosses boundaries of ownership in which cases any control may be severely impaired. It is important to emphasise the need for cooperation between those affected in order to produce satisfactory results. The percentage of highway sites which require continuation of treatment because there is material on adjacent land is considerable.

Minimisation of disturbance will limit spread. Where time permits, the use of an appropriately timed herbicide programme can be effective. This is also likely to be the least expensive method of control. Assessments of its effectiveness require assessment over a period of years.

When the time scale requires more rapid control, physical removal can be very effective when carefully carried out. Large scale programmes will be likely to require some form of separation procedure in order to limit the quantity of material requiring removal.

Future work

The criteria of success of any treatment programme treatment still lie very heavily on assessment of above ground material, perhaps only for a single season. This is of questionable reliability, as material has been observed to reappear after several seasons, during which no above ground material has been noted. It is still unclear how long rhizome can remain viable at depth in the soil though there are strong suggestions that this can be a considerable number of years. The shortening of the time interval between site redevelopment can mean that deep buried material may be reactivated by renewed activities. The chosen deposit sites are often under features such as car parks which may be an early target for such change. Further work therefore is desirable on this aspect.

Influence of shading on cane density needs consideration as observations have suggested diminished vigour in such areas. It could be presumed that underground material would be directly influenced by the situation, but this could require further work as could work in assessing whether underground extension growth in such situations is greater than in more favourable conditions.

Further tracer work in relation to the spread of various herbicides, but particularly glyphosate, through the plant would be useful to clarify in which areas could remain viable in relation to sub lethal dosage rates. This could assist in targeting in relation to viability assessment.

It has been suggested that the use of follow up substances after the use of glyphosate, could increase efficacy of the material and accelerate better control.

Commercial sorting equipment is available which can reliably sort to particular size parameters. The potential maximum residue size likely to remain within the sorted body could then be assessed in relation to its potential for survival at depth, This is based on the likelihood that duration of survivability is directly related to the size of material. Current work requires encapsulation of excavated material in membranes. Such membranes could have a localised effect on the hydrology of area. If separation techniques could be deployed to ensure freedom of rhizome down to a specific size, it could be useful if, tying in with previous work, an assessment could be made of adequate depth of burial collated with the period for which such a size of rhizome can be determined to retain viability.

It is also important that a good sampling methodology is developed for field sites to ensure that assessment of future requirements following treatment is reliable.

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BSBI records (2011)

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japonica
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sachalinensis
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bohemica
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conollyana

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Gauntletts Nursery

Personal communication with Mr Don Harris (DH), 1,Bell View Redruth (01209 214342) 14.30 2001-06-22

Mr Harris confirmed that Gauntletts Nursery (the Japanese Nurseries) was sited at the present Green Lane Nursery (now part of Murdoch Training Centre).

A nursery was originally established on the site in the early part of the 19th century by John Nicholls. This was sold to Gauntlett who came from the Hampshire area. When Gauntlett moved to Chiddingfold in 1906, his foreman, Sanders, purchased the nursery. This was purchased by Mr Harris in 1953 who ran it for a number of years

until it was sold to a Mr Kendall (in 1972?) who changed the name to Green Lane Nursery.
Mr Harris still lives on part of the site and there is still some Japanese knotweed on it. He also has a copy of one of Gauntlett's catalogues.
Visited Don Harris 10.07.01
John Nicholl's (founder of nursery prior to Gauntlett) diary given by J and F Sanders to Redruth Library in the late 1940s.
Undated catalogue of Gauntletts in Mr Harris' possession. Refers to site being in Surrey.
Listed species:-
Polygonum sericeum
P. spectabile
P.cookii " new mammoth introduction by Surgeon General Henry Cook from North America 16 feet high canes 5 inches in circumference 2/6" Claim that all stock obtained by Gauntletts.
P.sieboldii syn cuspidatum 6d each 5/- dozen.
P.sachalinensis "often 10 feet high Leaves 12 inches long greenish white flowers 6d each 5/- doz."
Also seen:- The Illustrated Dictionary of Horticulture - An Encyclopaedia of Horticulture Ed. George Nicholson. Pub.Lupcott Gill 170 Strand 1887 3 volumes.
Refers to the following species:-
P. cuspidatum "It is best grown as an isolated specimen"
P.sachalinensis 10 feet Sachalin Islands 1869 angular striated stems.

Appendix 1

Rylands and another v Fletcher

[1861-73] All ER Rep 1

Also reported House of Lords: LR 3 HL 330; 37 LJ Ex 161; 19 LT 220; 33 JP 70 Court of Exchequer Chamber: LR 1 Exch 265; 4 H & C 263; 35 LJ Ex 154; 14 LT 523; 30 JP 436; 12 Jur NS 603; 14 WR 799

HOUSE OF LORDS AND COURT OF EXCHEQUER CHAMBER

House of Lords: Lord Cairns LC and Lord Cranworth Court of Exchequer Chamber: Willes, Blackburn, Keating, Mellor, Montague Smith and Lush JJ

6, 7 July 1868

17 July 1868

Nuisance - Rylands v Fletcher doctrine - Accumulation on land of matter dangerous to neighbour in event of escape - Liability of owner for damage due to escape.

Animal - Cattle - Trespass - Damage to neighbour's property - Injury to human being - Liability of owner.

If a person brings or accumulates on his land anything - eg, water, or filth, or noxious fumes - which, if it should escape, may cause damage to his neighbour, he does so at his peril. If it does escape and cause damage, he is responsible, however careful he may have been, and whatever precautions he may have taken to prevent the damage.

Per LORD BLACKBURN: The owner of cattle must keep them in at his peril or he will be answerable for the natural consequences of their escape, ie, with regard to tame beasts, for the grass they eat and trample on, although not for any injury to the person of others, for it is not the general nature of horses to kick or bulls to gore, but if the owner knows that the beast has a vicious propensity to attack man he will be answerable for that too.

Notes

Applied: *Jones v Festiniog Rail Co* (1868) LR 3 QB 733. Distinguished: *The Thetis* (1869) LR 2 A & E 365; *Saxby v Manchester Sheffield and Lincolnshire Rail Co* (1869) 38 LJCP 153; *Carstairs v Taylor* (1871) LR 6 Exch 217; *Wilson v Newberry* (1871) LR 7 QB 31; *Dunn v Birmingham Canal Co* (1872) LR 7 QB 244; *Ross v Fedden* (1872) LR 7 QB 661 Applied: *Smith v Fletcher* (1872) LR 7 Exch 305. Distinguished: *Smith v Fletcher* (1874) LR 9 Exch 64; *Child v Hearn* (1874) LR 9 Exch 176 Considered and Applied: *Crompton v Lea* (1874) LR 19 Eq 115. Considered: *Madras Rail Co v Zeminder of Carvetinagaram* (1874) 30 LT 770; *Cattle v Stockton Waterworks Co* [1874-80] All ER Rep 220. Distinguished: *Nichols v Moreland* (1876) LR 2 ExD 1.

[1861-73] All ER Rep 1 at 2

Considered: *Wilson v Waddell* (1876) 2 App Cas 95; *Humphries v Cousins* [1874-80] All ER Rep 313; *Hardman v North Eastern Rail Co* [1874-80] All ER Rep 735. Distinguished: *Nitro-Phosphate and Odam's Chemical Manure Co v London amt St Katherine Docks Co* (1878) 27 WR 267. Considered and Applied: *Crowhurst v Amersham Burial Board* [1874-80] All ER Rep

89. Distinguished: *Box v Jubb* [1874-80] All ER Rep 741; *Anderson v Oppenheimer* (1880) L QBD 602. Applied: *Powell v Fall* (1880) 5 QB 597. Considered: *Dixon v Metropolitan Board of Works* (1881) 7 QBD 418. Applied: *Snow v Whitehead* (1884) 27 Ch D 588 Considered: *Whalley v Lancashire and Yorkshire Rail Co* (1884) 13 QBD 131; *Gas Light and Coke Co v St Mary Abbots Kensington Vestry* (1884) Cab & El 368. Distinguished: *Snook v Grand Junction Waterworks Co* (1886) 2 TLR 308. Considered and Applied: *Evans v Manchester Sheffield and Lincolnshire Rail Co* (1887) 36 Ch D 626. Distinguished: *Abelson v Brockman* (1889) 54 JP 119. Applied: *Filburn v People's Palace and Aquarium Co* (1890) 25 QBD 258. Distinguished: *National Telephone Co v Batter* [1893] 2 Ch 186; *Green v Chelsea Waterworks Co* [1891-4] All ER Rep 543; *Gill v Edouin* (1894) 71 LT 762; *Ponting v Noakes* [1891-4] All ER Rep 404. Considered: *Grosvenor Hotel Co v Hamilton* (1894) 71 LT 362. Distinguished: *Price v South Metropolitan Gas Co* (1895) 65 LJQB 126; *Greenhill v Low Beechburn Coal Co* [1897] 2 QB 165; *Blake v Woolf* [1895-9] All ER Rep 185. Applied: *Batcheller v Tunbridge Wells Gas Co* (1901) 84 LT 765. Considered and Distinguished: *Eastern and South African Telegraph Co v Cape Town Tramways Co* [1902] AC 381. Distinguished: *Ely Brewery Co v Pontypridd UDC* (1903) 2 LGR 40. Applied: *Giddy v Smith* (1904) 20 TLR 596; *Foster v Warblington UDC* [1904-7] All ER Rep 366; *Hobart v Southend-on-Sea Corpn* (1906) 4 LGR 757. Distinguished: *Chichester Corpn v Foster* [1906] 1 KB 167; *Evans v Liverpool Corpn* [1906] 1 KB 160. Considered and Explained: *Baker v Snell* [1908-10] All ER Rep 398. Applied: *West v Bristol Tramways Co* [1908-10] All ER Rep 215. Explained and Distinguished: *Whitmores* [1909] 1 Ch 427. Considered and Explained: *Wing v London General Omnibus Co* [1908-10] All ER Rep 496. Applied: *Lowery v Walker* [1910] 1 KB 173; *Jones v Llanrwst UDC* [1908-10] All ER Rep 922. Distinguished: *Baker v Herbert* [1911-13] All ER Rep 509. Considered and Distinguished: *Rickards v Lothian* [1911-13] All ER Rep 71. Applied: *Charing Cross West End and City Electricity Supply Co Ltd v London Hydraulic Power Co* [1914-15] All ER Rep 85. Considered and Distinguished: *Goodbody v Poplar Borough Council* (1914) 84 LJKB 1230. Considered: *Heath's Garages Ltd v Hodges* [1916-17] All ER Rep 358; *Holgate v Bleazard* [1916-17] All ER Rep 817; *Greenock Corpn v Caledonian Rail Co Same v Glasgow and South-Western Rail Co* [1916-17] All 77R Rep 426. Applied: *Mansel v Webb* [1918-19] All ER Rep 794; *Miles v Forest Rook Granite Co* (1918) 34 TLR 500; *Musgrove v Pandelis* [1918-19] All ER Rep 589; *A-G v Cory Kennard v Cory* [1921] 1 AC 521; *Rainham Chemical Works Ltd v Belvedere Fish Guano Co* [1921] All ER Rep 48; *Hoare & Co Ltd v Sir Robert McAlpine Sons & Co* [1922] All ER Rep 759. Distinguished: *Manton v Brocklebank* [1923] All ER Rep 416. Considered: *Hines v Tousley* (1926) 95 LJKB 773 Distinguished: *St Anne's Well Brewery Co v Roberts* [1928] All ER Rep 28. Considered: *Pontardawe RDC v Moors-Gwyn* [1929] 1 Ch 656. Distinguished: *Fardon v Harcourt-Rivington* [1932] All ER Rep 81; *Wilkins v Leighton* [1932] All ER Rep 55. Applied: *A-G v Corke* [1932] All ER Rep 711 Considered: *North-Western Utilities Ltd v London Guarantee and Accident Co Ltd* [1935] All ER Rep 196; *Marchant Manufacturing Co v Leonard D Ford and Teller Ltd* (1936) 154 LT 430. Applied: *Western Engraving Co v Film Laboratories Ltd* [1936] 1 All ER 106; *Shiffman v Venerable Order of Hospital of St John of Jerusalem* [1936] 1 All ER 557.

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Distinguished: *Howard v Furness Houlder Argentine Lines Ltd and Brown Ltd* [1936] 2 All ER 781; *Collingwood v Home and Colonial Stores Ltd* [1936] 3 All ER 200. Applied: *Hale v Jennings Bros* [1938] 1 All ER 579. Considered: *McQuaker v Goddard* [1940] 1 All ER 471; *Thomas and Evans Ltd v Mid-Rhondda Co-operative Society Ltd* [1940] 4 All ER 357. Distinguished: *Peters v Prince of Wales Theatre (Birmingham) Ltd* [1942] 2 All ER 533. Explained and Distinguished: *Read v J Lyons & Co* [1946] 2 All ER 471. Considered: *Sutcliffe v Holmes* [1946] 2 All ER 599. Distinguished: *Burley Ltd v Stepney Corpn* [1947] 1 All ER 507; *Sochacki v Sas* [1947] 1 All ER 344. Considered: *Smeaton v Ilford Corpn* [1954] 1 All ER 923. Distinguished: *Penny v Kendricks Transport Ltd* [1955] 1 All ER 154. Considered: *Balfour v Barty-King* [1957] 1 All ER 156; *Behrens v Bertram Mills Circus Ltd* [1957] 1 All ER 583; *A-G (Glamorgan County Council and Pontardawe RDC) v PYA Quarries Ltd*[1957] 1 All ER 894. Applied: *Halsey v Esso Petroleum Co Ltd* [1961] 2 All ER 145. Referred to: *Smith v London and South Western Rail Co* (1870) LR 6 CP 14; *A-G v Tomline* (1879) 48 LJ Ch 593; *Fleming v Manchester Corpn* (1881) 44 LT 517; *Tillett v Ward* (1882) 10 QBD 17; *Darley Main Colliery Co v Mitchell* [1886-90] All ER Rep 449; *Ruddiman v Smith* (1889) 37 WR 528; *Prinsep v Belgravia Estate* (1895) 39 Sol Jo 381; *St Helen's Cotton v United Alkali Co* (1901)

Times June 19; *Canadian Pacific Rail Co v Roy* [1902] AC 220; *Ilford Gas Co v Ilford UDC* [1903] 67 JP 365; *Manchester Corpn v New Moss Colliery Co* [1906] 1 Ch 278; *Jones v Lee* [1911-13] All ER Rep 313; *Remorquage a Hélice* (Société *Anon*[1911] 1 KB 243; *Titterton v Kingsbury Collieries* (1911) 104 LT 569; *Maxey Drainage Board v Crest Northern Rail Co* (1912) 76 JP 236; *Cheater v Cater* [1916-17] All ER Rep 239; *Job Edwards Ltd v Birmingham Navigations* [1924] 1 KB 341; *Gayler and Pope Ltd v B Davies & Son Ltd* [1924] All ER Rep 94; *Booth v Thomas* (1926) 95 LJ Ch 160; *Noble v Harrison* [1926] All ER Rep 284; *Smith v Great Western Rail Co* [1926] All ER Rep 242; *Glanville v Sutton* (1927) 44 TLR 98; *Great Western Rail Co v Mostyn* [1927] All ER Rep 113; *Sycamore v Ley* [1932] All ER Rep 97; *Bartlett v Tottenham* [1932] 1 Ch 114; *Bishop v Consolidated London Properties Ltd* [1933] All ER Rep 963; *Knott v LCC* [1933] All ER Rep 172; *Markland v Manchester Corpn* [1934] 1 KB 566; *Deen v Davies* [1935] All ER Rep 9; *Greenwood Tileries Ltd v Clapson* [1937] 1 All ER 765; *Ryan v Youngs* [1938] 1 All ER 522; *Westripp v Baldcock* [1938] 2 All ER 779; *Hanson v Wearmouth Coal Co* [1939] 3 All ER 47; *Mulholland v Baker* [1939] 3 All ER 253; *Tilley v Stevenson* [1939] 4 All ER 207; *Rouse v Gravelworks* [1940] 1 All ER 26; *Sedleigh-Denfield v O'Callagan* [1940] 3 All ER 349; *Haseldine v CA Dow & Son Ltd* [1941] 3 All ER 156; *Brackenborough v Spalding UDC* [1942] 1 All ER 34; *J and J Makin Ltd v London and North Eastern Rail Co* [1943] 1 All ER 645; *Haigh v Deudraeth RDC* [1945] 1 All ER 12; *Rands v McNeil* [1954] 3 All ER 593; *Cunliffe v Bankes* [1945] 1 All ER 459; *Newcastle-upon-Lyme Corpn v Wolstanton Ltd* [1946] 2 All ER 447; *Spice v Smee* [1946] 1 All ER 489; *Searle v Wallbank* [1947] 1 All ER 12; *Longhurst v Metropolitan Water Board* [1948] 2 All ER 834; *Neath RDC v Williams* [1950] 2 All ER 625; *Bolton v Stone* [1951] 1 All ER 1078; *Pride of Derby and Derbyshire Angling Association Ltd v British Celanese Ltd* [1953] 1 All ER 179; *Beckett v Newalls Insulation Co* [1953] 1 All ER 250; *Southport Corpn v Esso Petroleum Co* [1954] 2 All ER 561; *Rands v McNeil* [1954] 3 All ER 593; *Prosser & Son Ltd v Levy* [1955] 3 All ER 577; *Davey v Harrow Corpn* [1957] 2 All ER 305; *Fowler v Lanning* [1959] 1 All ER 290; *Overseas Tankship* [1961] 1 All ER 404.

As to nuisances between neighbouring properties and dangerous property see 28 HALSBURY'S LAWS (3rd Edn) 131-149; and for cases see 36 DIGEST (Repl) 281 et seq. As to the liability of owners of trespassing animals see 1 HALSBURY'S LAWS (3rd Edn) 668-680; and for cases see 2 DIGEST (Repl) 308 of seq.

Cases referred to:

(1) *Anon* (1480) YB 20 Edw 4, fo 10, pl 10; 17 CBNS 251, n; 2 Digest (Repl) 309, 126.

(2) *Tenant v Goldwin* (or Golding) (1704) 1 Salk 21, 360; Holt, KB 500; 2 Ld Raym 1089; 6 Mod Rep 311; 91 ER 20, 314; 36 Digest (Repl) 287, 356.

(3) *Cox v Burbidge* (1863) 13 CBNS 430; 1 New Rep 238; 32 LJCP 89; 9 Jur NS 970; 11 WR 435; 143 ER 171; 2 Digest (Repl) 319, 187.

(4) *May v Burdett* (1846) 9 QB 101; 16 LJQB 64; 7 LTOS 253; 111 Jur 692; 115 ER 1213; 2 Digest (Repl) 329, 216.

(5) *Anon* (1580) 3 Dyer, 372 b, pl 10; 73 ER 835; 7 Digest (Repl) 287, 136.

(6) *Sutton v Clarke* (1815) 6 Taunt 29; 1 Marsh 429; 128 ER 945; 42 Digest 975, 57.

(7) *Hammack v White* (1862) 11 CBNS 588; 31 LJCP 129; 5 LT 676; 8 Jur NS 796; 10 WR 230; 142 ER 926; 2 Digest (Repl) 317, 171.

(8) *Scott v London Loch Co* (1865) 3 H & C 596; 5 New Rep 420; 34 LJ Ex 220; 13 LT 148; 11 Jur NS 204; 13 WR 410; 159 ER 665, Ex Ch; 36 Digest (Repl) 145, 772.

(9) *Smith v Kenrick* (1849) 7 CB 515; 18 LJCP 172; 12 LTOS 556; 13 Jur 362; 137 ER 205; 36 Digest (Repl) 248, 8.

(10) *Baird v Williamson* (1863) 15 CBNS 376; 3 New Rep 86; 33 LJCP 101; 9 LT 412; 12 WR 150; 143 ER 831; sub nom Williamson v Baird, 10 Jur NS 152; 33 Digest (Repl) 866, 1146.

(11) *Lambert and Olliot v Bessey* (1680) T Raym 421, 467; 83 ER 220, 244; 1 Digest (Repl) 34, 259.

Also referred to in argument:

Bonomi v Backhouse (1859) EB & E 646; 28 LJQB 378; 33 LTOS 331; 5 Jur NS 1345; 7 WR 667; 120 ER 652, Ex Ch; on appeal sub nom Backhouse v Bonomi (1861) 9 HL Cas 503; 34 LJQB 181; 4 LT 754; 7 Jur NS 809; 9 WR 769; 11 ER 825, HL; 33 Digest (Repl) 841, 984.

Chadwick v Trower (1839) 6 Bing NC 1; 8 Scott, 1; 8 LJ Ex 286; 133 ER 1, Ex Ch; 7 Digest (Repl) 310, 268.

Hodgkinson v Ennor (1863) 4 B & S 229; 2 New Rep 272; 32 LJQB 231; 8 LT 451; 27 JP 469; 9 Jur NS 1152; 11 WR 775; 122 ER 446; 44 Digest 39, 276.

Aldred's Case (1610) 9 Co Rep 57 b; 77 ER 816; 36 Digest (Repl) 267, 183.

Bagnall v London and North Western Rail Co (1862) 1 H & C 544; 31 LJ Ex 480; 9 LT 419; 9 Jur NS 254; 10 WR 802, Ex Ch; 38 Digest (Repl) 30, 155.

Williams v Groucott (1863) 4 B & S 149; 2 New Rep 419; 8 LT 458; 27 JP 693; 9 Jur NS 1237; 11 WR 886; 122 ER 416; sub nom Groucott v Williams, 32 LJQB 237; 2 Digest (Repl) 303, 107.

Chauntler v Robinson (1849) 4 Exch 163; 19 LJ Ex 170; 14 LTOS 107; 154 ER 1166; 36 Digest (Repl) 299, 435.

Gregory v Piper (1829) 9 B & C 591; 4 Man & Ry KB 500; 109 ER 220; 34 Digest (Repl) 187, 1312.

Turbervill (Tubervil) v Stamp (1697) Holt, KB 9; Carth 425; Skin 681; Comb 459; 1 Com 32; 1 Ld Raym 264; 12 Mod Rep 152; 1 Salk 13; 90 ER 846; 2 Digest (Repl) 91, 551.

Filliter v Phippard (1847) 11 QB 347; 17 LJQB 89; 10 LTOS 225; 11 JP 903; 12 Jur 202; 116 ER 506; 36 Digest (Repl) 76, 407.

Butler v Hunter (1862) 7 H & N 826; 31 LJ Ex 214; 10 WR 214; 158 ER 702; 34 Digest (Repl) 197, 1386.

Singleton v Williamson (1862) 7 H & N 747; 31 LJ Ex 287; 5 LT 645; 26 JP 231; 8 Jur NS 157; 10 WR 301; 158 ER 670; 18 Digest (Repl) 444, 1879.

Barber v Nottingham and Grantham Railways Canal Co (1864) 15 CBNS 726; 3 New Rep 510; 33 LJCP 193; 9 LT 829; 10 Jur NS 260; 12 WR 376; 143 ER 970; 38 Digest (Repl) 458, 1057.

Acton v Blundell (1843) 12 M & W 324; 13 LJ Ex 289; 1 LTOS 207; 152 ER 1223, Ex Ch; 33 Digest (Repl) 865, 1139.

Chasemore v Richards (1859) 7 HL 349; 29 LJ Ex 81; 33 LTOS 350; 5 Jur NS 873; 23 JP 596; 7 WR 685; 11 ER 140, HL; 44 Digest 34, 252.

Dickinson v Grand Junction Canal Co (1852) 7 Exch 282; 21 LJ Ex 241; 18 LTOS 258; 16 Jur 200; 155 ER 953; 44 Digest 11, 40.

Partridge v Scott (1838) 3 M & W 220; 1 Horn & H 31; 7 LJ Ex 101; 150 ER 1124; 19 Digest (Repl) 74, 420.

Ellis v Sheffield Gas Consumers' Co (1853) 2 E & B 767; 2 CLR, 249; 23 LJQB 42; 22 LTOS 84; 17 JP 823; 18 Jur 146; 2 WR 19; 118 ER 955; 36 Digest (Repl) 159, 838.

Peachey v Rowland (1853) 13 CB 182; 22 LJCP 81; 20 LTOS 208; 17 Jur 764; 138 ER 1167; 34 Digest (Repl) 196, 1381.

Steel v South-Eastern Rail Co (1855) 16 CB 550; 25 LTOS 129; 139 ER 875; 34 Digest (Repl) 200, 1406.

Broadbent v Imperial Gas Co (1857) 7 De GM & G 436; 26 LJ Ch 276; 28 LTOS 329; 21 JP 117; 3 Jur NS 221; 5 WR 272; 44 ER 170, LC; on appeal sub nom Imperial Gas Light and Coke Co v Broadbent (1859) 7 HL Cas 600; 29 LJ Ch 377; 34 LTOS 1; 23 JP 675; 5 Jur NS 1319; 11 ER 239, HL; 38 Digest (Repl) 20, 90.

Appeal from a decision of the Court of Exchequer Chamber by the defendants in an action brought against them by the plaintiff for damage done to his mines through the escape of water from a reservoir on the defendants' land.

The plaintiff was a tenant of Lord Wilton. The defendants, who were proprietors of a mill, made upon land of Lord Wilton's, in pursuance of an arrangement made with him for that purpose, a reservoir, employing competent persons to construct the same. It turned out that beneath the site of the reservoir were old shafts running down into coal workings long disused which communicated with other old workings situate under the land of one Whitehead. The plaintiff's colliery, called the Red House Colliery, adjoined Whitehead's land, and the plaintiff, soon after he had commenced working the Red House Colliery, made arrangements with Whitehead to get, by means of the Red House pit, the coal lying under Whitehead's land. In pursuance of those arrangements the plaintiff had worked through from the Red House Colliery into the coal lying under Whitehead's land, and so into the old workings situated under Whitehead's land. As a result the workings of the plaintiff's colliery were made to communicate with the old workings under the reservoir. These underground works were effected several years before the defendants commenced making their reservoir, but the fact of their existence was not known to the defendants or any agent of theirs, or any person employed by them, until the reservoir burst, as is hereinafter mentioned. In the course of constructing the reservoir the shafts were perceived, but it was not known or suspected that they had been made for the purpose of getting coal beneath the site of the reservoir. The Special Case stated in the action contained a finding that there was no

personal negligence or default on the part of the defendants themselves in relation to the selection of the site or the construction of the reservoir, but reasonable and proper care was not used by the persons employed with reference to the shafts so met with to provide for the sufficiency of the reservoir to bear the pressure which, when filled, it would have to bear. The reservoir in consequence burst downwards into the shafts, and the water found its way into the plaintiff's mine. The majority of the Court of Exchequer held that the non-exercise of sufficient care upon the part of the persons employed to construct the reservoir did not, in the absence of any notice to the defendants of the underground communication, affect the defendants with any liability, there being in the absence of such notice no duty cast upon the defendants to use any particular amount of care in the construction of a reservoir upon their own land. BRAMWELL, B, was of opinion that the question of knowledge was immaterial, and that the defendants were, therefore, liable. The plaintiff appealed to the Court of Exchequer Chamber.

Manisty, QC, and JA Russell for the plaintiff. Mellish, QC, and Jones for the defendants.

Cur adv vult, 14 May 1888

BLACKBURN J:

(read the following judgment of the court)

This was a Special Case stated by an arbitrator under an order of nisi prius, in which the question for the court is stated to be whether the plaintiff is entitled to recover any, and, if any, what, damages from the defendants by reason of the matters thereinbefore stated. In the Court of Exchequer, POLLOCK, CB, and MARTIN, B, were of opinion that the plaintiff was not entitled to recover at all, BRAMWELL, B, being of a different opinion. The judgment in the Court of Exchequer was, consequently, given for the defendants in conformity with the opinion of the majority of the court. The only question argued before us was whether this judgment was right, nothing being said about the measure of damages in case the plaintiff should be held entitled to recover.

We have come to the conclusion that the opinion of BRAMWELL, B, was right, and that the answer to the question should be that the plaintiff was entitled to recover damages from the defendants by reason of the matters stated in the Case, and consequently that the judgment below should be reversed; but we cannot, at present, say to what damages the plaintiff is entitled. It appears from the statement in the Case, that the plaintiff was damaged by his property being flooded by water which, without any fault on his part, broke out of a reservoir constructed on the defendants' land by the defendants' orders and maintained by the defendants. It appears from the statement in the Case, that the coal under the defendants' land had, at some remote period, been worked out, but that this was unknown at the time when the defendants gave directions to erect the reservoir, and the water in the reservoir would not have escaped from the defendants' land, and no mischief would have been done to the plaintiff, but for this latent defect in the defendants' subsoil. It further appears from the Case that the defendants selected competent engineers and contractors to make the reservoir, and themselves personally continued in total ignorance of what we have called the latent defect in the subsoil, but that the persons employed by them, in the course of the work, became aware of the existence of ancient shafts filled up with soil, though they did not know or suspect that they were shafts communicating with old workings. It is found that the defendants personally were free from all blame, but that, in fact, proper care and skill was not used by the persons employed by them to provide for the sufficiency of the reservoir with reference to these shafts. The consequence was, that the reservoir, when filled with water, burst into the shafts, the water flowed down through them into the old workings, and thence into the plaintiff's mine, and there did the mischief. The plaintiff, though free from all blame on his part, must bear the loss, unless

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he can establish that it was the consequence of some default for which the defendants are responsible.

The question of law, therefore, arises: What is the liability which the law casts upon a person who, like the defendants, lawfully brings on his land something which, though harmless while it remains there, will naturally do mischief if it escape out of his land? It is agreed on all hands that he must take care to keep in that which he has brought on the land, and keep it there in order that it may not escape and damage his neighbour's, but the question arises whether the duty which the law casts upon him under such circumstances is an absolute duty to keep it in at his peril, or is, as the majority of the Court of Exchequer have thought, merely a duty to take all reasonable and prudent precautions in order to keep it in, but no morn. If the first be the law, the person who has brought on his land and kept there something dangerous, and failed to keep it in, is responsible for all the natural consequences of its escape. If the second be the limit of his duty, he would not be answerable except on proof of negligence, and consequently would not be answerable for escape arising from any latent defect which ordinary prudence and skill could not detect. Supposing the second to be the correct view of the law, a further question arises subsidiary to the first, namely, whether the defendants are not so far identified with the contractors shorn they employed as to be responsible for the consequences of their want of skill in making the reservoir in fact insufficient with reference to the old shafts, of the existence of which they were aware, though they had not ascertained where the shafts went to.

We think that the true rule of law is that the person who, for his own purposes, brings on his land, and collects and keeps there anything likely to do mischief if it escapes, must keep it in at his peril, and, if he does not do so, he is prima facie answerable for all the damage which is the natural consequence of its escape. He can excuse himself by showing that the escape was owing to the plaintiff's default, or, perhaps, that the escape was the consequence of vis major, or the act of God; but, as nothing of this sort exists bore, it is unnecessary to inquire what excuse would be sufficient. The general rule, as above stated, seems on principle just. The person whose grass or corn is eaten down by the escaped cattle of his neighbour, or whose mine is flooded by the water from his neighbour's reservoir, or whose cellar is invaded by the filth of his neighbour's privy, or whose habitation is made unhealthy by the fumes and noisome vapours of his neighbour's alkali works, is damnified without any fault of his own; and it seems but reasonable and just that the neighbour who has brought something on his own property which was not naturally there, harmless to others so long as it is confined to his own property, but which he knows will be mischievous if it gets on his neighbour's, should be, obliged to make good the damage which ensues if he does not succeed in confining it to his own property. But for his act in bringing it there no mischief could have accrued, and it seems but just that he should at his peril keep it there, so that no mischief may accrue, or answer for the natural and anticipated consequences. On authority this, we think, is established to be the law, whether the thing so brought be beasts or water, or filth or stenches.

The case that has most commonly occurred, and which is most frequently to be found in the books, is as to the obligation of the owner of cattle which he has brought on his land to prevent their escaping and doing mischief. The law as to them seems to be perfectly settled from early times; the owner must keep them in at his peril, or he will be answerable for the natural consequences of their escape, that is, with regard to tame beasts, for the grass they eat and trample upon, although nor for any injury to the person of others, for our ancestors have settled that it is not the general nature of horses to kick or bulls to gore, but if the owner knows that the beast has a vicious propensity to attack man he will be answerable for that too. As early as 1480 (*Anon* (1)) BRIAN, CJ, lays

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down the doctrine in terms very much resembling those used by LORD HOLT in *Tenant v Goldwin* (2) which will be referred to later. It was trespass with cattle. Plea: that the plaintiff's land adjoined a place where the defendant had common; that the cattle strayed from the common, and the defendant drove them back as soon as he could. It was held a bad plea. BRIAN, CJ, says:

> "It behoves him to use his common so that it shall do no hurt to another man, and if the land in which he has common be not inclosed, it behoves him to keep the beasts in the common, and out of the land of any other."

He adds, when it was proposed to amend by pleading that they were driven out of the common by dogs,

> "that although that might give a right of action against the master of the dogs, it was no defence to the action of trespass by the person on whose land the cattle went."

In *Cox v Burbidge* (3) WILLIAMS, J, says (13 CBNS at p 438):

> "I apprehend the law to be perfectly plain. If I am the owner of an animal in which, by law, the right of property can exist, I am bound to take care that it does not stray into the land of my neighbour, and I am liable for any trespass it may commit, and for the ordinary consequences of

> that trespass. Whether or not the escape of the animal is due to my negligence is altogether immaterial."

So in *May v Burdett* (4) the court, after an elaborate examination of the old precedents and authorities, came to the conclusion that a person keeping a mischievous animal is bound to keep it secure at his peril. And in 1 HALE'S PLEAS OF THE CROWN, p 430, LORD HALE states that where one keeps a beast knowing that its nature or habits were such that the natural consequence of his being loose is that he will harm men, the owner

> "must at his peril keep him up safe from doing hurt, for though he uses his diligence to keep him up, if he escape and do harm, the owner is liable to answer damages";

though, as he proceeds to show, he will not be liable criminally without proof of want of care.

In these latter authorities the point under consideration was damage to the person, and what was decided was that where it was known that hurt to the person was the natural consequence of the animal being loose, the owner should be responsible in damages for such hurt, though where it was not known to be so the owner was not responsible for such damages, but where the damage is like eating grass, and other ordinary ingredients in damage feasant, the natural consequence of the escape, the rule as to keeping in the animal is the same. In COMYN'S DIGEST, "Droit" M 2, it is said that "if the owner of 200 acres in a common moor enfeoffs B of fifty acres, B ought to inclose at his peril to prevent damage by his cattle to the other 150 acres, for if his cattle escape thither they may be distrained damage feasant. So the owner of the 150 acres ought to prevent his cattle from doing damage to the fifty acres at his peril."

The authority cited is *Anon* (5) where the decision was that the cattle might be distrained. The inference from that decision that the owner was bound to keep in his cattle at his peril is, we think, legitimate, and we have the high authority of COMYNS for saying that such is the law. In the note to FITZHERBERT, NATURA BREVIUM, 128, which is attributed to LORD HALE, it is said:

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> "If A and B have lands adjoining, where there is no inclosure, the one shall have trespass against the other on an escape of their beasts respectively (3 Dyer, 372b, pl 10; Rastal Ent p 621; and YB 20 Edw 4, fo 10, pl 10) although wild dogs, etc, drive the cattle of the one into the lands of the other."

No case is known to us in which, on replevin, it has even been attempted to plead in bar to an avowry for distress damage feasant that the cattle had escaped without any negligence on the part of the plaintiff; and surely, if that could have been a good plea in bar, the facts must often have been such as would lave supported it. These authorities, and the absence of any authority to the contrary, justify WILLIAMS, J, in saying, as he does in *Cox v Burbidge* (3) that

> "the law is clear that in actions for damage occasioned by animals that not been kept in by their owners, it is quite immaterial whether the escape is by negligence or not."

As has been already said, there does not appear to be any difference in principle between the extent of the duty cast on him who brings cattle on his land to keep them in, and the extent of the duty imposed on him who brings on his land water, filth, or stenches, or any other thing which will, if it escape, naturally do damage, to prevent their escaping and injuring his neighbour. *Tenant v Goldwin* (2) is an express authority that the duty is the same, and is to keep them in at his peril. As MARTIN, B, in his judgment below, appears not to have understood that case in the same manner as we do, it is proper to examine it in sonic detail. It was a motion in arrest of judgment after judgment by default, and, therefore, all that was well pleaded in the declaration was admitted to be true. The declaration is set out at full length in the report in 6 Mod 311. It alleged that the plaintiff had a cellar which lay contiguous to a messuage of the defendant, "and used (solebat) to be separated and fenced from a privy house of office, parcel of the said messuage of defendant, by a thick and close wall which belongs to the said messuage of the defendant, and by the defendant of right ought to have been repaired (de jure debuit reparari)."

Yet he did not repair it, and for want of repair filth flowed into plaintiff's cellar.

The case is reported both by SALKELD, who argued it, in 6 MODERN REPORTS, and by LORD RAYMOND whose report is the fullest. The objection taken was that there was nothing to show that the defendant was under any obligation to repair the wall, that, it was said, being a charge not of common right, and the allegation that the defendant de jure debuit reparari being an inference of law which did not arise, from the facts alleged. SALKELD argued that this general mode of stating the right was sufficient in a declaration, and also that the duty alleged did, of common right, result from the facts stated. It is not now material to inquire whether Im was or was not right on the pleading point. All three reports concur in saying that LORD HOLT, during the argument, intimated an opinion against him on that, but that after consideration the court gave judgment for him on the second ground.

In the report in 6 Mod Rep at p 314, it is stated:

> "And at another day per totem curiam the declaration is good, for there is a sufficient cause of action appearing in it, but not upon the word solebat. If the defendant has a house of office enclosed with a wall which is his, he is, of common right, bound to use it so as not to annoy another .... The reason here is, that one must use his own so as thereby not to hurt another, and as of common right one is bound to keep his cattle from trespassing on his neighbour, so he is bound to use anything that is his so

> as not to hurt another by such user .... Suppose one sells a piece of pasture lying open to another piece of pasture which the vendor has, the vendee is bound to keep his cattle from running into the vendor's piece; so of dung or anything else."

There is here an evident allusion to the same case in DYER as is referred to in COMYNS DIGEST, "Droit" M 2.

LORD RAYMOND, in his report, says (2 Ld Raym at p 1092):

> "The last day of term, HOLT, CJ, delivered the opinion of the court that the declaration was sufficient. he said that upon the face of this declaration there appeared a sufficient cause of action to entitle the plaintiff to have his judgment; that they did not go upon the solebat or the jure debuit reparari, as if it were enough to Say that the plaintiff had a house, and the defendant had a wall, and he ought to repair the wall; but if the defendant has a house of office, and the wall which separates the house of office from the plaintiff's house is all the defendant's, he is, of common right, bound to repair it. The reason of this case is upon this account, that every one must so use his own as not to do damage to another; and as every man is bound so to look to his cattle as to keep them out of his neighbour's ground, that so he may receive no damage; so he must keep in the filth of his house of office that it may not flow in upon and damnify his neighbour. So if a man has two pieces of pasture which he open to one another, and sells one piece, the vendee must keep in his cattle so as they shall not trespass upon the vendor. So a man shell not lay his dung so high as to damage his neighbour, and the reason of these cases is because every man must so use his own as not to damnify another."

SALKELD, who had been counsel in the case, reports the judgment much more concisely, but to the same effect. He says (1 Salk at p 361):

> "The reason he gave for his judgment was because it was the defendant's wall, and the defendant's filth, and he was bound of common right to keep his wall so as his filth might not damnify his neighbour, and that it was a trespass on his neighbour, as if his beasts should escape, or one should make a great heap on the border of his ground, and it should tumble and roll down upon his neighbour's... he must repair the wall of his house of office, for be, whose dirt it is must keep it, that it may not trespass."

It is worth noticing how completely the reason of LORD HOLT corresponds with that of BRIAN, CJ, in *Anon* (1) already cited.

MARTIN, B, in the court below says that he thinks this was a case without difficulty, because the defendant bad, by letting judgment go by default, admitted his liability to repair the wall, and that be cannot see how it is an authority for any case in which no such liability is admitted. But a perusal of the report will show that it was because LORD HOLT and his colleagues thought (no matter, for this purpose, whether rightly or wrongly) that the liability was not admitted that they took so much trouble to consider what liability the law would raise from the admitted facts, and it does, therefore, seem to us to be a very weighty authority in support of the position that be who brings and keeps anything, no matter whether beasts, or filth, or clean water, or a heap of earth or dung, on his premises, must at his peril prevent if from getting on his neighbour's, or make good all the damage which is the natural consequence, of its doing so.

No case has been found in which the question of the liability for noxious vapours escaping from a man's works by inevitable accident has been discussed, but the following case will illustrate it. Some years ago several actions were brought against the occupiers of some alkali works at Liverpool for the damage alleged to be caused by the chlorine fumes of their works. The defendants proved

that they had, at great expense, erected a contrivance by which the fumes of chlorine were condensed, and sold as muriatic acid, and they called a great body of scientific evidence to prove that this apparatus was so perfect that no fumes possibly could escape from the defendants' chimneys. On this evidence it was pressed upon the juries that the plaintiff's damage must have been due to some of the numerous other chimneys in the neighbourhood. The juries, however, being satisfied that the mischief was occasioned by chlorine, drew the conclusion that it had escaped from the defendants' works somehow, and in each case found for the plaintiff. No attempt was made to disturb those verdicts on the ground that the defendants had taken every precaution which prudence or skill could suggest to keep these fumes in, and that they could not be responsible unless negligence were shown, yet if the law be as laid down by the majority of the Court of Exchequer it would have been a very obvious defence. If it had been raised, the answer would probably have been that the uniform course of pleading in actions for such nuisances is to say that the defendant caused the noisome vapours to arise on his premises and suffered them to come on the plaintiff's without stating that there was any want of care or skill on the defendant's part; and that *Tenant v Goldwin* (3) showed that this was founded on the general rule of law that he whose stuff it is must keep it so that it may not trespass. There is no difference in this respect between chlorine and water; both will, if they escape, do damage, the one by scorching and the other by drowning, and he who brings them on his land must at his peril see that they do not escape and do that mischief.

What is said by GIBBS, CJ, in *Sutton v Clarke* (6) 6 Taunt at p 44, though not necessary for the decision of the case, shows that that very learned judge took the same view of the law that was taken by LORD HOLT. But it was further said by MARTIN, B, that when damage is done to personal property, or even to the person by collision, either upon land or at sea, there must be negligence in the party doing the damage to render him legally responsible. This is no doubt true, and this is not confined to cases of collision, for there are many cases in which proof of negligence is essential, as, for instance, where an unruly horse gets on the footpath of a public street and kills a passenger: *Hammack v White* (7) or where a person in a dock is struck by the falling of a bale of cotton which the defendant's servants are lowering: *Scott v London Dock Co* (6). Many other similar cases may be found. But we think these cases distinguishable from the present. Traffic on the highways, whether by land or sea, cannot be conducted without exposing those whose persons or property are near it to some inevitable risk; and, that being so, those who go on the highway, or have their property adjacent to it, may well be held to do so subject to their taking upon themselves the risk of injury from that inevitable danger, and persons who, by the licence of the owners, pass near to warehouses where goods are being raised or lowered, certainly do so subject to the inevitable risk of accident. In neither case, therefore, can they recover without proof of want of care or skill occasioning the accident; and it is believed that all the cases in which inevitable accident has been held an excuse for what prima facie was a trespass can be explained on the same principle, namely, that the circumstances were such as to show that the plaintiff had taken the risk upon himself. But there is no ground for saying that the plaintiff here took upon himself any risk arising from the uses to which the defendants should choose to apply their land. He neither knew what there might be, nor could he in any way control the defendants, or hinder their building what reservoirs they liked, and storing up in them what water they pleased, so long as the defendants succeeded in preventing the water which they there brought from interfering with the plaintiff's property.

The view which we take of the first point renders it unnecessary to consider whether the defendants would or would not be responsible for the want of care

[1861-73] All ER Rep 1 at 11

and skill in the persons employed by them. We are of opinion that the plaintiff is entitled to recover, but as we have not heard any argument as to the amount, we are not able to give judgment for what damages. The parties probably will empower their counsel to agree on the amount of damages; should they differ on the Principle the case may be mentioned again.

The defendants appealed to the House of Lords.

Sir Roundell Palmer, QC, and Jones, QC, for the defendants. Manisty, QC, and Russell, QC, for the plaintiff.

Their Lordships took time for consideration.

17 July 1868. The following opinions were read.

LORD CAIRNS LC:

The plaintiff in this case is the occupier of a mine and works under a close of land. The defendants are the owners of a mill in his neighbourhood, and they proposed to make a reservoir for the purpose of keeping and storing water to be used about their mill upon another close of land, which, for the purposes of this case, may be taken as being adjoining to the close of the plaintiff, although in point of fact some intervening land lay between the two. Underneath the close of land of the defendants on which they proposed to construct their reservoir there were old and disused mining passages and works. There were five vertical shafts, and some horizontal shafts communicating with them. The vertical shafts had been filled up with soil and rubbish; and, it does not appear that any person was aware of the existence either of the vertical shafts or of the horizontal works communicating with them. In the course of the working by the plaintiff of his mine, he had gradually worked through the seams of coal underneath the close, and had come into contact with the old and disused works underneath the close of the defendants.

In that state of things the reservoir of the defendants was constructed. It was constructed by them through the agency and inspection of an engineer and contractor. Personally the defendants appear to lave taken no part in the works, nor to have been aware of any want of security connected with them. As regards the engineer and the contractor, we must take it from the Case that they did not exercise, as far as they were concerned, that reasonable care and caution which they might have exercised, taking notice, as they appear to have taken notice, of the vertical shafts filled up in the manner which I have mentioned. However, when the reservoir was constructed and filled, or partly filled, with water, the weight of the water, bearing upon the imperfectly filled-up and disused vertical shafts, broke through those shafts. The water passed down them and into the horizontal workings and from the horizontal workings under the close of the defendants, it passed on into the workings under the close of the plaintiff and flooded his mine, causing considerable damage, for which this action was brought. The Court of Exchequer, when the Special Case stating the facts to which I have referred was argued before them, were of opinion that the plaintiff had established no cause of action. The Court of Exchequer Chamber, before whom an appeal from their judgment was argued, were of a contrary opinion, and unanimously arrived at the conclusion that there was a cause of action, and that the plaintiff was entitled to damages.

The principles on which this case must be determined appear to me to be extremely simple. The defendants, treating them as the owners or occupiers of the close on which the reservoir was constructed, might lawfully have used that close for any purpose for which it might, in the ordinary course of the enjoyment of land, be used, and if, in what I may term the natural user of that land, there had been any accumulation of water, either on the surface or underground, and if by the operation of the laws of nature that accumulation of water had passed off into the close occupied by the plaintiff, the plaintiff could not have

[1861-73] All ER Rep 1 at 12

complained that that result had taken place. If he had desired to guard himself against it, it would have lain on him to have done so by leaving or by interposing some barrier between his close and the close of the defendants in order to have prevented that operation of the laws of nature.

As an illustration of that principle, I may refer to a case which was cited in the argument before your Lordships, *Smith v Kenrick* (9) in the Court of Common Pleas. On the other hand, if the defendants, not stopping at the natural use of their close, had desired to use it for any purpose which I may term a non-natural use, for the purpose of introducing into the close that which, in its natural condition, was not in or upon it - for the purpose of introducing water, either above or below ground, in quantities and in a manner not the result of any work or operation on or under the land, and if in consequence of their doing so, or in consequence of any imperfection in the mode of their doing so, the water came to escape and to pass off into the close of the plaintiff, then it appears to me that that which the defendants were doing they were doing at their own peril; and if in the course of their doing it the evil arose to which I have referred - the evil, namely, of the escape of the water, and its passing away to the close of the plaintiff and injuring the plaintiff - then for the consequence of that, in my opinion, the defendants would be liable. As *Smith v Kenrick* (9) is an illustration of the first principle to which I have referred, so also the second principle to which I have referred is well illustrated by another case in the same court, *Baird v Williamson* (10) which was also cited in the argument at the Bar.

These simple principles, if they are well founded, as it appears to me they are, really dispose of this case. The same result is arrived at on the principles referred to by BLACKBURN, J, in his judgment in the Court of Exchequer Chamber, where he states the opinion of that court as to the law in these words:

> "We think that the true rule of law is that the person who, for his own purposes, brings on his land and collects and keeps there anything likely to do mischief if it escapes, must keep it in at his peril, and, if he does not do so, he is prima facie answerable for all the damage which is the natural consequence of its escape. He can excuse himself by showing that the escape was owing to the plaintiff's default, or, perhaps, that the escape was the consequence of via major or the act of God; but, as nothing of this sort exists here, it is unnecessary to inquire what excuse would be sufficient. The general rule as above stated seems on principle just. The person whose grass or corn is eaten down by the escaping cattle of his neighbour, or whose mine is flooded by the water from his neighbour's reservoir, or whose cellar is invaded by the filth of his neighbour's privy, or whose habitation is made unhealthy by the fumes and noisome vapours of his neighbour's alkali works, is damnified without any fault of his own; and it seems but reasonable and just that the neighbour who has brought something on his own property which was not naturally there, harmless to others so long as it is confined to his own property, but which he knows will be mischievous if it gets on his neighbour's, should be obliged to make good the damage which ensues if he does not succeed in confining it to his own property. But for his act in

> bringing it there no mischief could have accrued, and it seems but just that he should at his peril keep it there, so that no mischief may accrue, or answer for the natural and anticipated consequence. On authority this, we think, is established to be the law, whether the things so brought be beasts, or water, or filth, or stenches."

In that opinion, I must say, I entirely concur. Therefore, I have to move your Lordships that the judgment of the Court of Exchequer Chamber be affirmed, and that the present appeal be dismissed with costs.

[1861-73] All ER Rep 1 at 13

LORD CRANWORTH:

I concur with my noble and learned friend in thinking that the rule of law was correctly stated by BLACKBURN, J, in delivering the opinion of the Exchequer Chamber. If a person brings or accumulates on his land anything which, if it should escape, may cause damage to his neighbour, he does so at his peril. If it does escape and cause damage, he is responsible, however careful be may have been, and whatever precautions be may have taken to prevent the damage. In considering whether a defendant is liable to a plaintiff for damage which the plaintiff may have sustained, the question in general is, not whether the defendant has acted with due care and caution, but whether his acts have occasioned the damage. This is all well explained in the old case of Lambert and *Olliot v Bessey* (11). The doctrine is founded on good sense, for when one person in managing his own affairs causes, however innocently, damage to another, it is obviously only just that he should be the party to suffer. He is bound sic uti suo ut non laedat alienum. This is the principle of law applicable to cases like the present, and I do not discover in the authorities which were cited anything conflicting with it.

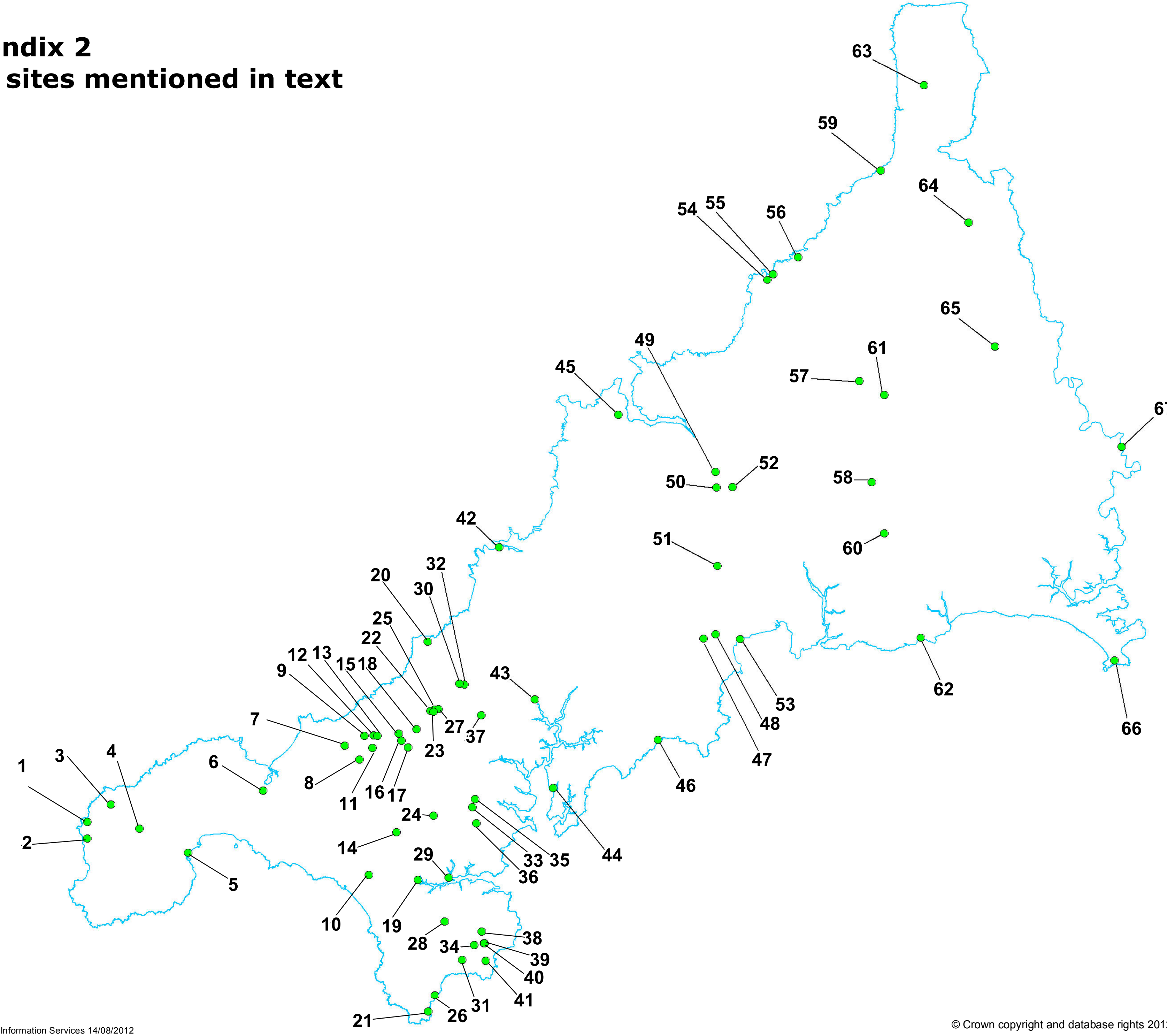
The doctrine appears to me to be well illustrated by the two cases in the Court of Common Pleas referred to by my noble and learned friend - I allude to *Smith v Kenrick* (9) and Baird v Williamson (10). In the former, the owner of a coal mine on the higher level worked out the whole of his coal, leaving no barrier between his mine, and the mine on the lower level, so that the water percolating through the upper mine flowed into the lower mine, and obstructed the owner of it in getting his coal. It was held that the owner of the lower mine had no ground of complaint. The defendant, the owner of the upper mine, had a right to remove all his coal; the damage sustained by the plaintiff was occasioned by the natural flow or percolation of water from the upper strata. There was no obligation on the defendant to protect the plaintiff against this. It was the plaintiff's business to erect or leave a sufficient barrier to keep out the water, or to adopt proper means for so conducting the water that it should not impede him in his workings. The water in that case was only left by the defendant to flow in its natural course. But in the later case of *Baird v Williamson* (10) the defendant, the owner of the upper mine, did not merely suffer the water to flow through his mine without leaving a barrier between it and the mine below, but in order to work his own mine beneficially he pumped up large quantities of water, which passed into the plaintiff's mine in addition to that which would have naturally reached it, and so occasioned him damage. Though this was done without negligence, and in the due working of his own mine, yet he was held to be responsible for the damage so occasioned. It was in consequence of his act, whether skilfully or unskilfully performed, that the plaintiff had been damaged, and he was, therefore, held liable for the consequences. The damage in the former case may be treated as having arisen from the act of God - in the latter from the act of the defendant.

Applying the principles of these decisions to the case now before the House, I come without hesitation to the conclusion that the judgment of the Exchequer Chamber was right. The plaintiff had a right to work his coal through the lands of Mr Whitehead and up to the old workings. If water naturally rising in the defendants' land (we may treat the land as the land of the defendants for the purpose of this case) had by percolation found its way down to the plaintiff's mine through the old workings and so had impeded his operations, that would not have afforded him any ground of complaint. Even if all the old workings had been made by the defendants they would have done no more than they were entitled to do, for, according to the principle acted on in *Smith v Kenrick* (9) the person working the mine under the close in which the reservoir was made had a right to win and carry away all the coal without leaving any wall or barrier against W Whitehead's land. But that is not the real state of the case. The defendants, in order to effect an object of their

own, brought on to their land, or on to land which for this purpose may be treated as being theirs, a large accumulated mass of water, and stored it up in a reservoir. The consequence of this was damage, to the plaintiff, and for that damage, however skilfully and carefully the accumulation was made, the defendants, according to the principles and authorities to which I have adverted, were certainly responsible. I concur, therefore, with my noble and learned friend in thinking that the judgment below must be affirmed, and that there must be judgment for the defendant in error.

Appeal dismissed.

Appendix 2
Main sites mentioned in text



P251

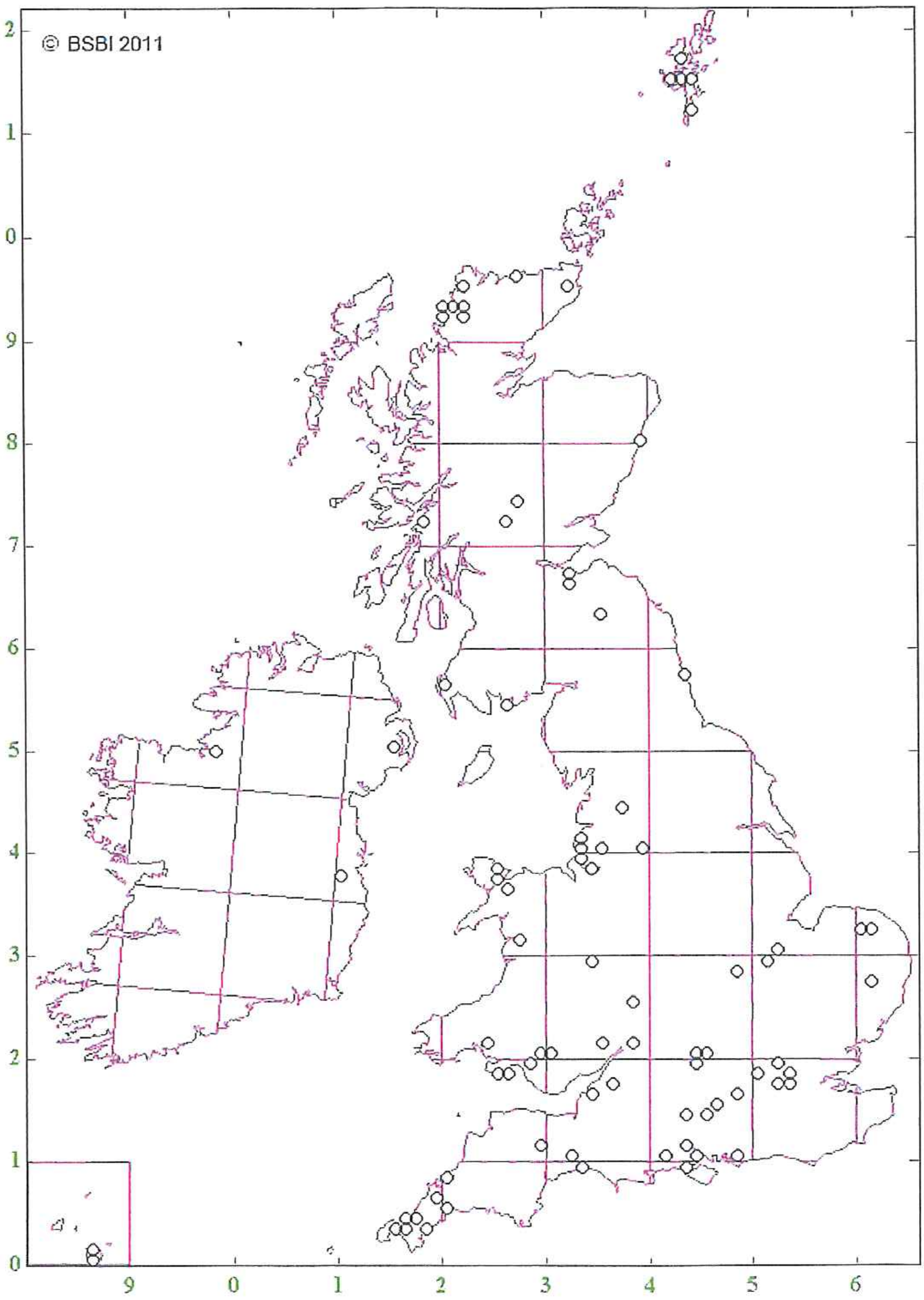
Produced by Geographic Information Services 14/08/2012

NUMBER	SITE NAME	GRID REFERENCE
1	Cot Valley	SW360324
2	Tregeseal Valley	SW360307
3	Jeffries Down Pendeen	SW385342
4	Receven Common	SW415317
5	Newlyn Green	SW465292
6	St Erth Civic Amenity Site	SW543357
7	Treswithian	SW628403
8	Killivose	SW643389
9	Rosewarne	SW648414
10	Loe Valley	SW653269
11	Dolcoath	SW656401
12	Tuckingmill	SW658414
13	East Hill	SW662414
14	Trenear	SW681313
15	Barncoose	SW684416
16	Carn Brea	SW686409
17	Seleggan	SW694402
18	Wesley Street, Redruth	SW702421
19	Gweek	SW704264
20	St Agnes	SW714511
21	Church Cove	SW714127
22	Scorrier Depot	SW717440
23	Scorrier Woods	SW720439
24	Butteriss Gate	SW720331
25	Scorrier external treatment site	SW721441
26	Cadgwith	SW721145
27	Scorrier	SW725441
28	Trezise	SW731221
29	Helford River	SW736266
30	Chiverton	SW747468
31	Ponsongath	SW750181
32	Three Burrows	SW752467
33	Mabe	SW760340
34	Zoar	SW762196
35	Treliever	SW763348
36	Argal	SW765323
37	Cusveorth	SW769435
38	Lanarth	SW770210
39	St Keverne Beacon	SW773198
40	St Keverne Beacon	SW773198
41	Trevothen	SW774180
42	Crantock	SW788610
43	Truro	SW825452
44	Messack	SW844360
45	Padstow	SW912747
46	Portholland	SW953410
47	Tregongeeves	SX001515
48	St Austell	SX013519
49	Brocton	SX013688
50	Ruthernbridge	SX014672

51 Bugle	SX015590
52 Nanstallon	SX030672
53 Charlestown	SX039514
54 Jilpool	SX066887
55 Rocky Valley	SX073894
56 Boscastle	SX099911
57 Butters Tor	SX162782
58 Goonzion Downs	SX175677
59 Milook	SS185001
60 Connon Bridge	SX188624
61 Bolventor	SX188768
62 Talland Bay	SX226516
63 Tiscott Wood	SS229090
64 Dolsdon	SX276947
65 South Petherwin	SX303818
66 Maker With Rame	SX427492
67 Gunnislake	SX435714

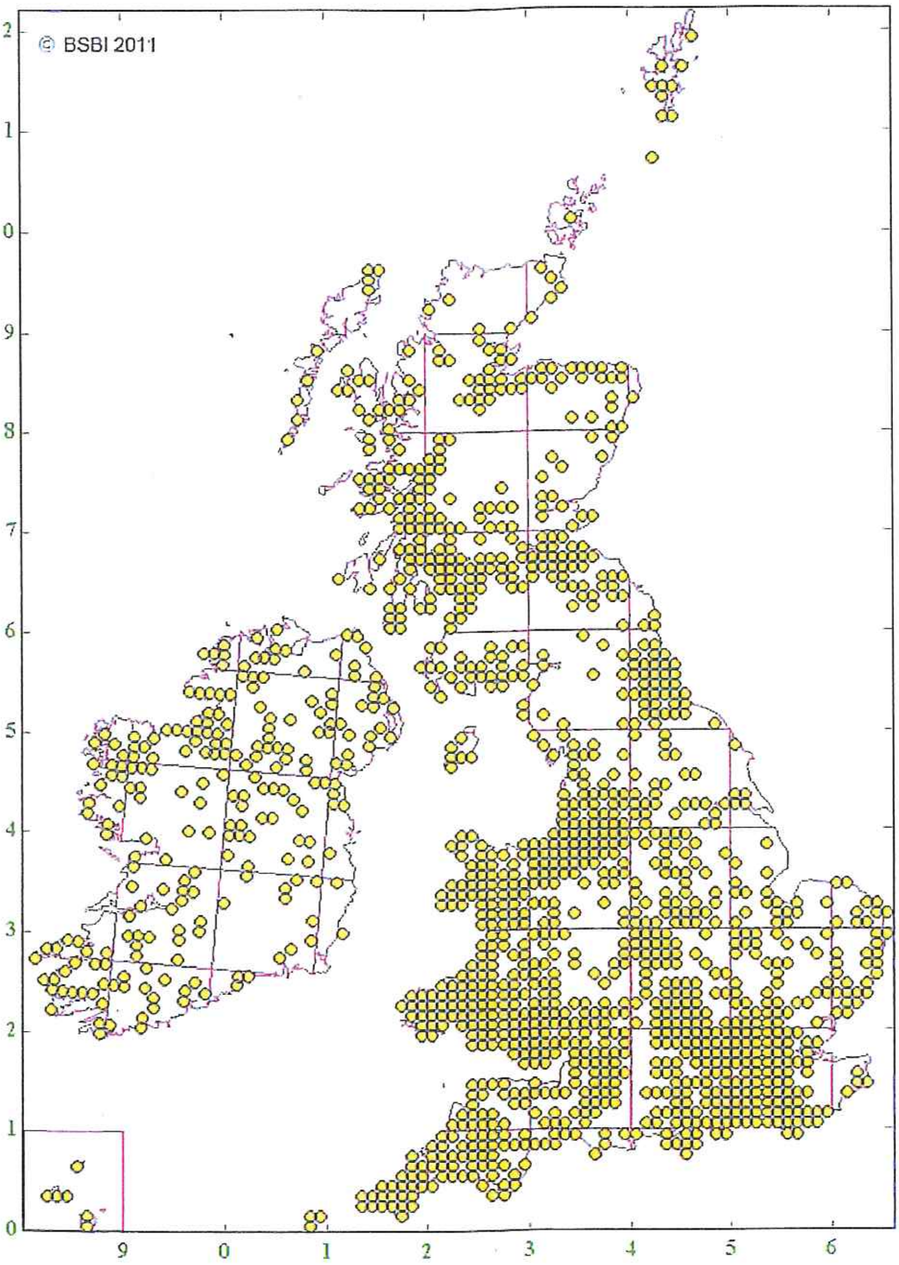
Appendix 3a

Hectad map of Fallopia japonica (Japanese Knotweed) in GB and Ireland -1930



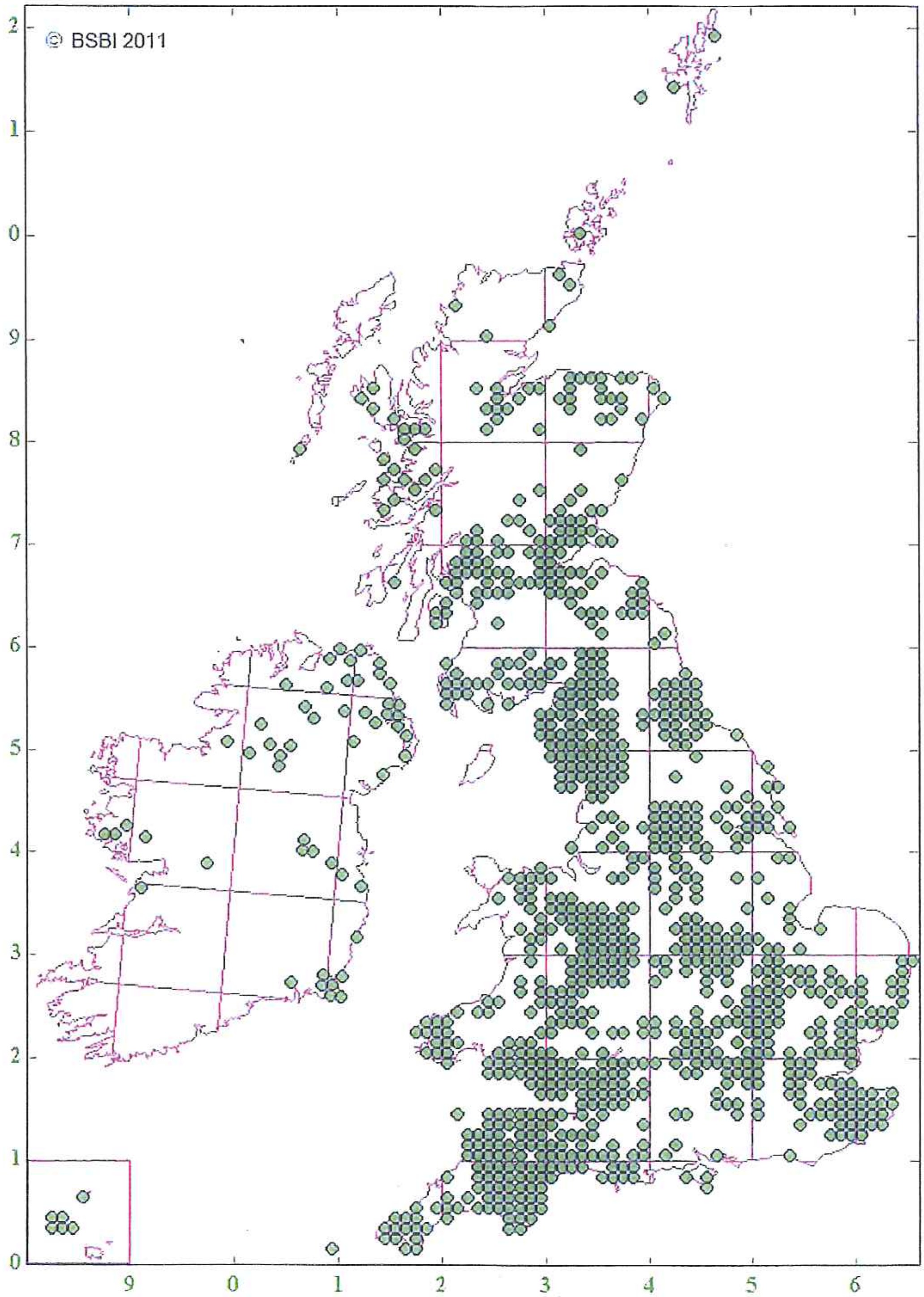
Appendix 3b

Hectad map of Fallopia japonica (Japanese Knotweed) in GB and Ireland 1930-1969



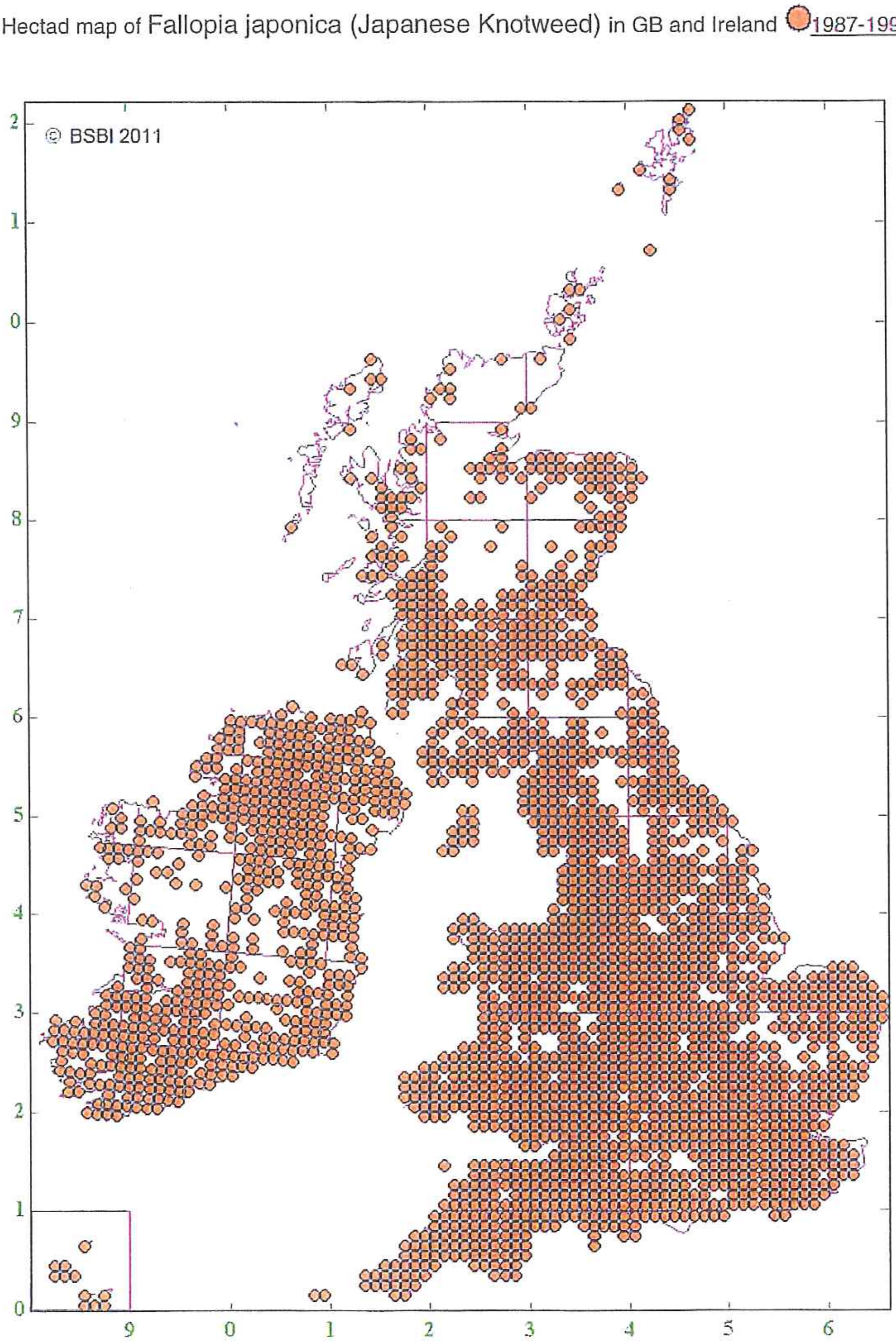
Appendix 3c

Hectad map of Fallopia japonica (Japanese Knotweed) in GB and Ireland 1970-1986



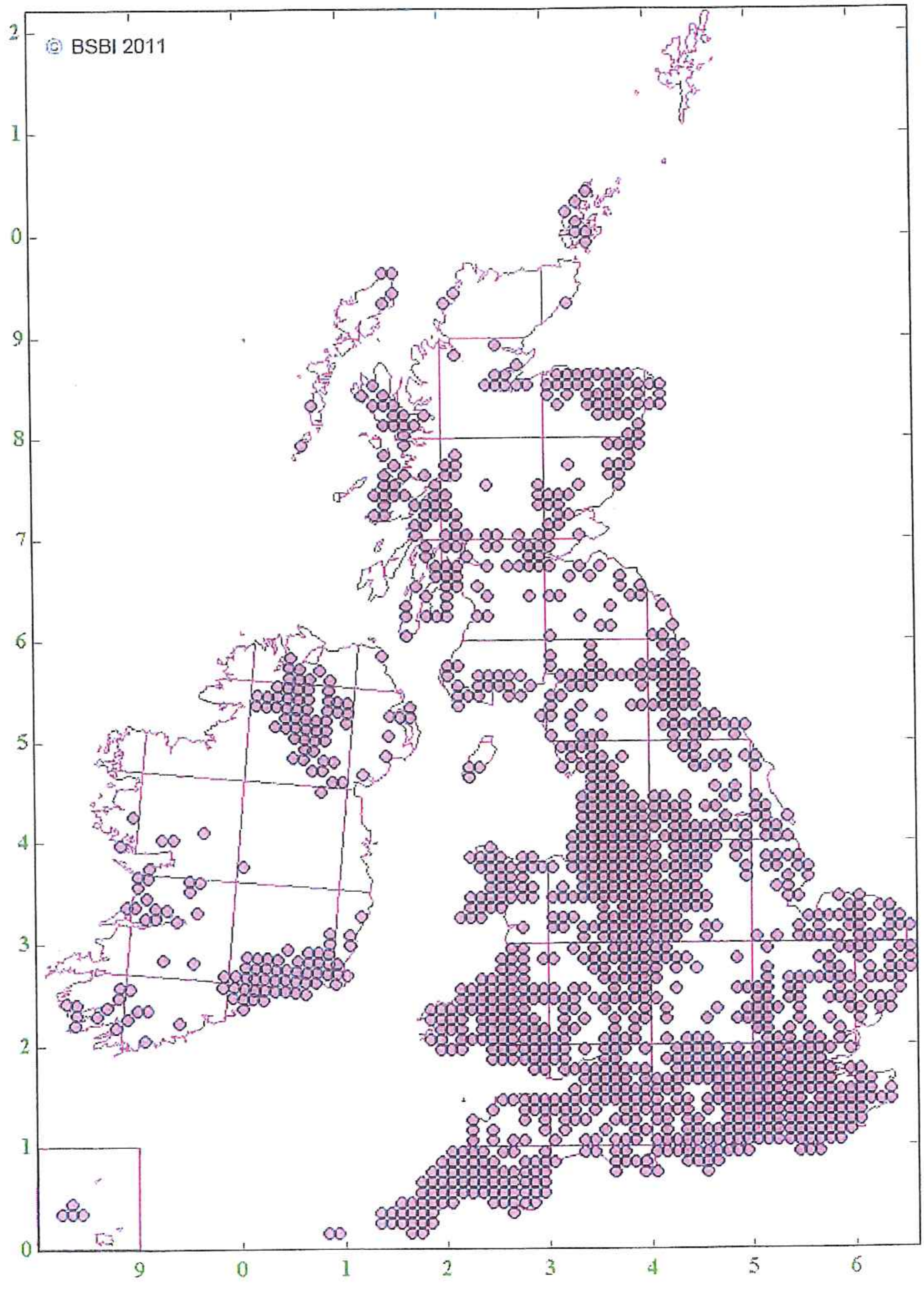
Appendix 3d

Hectad map of *Fallopia japonica* (Japanese Knotweed) in GB and Ireland



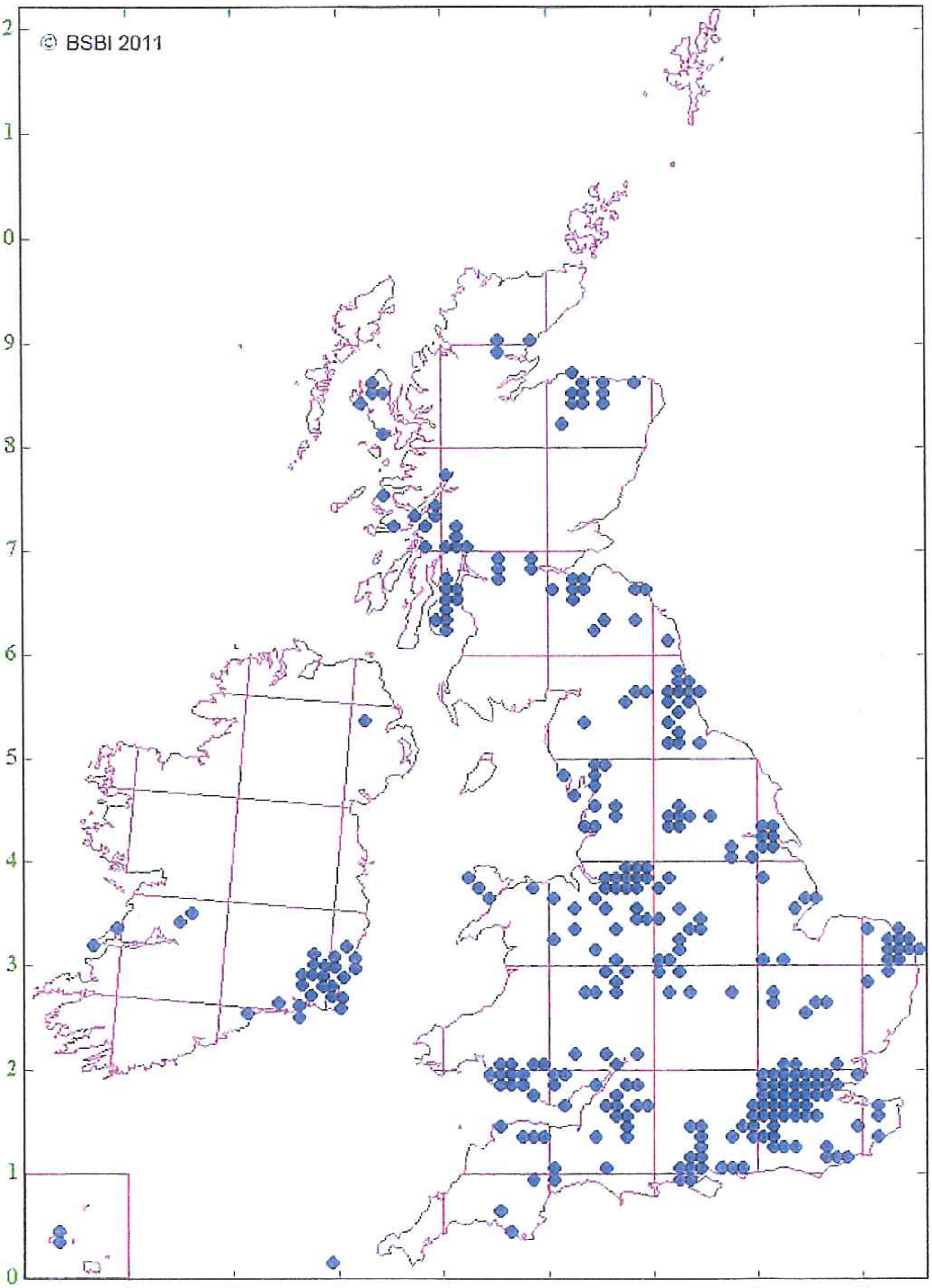
Appendix 3e

Hectad map of Fallopia japonica (Japanese Knotweed) in GB and Ireland 2000-2009



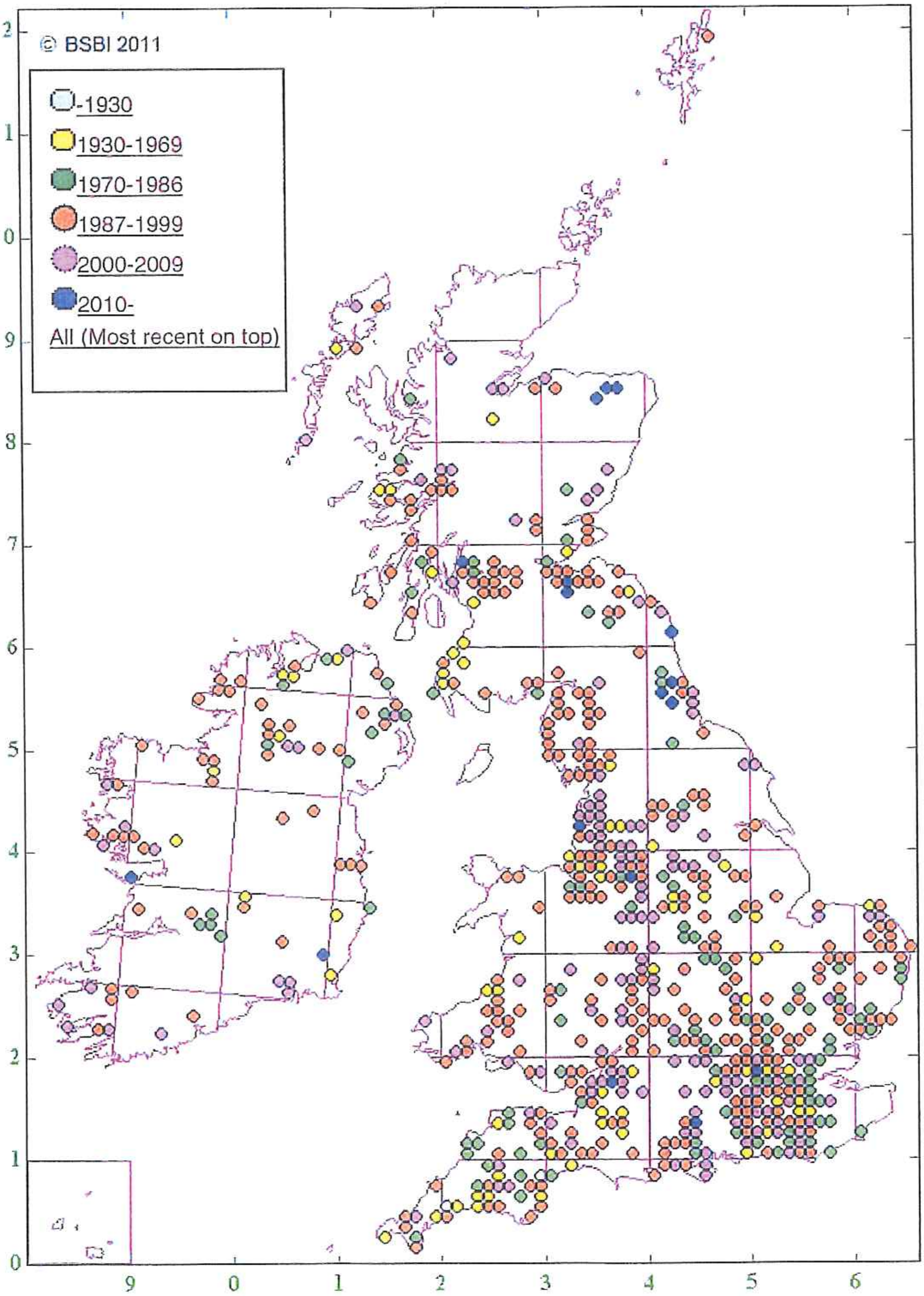
Appendix 3f

Hectad map of *Fallopia japonica* (Japanese Knotweed) in GB and Ireland 2010-



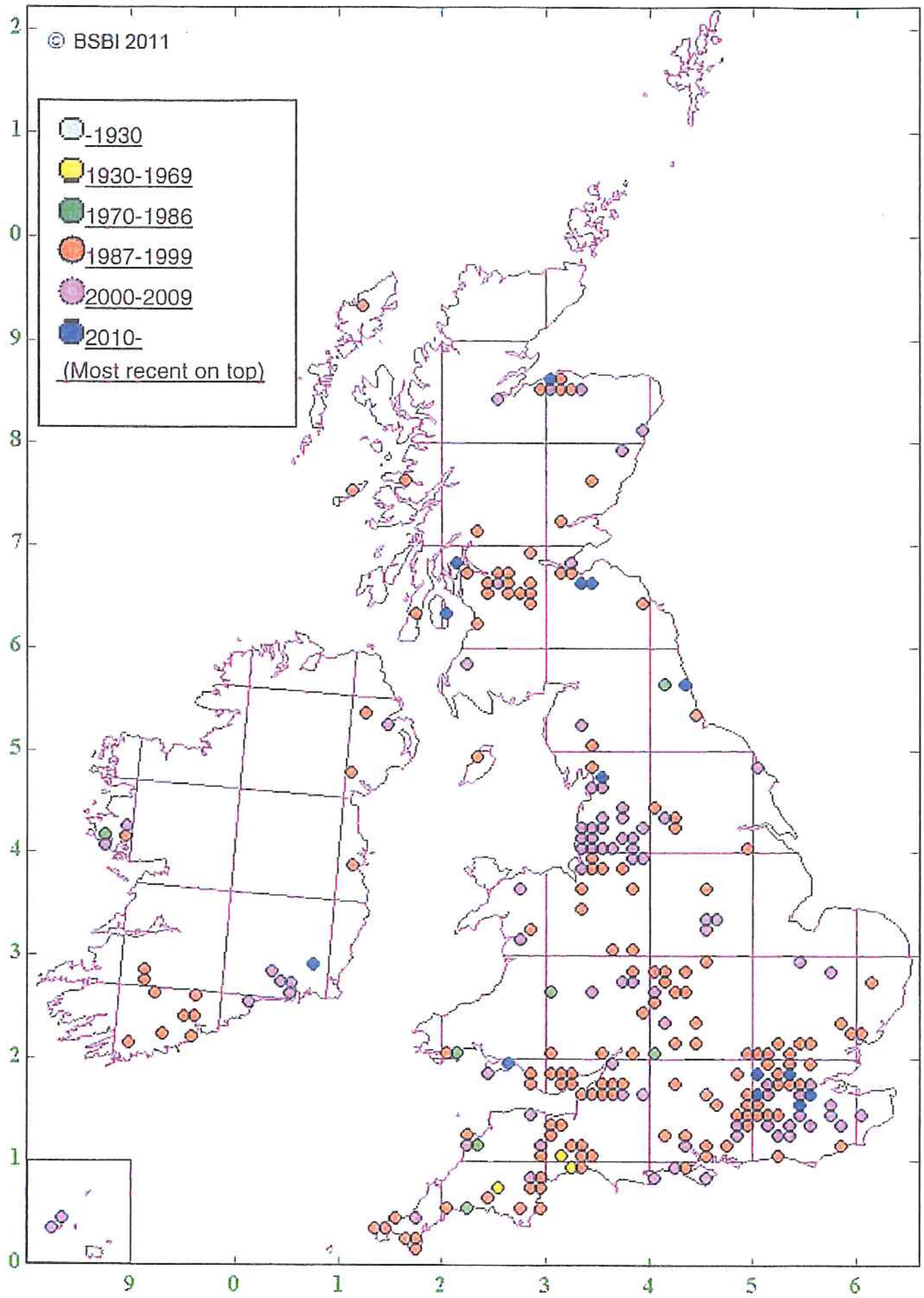
Appendix 3g

Hectad map of *Fallopia sachalinensis* (Giant Knotweed) in GB and Ireland



Appendix 3h

Hectad map of Fallopia x bohemica (F. japonica x sachalinensis) in GB and Ireland



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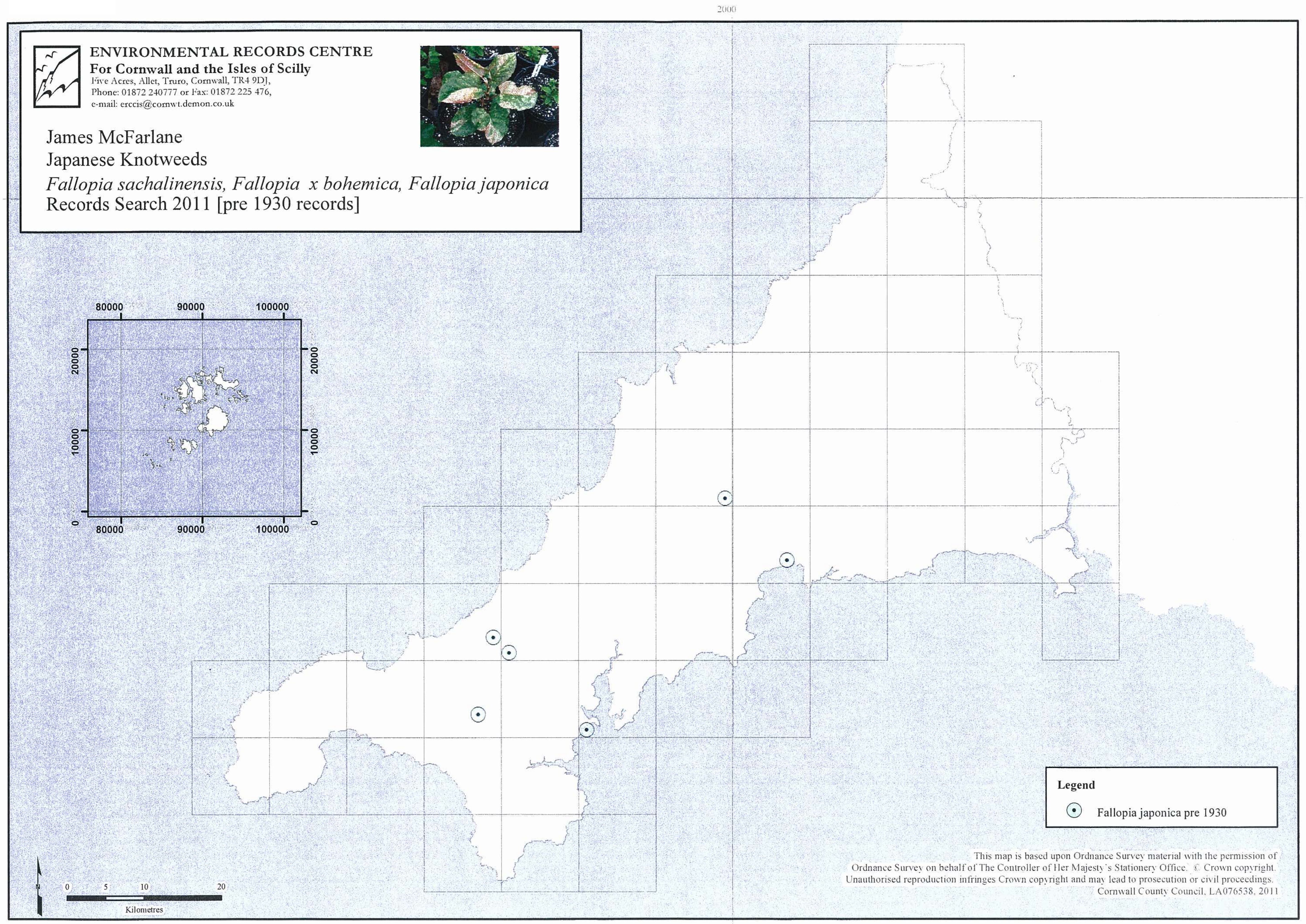
ENVIRONMENTAL RECORDS CENTRE
For Cornwall and the Isles of Scilly
Five Acres, Allet, Truro, Cornwall, TR4 9DJ,
Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [pre 1930 records]
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90000
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20000
10000
0
Legend
Fallopia japonica pre 1930
0
5
10
20
Kilometres
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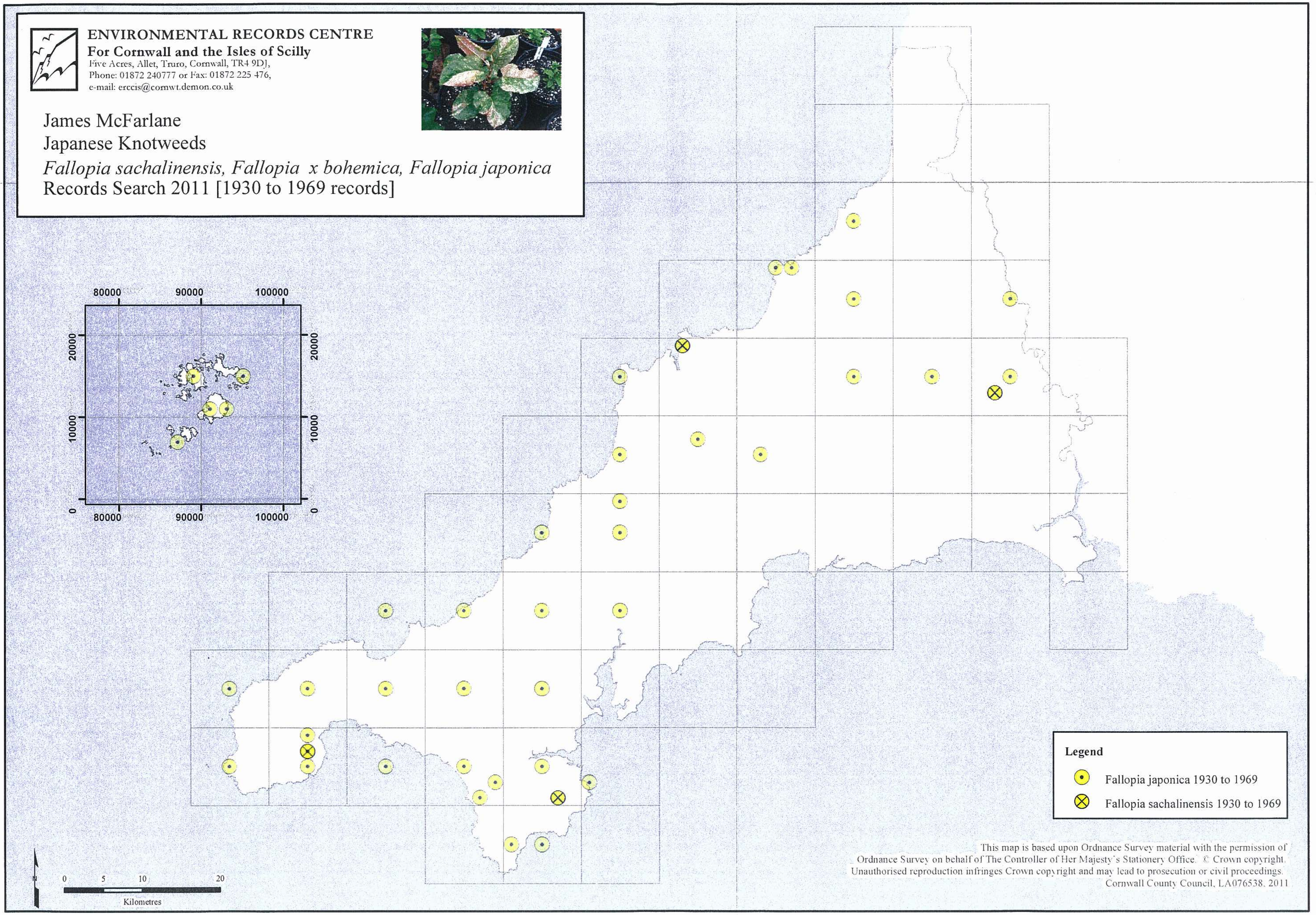
Cornwall County Council, LA076538, 2011

Appendix 5



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Five Acres, Allet, Truro, Cornwall, TR4 9DJ,
Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [1930 to 1969 records]
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90000
100000
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Fallopia japonica 1930 to 1969
Fallopia sachalinensis 1930 to 1969
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Kilometres
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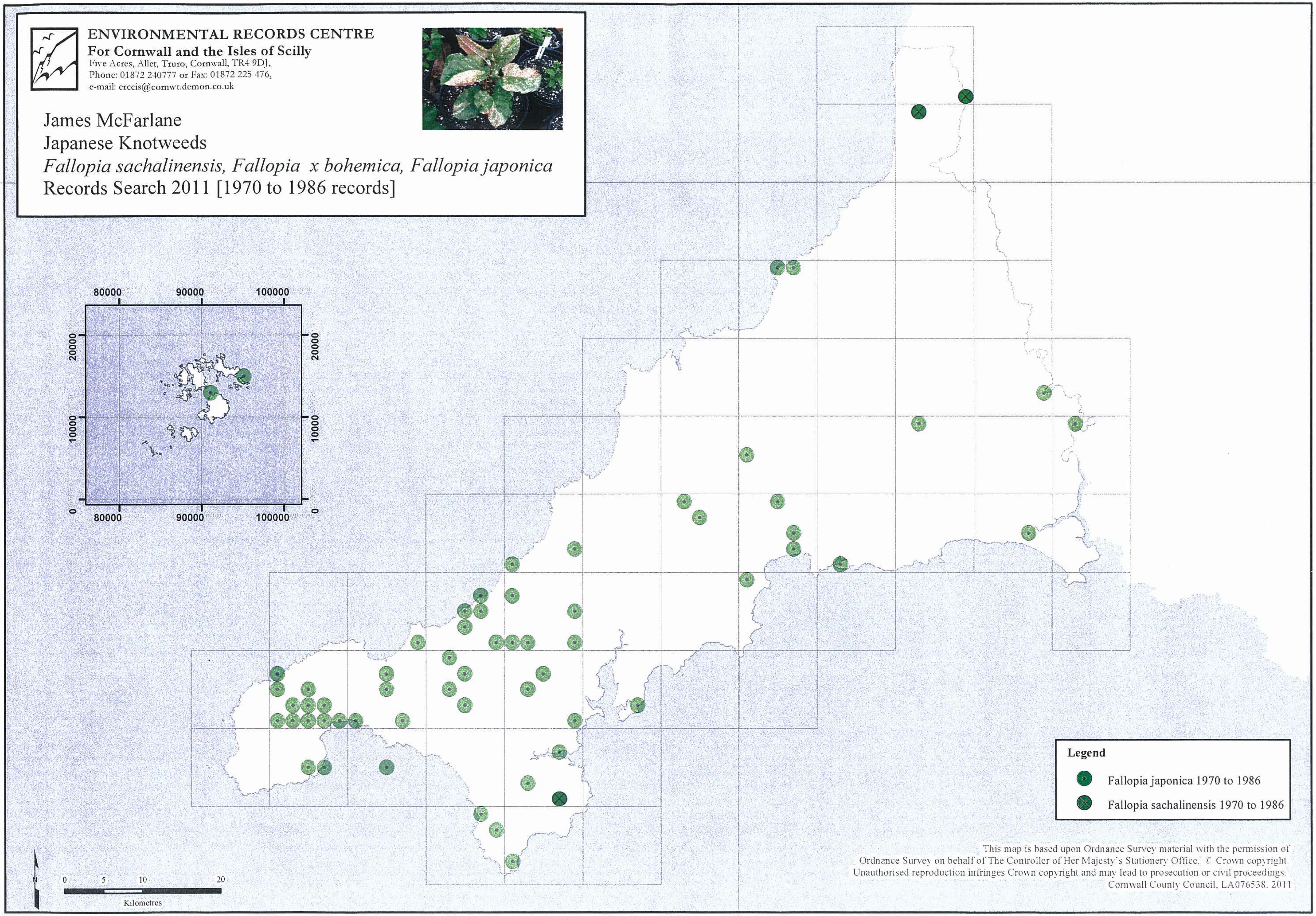
Appendix 6



ENVIRONMENTAL RECORDS CENTRE
For Cornwall and the Isles of Scilly
Five Acres, Allet, Truro, Cornwall, TR4 9DJ,
Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [1970 to 1986 records]
80000
90000
100000
20000
10000
0
Legend
Fallopia japonica 1970 to 1986
Fallopia sachalinensis 1970 to 1986
0
5
10
20
Kilometres
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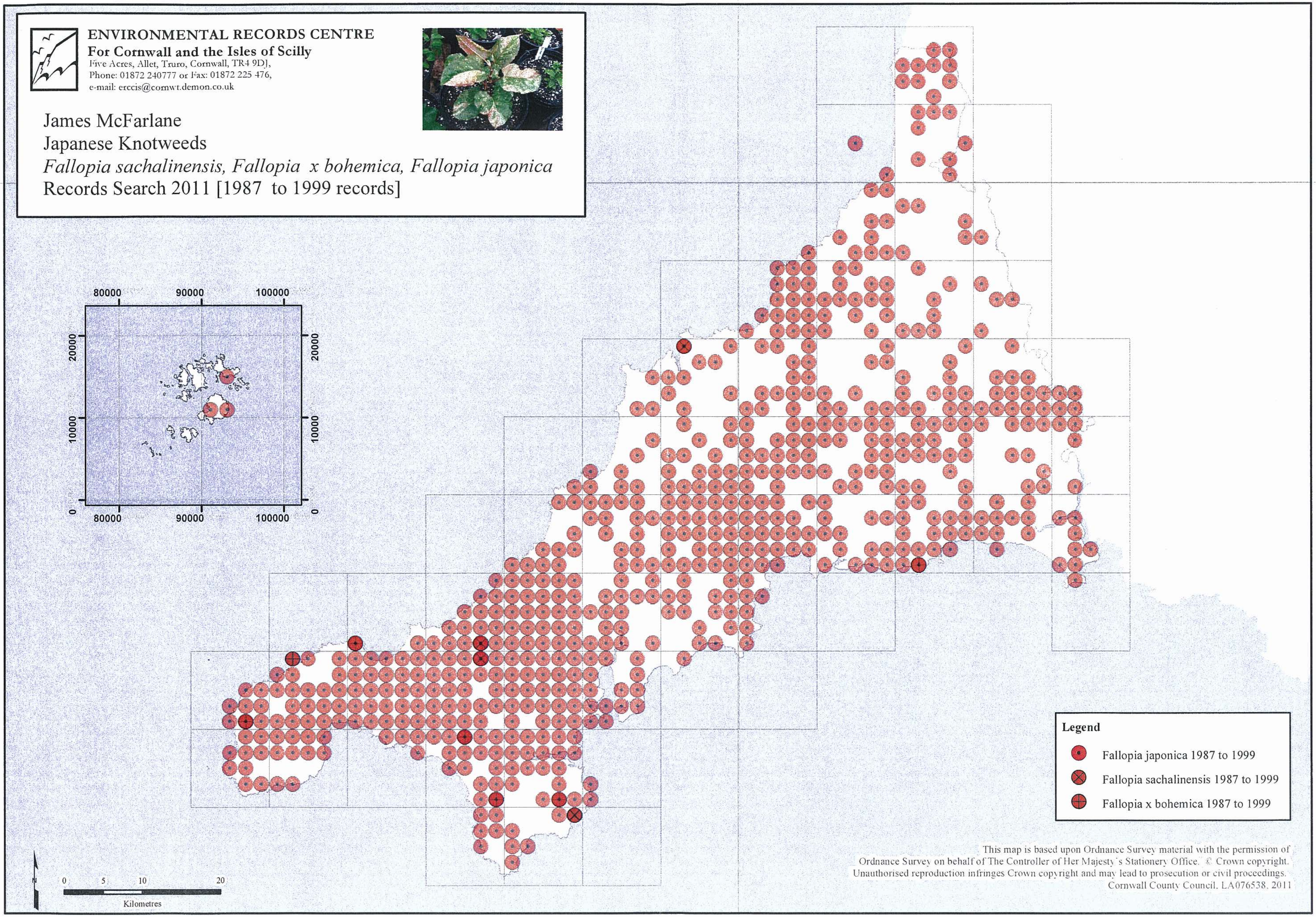
Appendix 7


ENVIRONMENTAL RECORDS CENTRE
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Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [1987 to 1999 records]
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Legend
Fallopia japonica 1987 to 1999
Fallopia sachalinensis 1987 to 1999
Fallopia x bohemica 1987 to 1999
0
5
10
20
Kilometres
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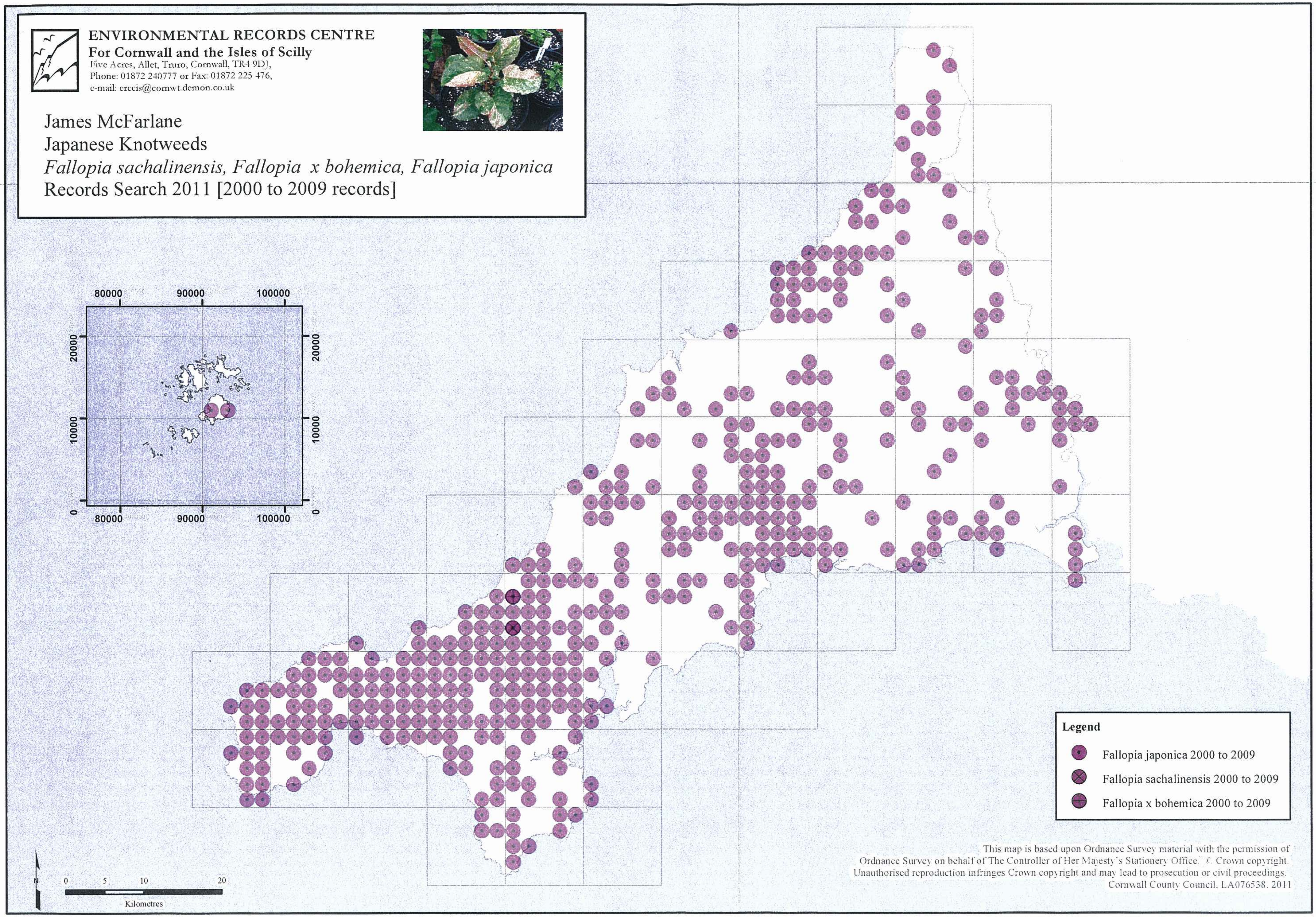
Appendix 8



ENVIRONMENTAL RECORDS CENTRE
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Five Acres, Allet, Truro, Cornwall, TR4 9DJ,
Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [2000 to 2009 records]
80000
90000
100000
20000
10000
0
Legend
Fallopia japonica 2000 to 2009
Fallopia sachalinensis 2000 to 2009
Fallopia x bohemica 2000 to 2009
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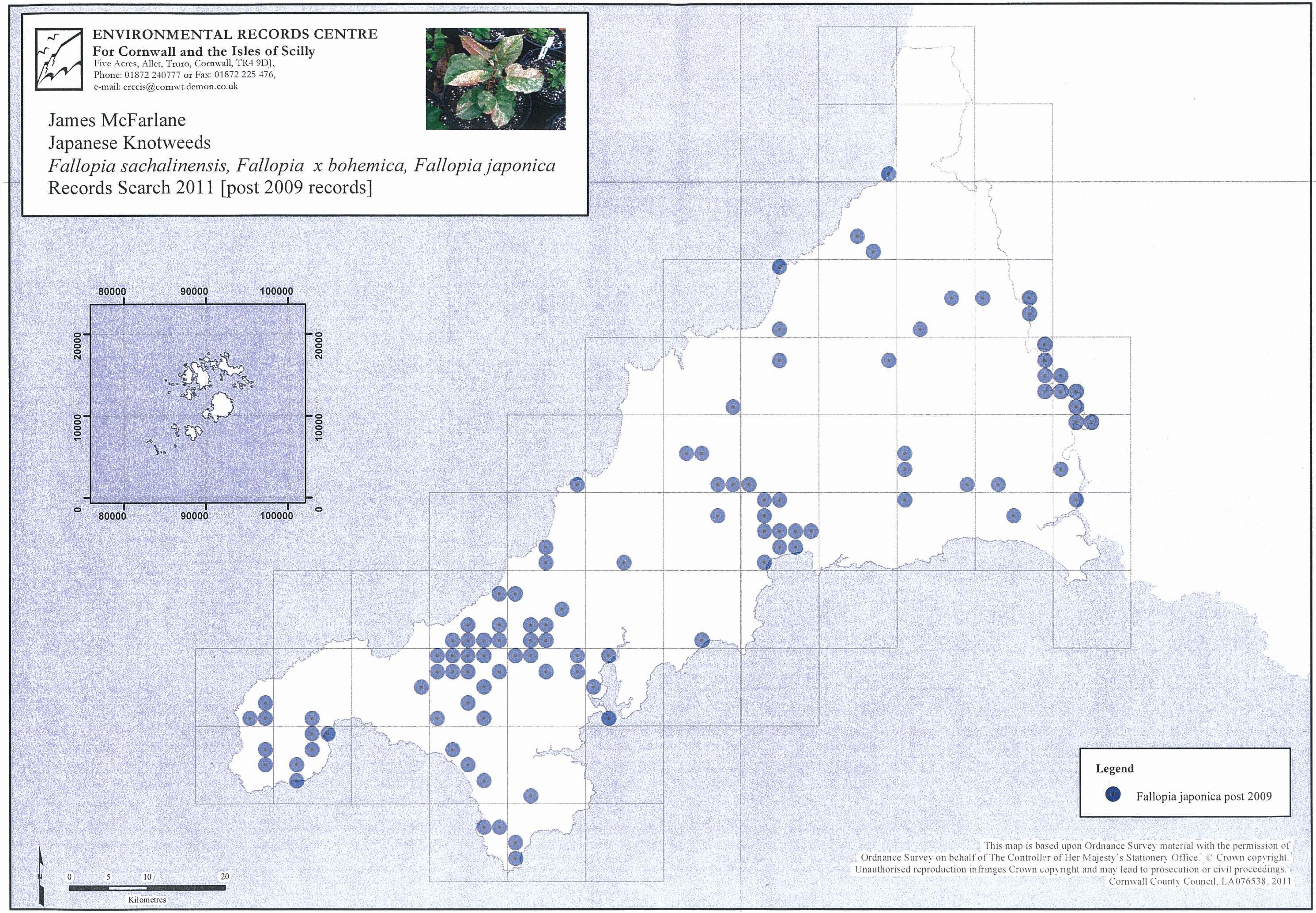
Cornwall County Council. LA076538. 2011
0 5 10 20
Kilometres

Appendix 9


ENVIRONMENTAL RECORDS CENTRE
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Phone: 01872 240777 or Fax: 01872 225 476,
e-mail: erccis@cornwt.demon.co.uk
James McFarlane
Japanese Knotweeds
Fallopia sachalinensis, Fallopia x bohemica, Fallopia japonica
Records Search 2011 [post 2009 records]
80000
90000
100000
20000
10000
0
Legend
Fallopia japonica post 2009
0
5
10
20
Kilometres
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Appendix 10

Original Recording Sheet

BOTANICAL SOCIETY OF THE BRITISH ISLES

JAPANESE KNOTWEED RECORDING SHEET

Thank you for contributing towards the Botanical Society of the British Isles survey of Japanese Knotweed in Cornwall. Records will be computerised and made available for public information. The information will be used for the nature conservation, research education and to target a coordinated to controlling Knotweed. Please fill in the information below as accurately as possible and return to Dr Colin French, 12 Seton Gardens, Weeth Road, Camborne, Cornwall TR14 7J5

Name
....
....

Address...
....

Telephone Number..
....

Date of Record..
....

Maps of distribution of Japanese Knotweed across the British Isles

LOCATION OF THE KNOTWED ……………………………………………………………..

SIX-FIGURED GRID REFERENCE FOR THE CENTRE OF THE KNOTWEED STAND
(to obtain a six-figured grid reference , locate the centre of the Knot weed on an Ordnance Survey Map. Each map should have written guidance regarding The National Grid Reference System, and how to obtain a grid reference; For instance, the six-figure grid reference for the post box on the top of Brown Willy Tor, Bodmin Moor is SX 159 800.)

HOW LONG HAS THE KNOTWEED BEEN KNOWN AT THIS SITE ……………
Please indicate the type/s of habitat covered in Knotweed in the appropriate box;

Rivers Edge		**Hedge**		**Farmland**		**Amenity Area**	
Derelict Land		**Garden**		**Woodland**		**Public Site**	
Roadside Verge		**Industrial/ Business site**		**Railway embankment**		**Other**	

You are not obligated to complete the Section Below concerning ownership, but this information may be of use to us.
NAME, ADDRESS AND PHONE NUMBER OF THE LANDOWNER IF KNOWN (please indicate on the sketch map if the Knotweed covers ground owned by more than one owner)

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

STETCH MAP (please remember to include details regarding location, distribution and the nearest road, river and /or habitation.

AREA OF GROUND COVERED BY KNOTWEED
……………………………………………………………………………………………………
……………………………………………………………………………………………………
LENGTH………………………………………………………………………………………
……………………………………………………………………………………………………
WIDTH…………………………………………………………………………………………
……………………………………………………………………………………………………
PERCENTAGE OF DENSE COVER (KNOTWWED ONLY)……………………………………………………………………………………
……………………………………………………………………………………………………

PERCENTAGE OF PARTIAL COVER…………………………………………………………………………………………
……………………………………………………………………………………………………..

Appendix 11

Data dictionary

Incorporated by

	1	GPS edited
	2	GPS unedited default
	3	Measured
	4	Observed
Type		
	1	Fallopia japonica **default**
	2	Fallopia x bohemica
	3	Fallopia sachalinensis
	4	Fallopia unidentfied
Location		
	1	Verge **default**
	2	Hedge
	3	Garden
	4	Built environment
	5	Cornish hedge
	6	Agricultural
	7	Woodland
	8	Waste
Watercourse		
	1	None (can be treated without effect on watercourse)
	2	Moving
	3	Static
	4	Dry ditch
Accessibility		
	1	To JCB size
	2	To minidig size
	3	To manually directed (rotovator) size
	4	Pedestrian access easy (with knapsack sprayer)
	5	Pedestrian access difficult
	6	Inaccessible
Ownership		
	1	Single
	2	Shared
Ground cover		
	1	More than 75% JK
	2	50% to 75%JK
	3	25% to 49% JK
	4	Less than 24% JK
Stem diameter		
	1	More than 2 cm (at ground level)
	2	1cm to 2cm
	3	Less than 1 cm
Cut		
	1	Not
	2	Occasionally
	3	Regularly
	4	Other
Herbicide treatment		
	1	None
	2	Yes, with detailed information
	3	Yes, without further information
Safety hazard		
	1	No
	2	Yes
Slope		

1	0 to 30 degrees
2	31 to 90 degrees

Appendix 12

Quality of data

Knotweed main
These sites were surveyed by the individual named (initials in database) and form a reliable record of the presence of the species determined at the date within the database. Accuracy of extent will vary, in decreasing order, from GPS survey unedited, survey edited, measured, through to observed. Treatment information will vary from information provided by operator involved to observation of condition e.g. epinastic growth.

Knotweed CF point and CF polygon.
These two data sets were provided as a starting point and have not been edited.

Highway sites.
Where these are not coincidental with Knotweed main, they act as an historical record from a period before the database was held by the CC. They also contain reports from Cormac gangs which await investigation, but which are presently being treated.

Trunk road.
Where these sites are not coincidental with HA data, these have generally been subject to a treatment regime prior to HA survey and have not been rediscovered. They are generally observed or measured rather than located by GPS, but can be considered to provide a quite accurate survey.

HA data
These are generally referenced as point data using GPS with an accuracy of plus or minus 10 metres.

Knotweed to check.
These are sightings provided by members of the public and the symbols are removed when the sites are surveyed. If the plant is not found at the time of survey, reference is made back to the correspondent. If no contact is made, the site remains on the database.

Recommendations.
When new Highway sites are reported, these be marked as sites to check as well as treatment sites. When checked they should be incorporated into Knotweed Main as many are already. Where no material is found on a highway site it should remain on the database.
A full survey, using GPS, of all highway sites should be completed in the financial year 2006/7.
Faster progress be made towards assessment of all reported sites.
All trunk road and HA sites be recorded under Knotweed Main. Where these are not rediscovered, the present site notation should remain.
The general principle should remain not to remove any marked site in case of the presence of dormant rhizome.

Appendix 13

Report form for use when JK is being treated for research rather than eradication

Organisation (name)

Contact (name, telephone e-mail postal address)

Object of research(text 40 characters)

When is the work anticipated to be completed (regular text 15 characters)

Will the results be published (yes-no)

Are you willing to allow contact details to be published on the University of Exeter website?(yes – no)

Have you previously published any work on this subject?(yes – no)

Is this research to be carried out with the plant in situ? (yes - no)

If yes:-

Where? (GR or description)

Nature of area (built environment – rural)

Vegetation category /adjacent vegetation(as in General categories of Phase 1 habitat survey) (a) woodland/scrub (b) grassland/marsh (c) tall herb e.g. bracken (d) heathland (e)mire (f) swamp including river banks (g) coast (j) miscellaneous - includes disturbed land

How much (area square metres)

Is the whole infestation being treated (yes – no)

Survey method (measuring – GPS – estimation)

When first noted (date)

Methods and equipment

(Manual – cutting – pulling - digging – grazing)

(Mechanical – excavation (burial - removal from site stockpiling for treatment on site) – rotovation – harrowing – other)

(Herbicide treatment Spraying – brush watering can (material and application rate (product/sq. metre))

Containment (geotextile – polythene - other)

If yes:-

Where? (GR or description)

Nature of area (built environment – rural)

Vegetation category /adjacent vegetation(as in General categories of Phase 1 habitat survey) (a) woodland/scrub (b) grassland/marsh (c) tall herb e.g. bracken (d) heathland (e)mire (f) swamp including river banks (g) coast (j) miscellaneous - includes disturbed land

How much (area square metres)

Is the whole infestation being treated (yes – no)

Survey method (measuring – GPS – estimation)

When first noted (date)

Methods and equipment (Manual – cutting – pulling - digging – grazing)
(Mechanical – excavation (burial - removal from site stockpiling for treatment on site) – rotovation – harrowing – other)
(Herbicide treatment Spraying – brush watering can (material and application rate (product/sq. metre))
Containment (geotextile – polythene - other)

Height at time of treatment (value cm.)

Time (value hours)

Dates of treatment (regular text 20 characters)

Inspection dates (regular text 20 characters)

What monitoring methods are being used (visual – trial excavation)

How long will monitoring be continued?(regular text 15 characters)

Previous history of site (regular text 20 characters)

Previous treatment (regular text 20 characters)

Reasons for choice of site(regular text 40 characters)

Disposal method(dessication – burning – burial on site – off site - none)

Soil type(regular text 20 characters)

Soil depth (value cm)

PH(value 3 characters)

Follow up (back to methods)

Cost (£)

Weather at time(s) of treatment (dry – sunny – overcast – damp)

Ownership of site (individual - company – public - utility – combination)

Site use present (unused - built environment –conservation site - garden)

Site use intended (no change – development)

Appendix 14 Operatives Reporting Form

Date	Site number	absent	<10 shoots	to20 shoots	>20 shoots	weak growth	normal growth	Tordon normal	Tordon high	Glyphosate	Topfilm	Mixture B	WQM needed	Ornamental/valued plants	All treated	More off highway	Notes

Appendix 15

JAPANESE KNOTWEED

GUIDANCE FOR HOUSEHOLDERS & LANDOWNERS

CORNWALL'S WEALTH OF WILDLIFE

CORNWALL BIODIVERSITY INITIATIVE

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How do I recognise rhizome? 9

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Why is Japanese knotweed a problem?

Japanese knotweed is not native to Europe, therefore the pests and diseases that control it in Japan are not present in the UK. In Japan, Japanese knotweed grows in harmony with other plants and only grows to a fraction of the size that it does in the UK. Similarly, many British plants that have been taken abroad have become highly invasive elsewhere.

Japanese knotweed growing in its native habitat on volcanic ash, Mount Fuji, Japan

Japanese knotweed is a problem throughout Europe and most of North America. Its vigorous growth excludes almost all of our native species, which cannot compete with the tall summer growth or the thick mulch of decaying canes and leaves in winter. Many of the insects that are dependent on our native plants are also lost.

Native flora, such as bluebells, are eventually crowded out by knotweed

Hard surfaces, such as tarmac, are often damaged by knotweed growth. There have been numerous instances of knotweed growing through the floors of houses, occasionally even through the foundations!

What does Japanese knotweed look like?

Japanese knotweed (scientific name *Fallopia japonica*) was introduced to the UK in the mid-nineteenth century as an ornamental plant. The plant is an invasive perennial weed that forms dense stands of tall canes during summer, which die back in autumn.

Red/purple shoots appear in early spring. As the canes grow, the leaves unfurl and the plant turns green. Growth is rapid and mature canes can reach 3 metres (10 feet) in height. The mature canes are hollow and have a characteristic pattern of purple speckles. The leaves are carried on stems in a distinctive zig-zag pattern.

Flowering occurs in late summer/autumn and consists of clusters of creamy-white flowers. Seeds are occasionally produced from pollination from related plants such as Russian Vine *Fallopia*

baldshuanica, **though it is extremely rare for these seeds to be fertile**, as all Japanese knotweed in the UK is believed to be a female clone.

During late autumn/winter the canes die off. The canes lose their leaves and turn dark brown. The dead canes remain standing, and may take up to three years to decompose. Dead material can form a dense litter that suppresses competition from native flora and garden plants.

Early infestations of Japanese knotweed rarely achieve the height associated with mature stands. Canes produced from encroaching knotweed, or growth from small pieces of plant material, tends to form short canes until the rhizome becomes established. **Early treatment of new infestations, when they are still very small, is highly recommended.**

Knotweed canes after winter die-back

How is it spread?

Knotweed regrowth from a section of cane

Japanese knotweed can produce seeds, but it is extremely rare for these seeds to germinate. The most common method of dispersal is by means of stem, crown and rhizome (underground stem) sections.

New plants will grow from the nodes of pieces of green stem, in soil or water. Mechanical cutters, such as flails, will spread knotweed in this fashion. If stems are dried until they are dark brown, they will not regrow unless the crown (base of the stem) is still attached.

The crown is able to survive drying and composting, and will rapidly produce new canes. If you wish to dispose of knotweed canes by drying or composting, **it is important that the stems are cut above the crown**, rather than pulling the plant, which will also dislodge the crown. Where local bylaws allow bonfires, canes can

Growth buds around the base of a winter knotweed crown

30 day regrowth from 2cm and 8cm rhizome sections

Flower tub created with contaminated soil

be pulled and dried on polythene sheet, before careful burning. Living crowns usually have growth buds and have a characteristic orange/red colouration when cut or peeled, similar to that of rhizome, described below.

The rhizome (a root-like underground stem) may reach a depth of 3 metres (10 feet) and extend up to 7 metres (23 feet) away from the parent plant. **Sections of rhizome as small as 0.7 gramme, or smaller than a one pence piece, can grow into a new plant!** Fragmenting the rhizome stimulates the production of small red buds, which grow into new plants. You should never accept topsoil without having first inspected it for rhizome.

How do I recognise rhizome?

Japanese knotweed rhizome appears knotty and leathery brown. Fresh rhizome snaps like a carrot, and usually possesses a dark orange central core with an orange/ yellow outer ring. (Other variations do occur, see photos). The rhizome is similar to a Dock taproot, but tends to be a different shape. The fleshy rhizome lacks the bendy qualities of most normal roots. If in doubt, material can be stored at between 10 - 20° Celsius, in a bag for 30 days, which would be sufficient duration for rhizome to commence budding and growth.

The Welsh Development Agency have developed a useful table for the identification of Japanese knotweed rhizome.

General Characteristics	YES	NO
Twig-like appearance		
Fleshy with hardness like carrot		
Brittle when fresh, break easily like carrot		
Young rhizome is white and very soft		
Exterior of Rhizome		
Colour dark brown, like coffee granules		
Texture of the outer bark leathery		
When bark is removed, tissue is pale orange/yellow		
Nodes at 1-2cm spacing		
Nodes slightly enlarged and 'knotty'		
At nodes white fibrous roots are common		
If present, fresh buds at nodes are red/pink		
Interior of Rhizome		
Longitudinal view:		
Colour: pale orange and light yellow, similar to a carrot		
Central core is usually dark orange/brown, like rust, and sometimes hollow		
Cross section:		
Cortex with rays coming from centre, like spokes from a wheel		
TOTAL		

Reproduced by kind permission of the Welsh Development Agency

If the "YES" score is greater than the "NO" score, then treat the identified rhizomes as Japanese knotweed.

How do I dispose of knotweed material, or soil containing its rhizome?

Gardeners, who have fly-tipped green waste on road verges, lay-bys and waste ground have largely been the cause of knotweed spread, as well as many other non-native invasive plants. This activity is illegal and highly damaging to the environment. If you witness an individual fly-tipping waste, you should note the vehicle type and registration, the time, date and location, and any additional details concerning the individual involved. This information should then be provided to the Environment Agency on the 24-hour freephone hotline, 0800 807060.

Regrowth fronm the crowns of fly-tipped knotweed canes

Fly tipping such as this has been responsible for the widespread distribution of Japanese Knotweed

If you intend to dispose of knotweed canes you should dispose of them within the confines of your garden, either by composting or burning. Remember that cut stem cannot regrow once it has dried to a dark brown colour. Dried cut stems can then be safely composted. Pulled stems, which will include crowns, are not suitable for composting. Stems should be dried on a layer of polythene to prevent rooting. If you wish to burn the stems you should contact the **Environmental Health Office of your local council** and ask advice regarding legislation concerning garden bonfires. When burning pulled stems, ensure that the crown is in the centre of the fire and is thoroughly combusted.

If you spread knotweed outside of your property you may be liable to prosecution.

Many local councils run Civic Amenity sites that receive green waste for centralised composting schemes. **These sites are not suitable for receiving**

Fly-tipped Japanese Knotweed soon becomes established and displaces native wildlife

knotweed, unless the material consists of dried cut canes, with no associated crowns. The level of composting achieved by centralised composting schemes is unlikely to guarantee the destruction of viable knotweed waste, particularly crown and rhizome. **This may subsequently lead to knotweed contamination of the compost produced from these sites.**

If you have knotweed stems that cannot be disposed of within the confines of their garden, they should be disposed of at your local landfill site by prior arrangement with your local Waste Disposal Authority. The landfill operators will then arrange for them to be disposed of at a depth that will prevent regrowth. It is important to ensure that this material is taken to a landfill, rather than to a composting scheme. Disposal to landfill should be avoided wherever possible. **If you have knotweed within the curtilage of your property, you should kill it rather than crop it.**

Dumping of garden waste over boundaries can lead to colonisation by Japanese Knotweed

How do I kill it?

Fortunately, Japanese knotweed is susceptible to a range of herbicides including glyphosate, the active ingredient in products such as 'Roundup biactive' and 'Glyphos biactive'. Whilst chemicals such as triclopyr, imazapyr and picloram are also effective against knotweed, glyphosate has many properties which make it more suitable for use by householders. Many formulations of glyphosate, are suitable for use in or near water, the product is deactivated by micro-organisms in soil, it doesn't leach and it possesses low toxicity to animals. The biactive formulations of glyphosate are generally regarded as the most suitable.

Glyphosate is a translocated herbicide, which means the plant carries the herbicide down to its rhizome. Contact herbicides may appear to kill the leaves and shoots of knotweed, but unless the herbicide is translocated down to the rhizome the plant will regrow.

Knotweed survives the winter as an underground rhizome. During autumn the plant draws food stores from the dying leaves and canes, down to the rhizome. Herbicide treatment during late summer and autumn appears to be more effective, as translocation is assisted by this process. If treating mature canes in autumn is likely to cause problems, earlier applications of herbicide during spring and summer can be used to control its growth. However, it is essential that there are plenty of green leaves to absorb the herbicide before application is undertaken.

Glyphosate is usually sprayed onto the foliage of knotweed. Beware of drift on to non-target plants and lawns. If you are concerned about the risk to other plants, use a weed wiper to apply the herbicide instead of a spray.

Great care needs to be exercised when using herbicides near lawns and shrubs. There are no sprays which are specific to knotweed, but products such as 2,4 D amine can be used at concentrations that do not harm grass. You must contact your local Environment Agency office before using a herbicide in or near a stream or river, a pond that discharges to a watercourse or a pond that is fed by groundwater. You can use a herbicide near a contained garden pond that is not supplied by groundwater or a watercourse without notifying the Environment Agency, although care is still needed to avoid damage to wildlife.

Always follow the guidance provided on the label of the product you intend to use. Wear suitable protective clothing and dispose of packaging appropriately.

The effect of first year glyphosate treatment

'Bonsai' knotweed produced after three years of treatment

If you are not confident with the use of herbicides, or lack the equipment and protective clothing, you should use the services of a qualified landscape gardening contractor. When employing contractors for spraying, you should insist on seeing their National Proficiency Tests Council (NPTC) Certificate of Competence for the use of pesticides. Each certificate has an individual number. Use the information within this leaflet to test the knowledge of potential contractors, to ensure that you employ someone with a good knowledge of knotweed control.

It will take **at least three years** of herbicide treatment before knotweed has been eradicated. By the third year of treatment, knotweed growth may be only a few centimetres tall and easily overlooked amongst grass and herbage. **It is essential that treatment continue until no further growth appears.** Any disturbance to the rhizome at this stage will stimulate further growth, however, controlled rotavation of the infested area can be used to stimulate the exhausted rhizome to produce more foliage, which can then be sprayed. If a rotavator is unavailable, a series of spade cuts will also stimulate the rhizome. Clean implements thoroughly after use to prevent spread of fragments.

I don't like using sprays, what else can I do to get rid of it?

It is very difficult to remove large or well-established infestations without the assistance of herbicides.

Cutting, mowing or grazing gradually weakens the plant, but if you are using this technique you must be aware that it will take many years to exhaust the rhizome (probably more than 10 years). Cutting should be performed at least once a month during the growing season. Great care needs to be taken with the cut material to avoid further spread (see page 11). Unless material can be disposed of within the confines of the property, cutting should not be adopted.

Pulling is more effective than cutting, because it removes crown and some rhizome. However, the waste generated is highly infectious and needs to be disposed of with great care (see page 11). Pulling is most effective where knotweed has recently become established, from infected topsoil for instance. **It may take very many years to exhaust the widespread rhizome of an established plant.**

Whose responsibility is it to control my knotweed?

The responsibility for the control of knotweed usually rests with the landowner or tenant of the land. The Environment Agency, or local government are not obliged to control knotweed on behalf of other landowners. Similarly, disputes between neighbours regarding problems associated with knotweed are largely a civil matter.

I have got knotweed coming onto my land from adjoining property. What can I do?

This is a common problem that often lacks a satisfactory answer. The best solution is to co-operate with the neighbouring landowner and co-ordinate your control efforts, by sharing costs or labour, for instance. If you do not know who owns the adjoining land, or you are in dispute with your neighbour, current legislation offers little support.

The Environmental Protection Act 1990 does provide some legal support if knotweed is causing a nuisance to private property. A private nuisance has been defined as an "unlawful interference with a person's use or enjoyment of land, or some right over, or in connection with it" (Read v Lyons & Co Ltd. 1945).

Wherever possible, it is best to encourage co-operation and support within the community to control knotweed and prevent further spread.

Where do I get more information on knotweed?

The Japanese Knotweed Manual by Lois Child and Max Wade (Packard Publishing Limited, Forum House, Stirling Road, Chichester, West Sussex. ISBN 1-85341-127-2) provides a comprehensive account of the problems associated with knotweed, as well as practical advice on managing the problem.

The following websites may contain helpful information:

www.cornwall.gov.uk/environment/knotweed

www.ex.ac.uk/knotweed

www.cabi.org/BIOSCIENCE/japanese_knotweed_alliance.htm

The Welsh Development Agency (01443 845500) produce a model specification and tender document that also contains useful information regarding knotweed. Order forms for the WDA publications are obtainable from QED Centre, Main Avenue, Treforest Estate, Treforest CF37 5YR Wales.

JAPANESE KNOTWEED

Control Forum for Cornwall

The Japanese Knotweed Control Forum for Cornwall was formed in 1997 to co-ordinate policy on the control of Japanese Knotweed in Cornwall. The Forum comprises representatives from a wide range of organisations including the Environment Agency, National Trust, the County and District Councils of Cornwall, Camborne School of Mines, Railtrack, English Nature, IMERYS and Cornwall Wildlife Trust.

Aims

To promote a co-ordinated approach to the control and management of Fallopia japonica (Japanese Knotweed, Donkey Rhubarb) and its hybrids in Cornwall through partnership.

The Forum has produced a number of publications and guidance notes, organised conferences and co-ordinated research projects. It has developed a GIS survey recording system in conjunction with the Botanical Society of the British Isles. The assistance of many town and parish councils in supplying information is gratefully acknowledged.

The Forum supports a web site: www.ex.ac.uk.knotweed which is regularly updated with new advice on management and control.

The Forum is interested in receiving details of any infestations of Japanese knotweed in Cornwall. Survey forms can be obtained from the web site or the County Council (01872 222000). To report sites with Japanese Knotweed in Devon please contact the Devon Environmental Records Centre (01392 279244).

The Forum co-ordinates guidance on good practice which is being developed continuously in the light of new research.

Other counties are beginning to develop strategies for Japanese knotweed control and enquiries relating to areas outside of Cornwall should be addressed to the local council or Environment Agency (0845 9333111).

We wish to thank Loughborough University for the use of their research and photographs in the production of this booklet and the Welsh Development Agency for the use of their 'Rhizome Identification Guide'.

This leaflet has been produced by the Environment Agency with assistance from members of the Japanese Knotweed Control Forum for Cornwall and Devon County Council.

Knotweed 'not's'

- **Do not** fly-tip Japanese knotweed, or any other garden waste.
- **Do not** contaminate green waste composting schemes with knotweed material.
- **Do not** accept topsoil unless you have first inspected it for knotweed rhizome.
- **Do not** delay. If you find you have knotweed growing on your land you should eradicate it.

Knotweed 'do's'

- **Do** follow good practice for the control of knotweed.
- **Do** ensure that herbicides are used safely and effectively.
- **Do** ensure that knotweed is burned or composted thoroughly, within the curtilage of your property.
- **Do** co-operate with neighbours to co-ordinate your knotweed control programme.

REMEMBER

Japanese knotweed is a foreign invasive plant that is severely damaging our countryside and property. With your co-operation it can be controlled.

ENVIRONMENT AGENCY

Tel 0845 9333111

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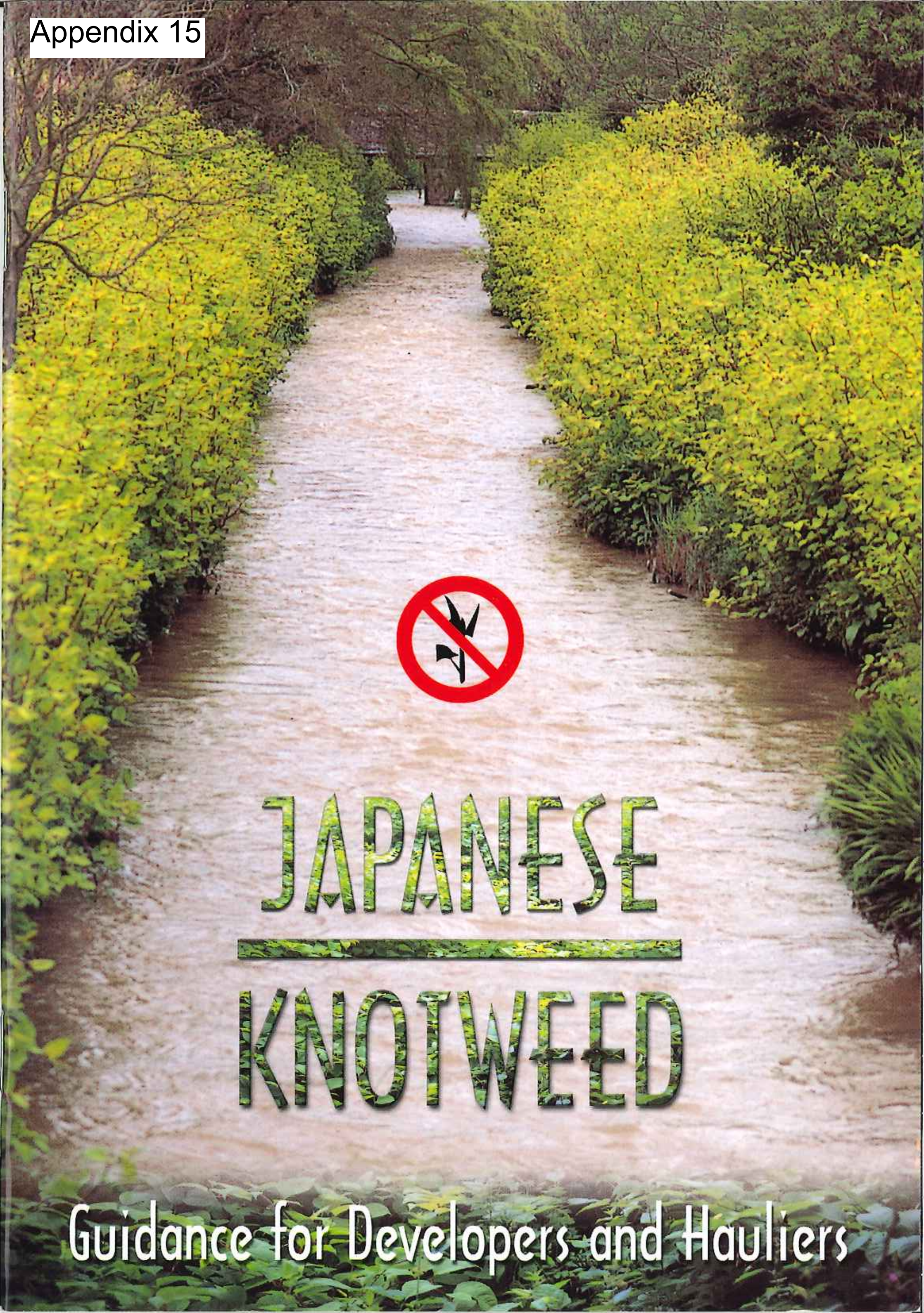
Designed and produced by
Cornwall County Council, Technical Services,
Planning, Transportation & Estates,
May 2001 P05969

Appendix 15



JAPANESE KNOTWEED

Guidance for Developers and Hauliers

Introduction

Japanese knotweed (scientific name Fallopia japonica) was introduced to the UK in the mid nineteenth century as an ornamental plant. Since then it has become a serious problem in a range of habitats, including roadsides, riverbanks and derelict land by displacing native flora and causing structural damage.

Japanese knotweed will eventually crowd out native flowers

In the UK, although Japanese knotweed plants produce seeds, these are almost always sterile. Therefore, spread is by vegetative means, either by rhizome (root) fragments, or by crown (base of stem) and stem fragments.

The majority of Japanese knotweed has been spread by riverbank erosion, inappropriate management with flails, flytipping garden waste, and the movement of contaminated soil.

Japanese Knotweed and the Law

The Wildlife and Countryside Act, 1981, made it an offence to spread Japanese knotweed. Section 34 of the Environment Protection Act, 1990, places a duty of care on all waste producers to ensure that any wastes are disposed of safely and that a written description of the wastes, and any specific harmful properties, is provided to the site operator.

Soil and waste containing Japanese knotweed is deemed to have the potential to cause ecological harm, and therefore does not qualify for exemption of Section 34 of the Environment Protection Act, 1990.

Structural damage due to Japanese knotweed growth

For further details regarding Waste Regulations, contact the Environment Agency.

To avoid potential environmental damage, structural damage to property, and possible enforcement action, it is essential that developers and hauliers are able to recognise Japanese knotweed during all stages of its growth.

Winter

During the winter months, Japanese knotweed dies back. The canes, often 2.5m high, die off and become brown and leafless. Canes may take up to three years to decompose, and often form a dense litter, thus preventing other plants from growing in association with Japanese knotweed. Established areas of Japanese knotweed often form characteristic stands of dead canes during the winter months. However, smaller or more recent infestations can be interspersed with native vegetation and are less obvious.

Spring

During early spring, the dark red shoots of the new growth appear. Growth is rapid, potentially 10cm per day at its peak.

Summer

By mid-summer, Japanese knotweed canes have usually achieved their maximum growth, which can be a height of 2.5m in mature specimens. During August and September the canes produce their clusters of white flowers. Sterile seed is often produced after flowering.

Japanese knotweed can grow in almost any soil type. It is most commonly found on riverbanks, roadsides, wasteland and areas of disturbed soil. **Potential development sites should be inspected for Japanese knotweed at the earliest opportunity.**

If the site has already been disturbed prior to inspection, or a haulier is required to check a load prior to removal, evidence of Japanese knotweed contamination can usually be detected if it is present. If the material contains topsoil, it may contain broken pieces of stem material, which may be green or dried brown depending on the time of year or the length of time the material has been disturbed. Whilst dried brown sections of stem cannot regenerate, they often indicate the presence of invasive material, such as crown, rhizome and green stem. Japanese knotweed crowns, often with the bases of stems still attached, may be present. Crowns range in size, depending on the maturity of the plant. Closer inspection can often reveal dormant red buds and rhizome material.

Japanese knotweed crowns are highly invasive and must be disposed of carefully to avoid regrowth.

Japanese knotweed rhizome can be found in topsoil and subsoil. Rhizome, which is actually an underground stem rather than a root, can grow to a depth of at least 3m, and to a distance of at least 7m from the parent plant. **Japanese knotweed rhizome is highly invasive. Sections of rhizome of similar size to a fingernail can regenerate into a new plant.** Any soil that is removed from within a 7m radius of a Japanese knotweed plant can be assumed to contain rhizome material. Rhizome can be easily identified from its orange/red colouration when broken, which resembles a carrot. Thicker lengths of rhizome can prove harder to snap. The characteristic colouration is revealed by scraping or cutting the surface with a pen-knife.

Small fragments of rhizome can regenerate

Rhizome should not be mistaken for tree roots, which tend to bend rather than snap, and lack the orange/red colouration. Large dock roots are similar to Japanese knotweed rhizome, but are usually thin and tapering.

Duty of Care for Hauliers

Prior to accepting waste material for transfer or disposal, it should be inspected for knotweed contamination. If material is found, the waste cannot be regarded as an inert waste, and inappropriate disposal may result in prosecution. Contaminated material should be taken to a landfill site, licensed to receive Japanese knotweed, and the landfill operator should be informed of the nature of the waste so that it can be disposed of appropriately within the site.

Hauliers should not accept contaminated waste unless they can guarantee its appropriate disposal. If hauliers are aware of waste producers who are failing to inform their hauliers of the presence of Japanese knotweed, or of hauliers who are knowingly disposing of knotweed infected material in an inappropriate manner, they should inform the Environment Agency.

Failure to appropriately dispose of waste material containing Japanese knotweed may lead to prosecution under Section 34 of the Environment Protection Act 1990 and Section 14 of the Wildlife & Countryside Act 1981.

Timely and appropriate management of land infected by Japanese knotweed can avoid excessive cost, potential prosecution and prevent physical damage to buildings and hard surfaces.

Infested development site in spring

The most important element to knotweed management for a developer is the early application of an appropriate herbicide prior to any land disturbance. The most effective time to apply a herbicide is from July to September (or until the first frosts cause leaf fall). Avoid treating when in flower. Spring treatment is acceptable, but less effective.

Ineffective suppression of knotweed

Herbicides are not effective during the winter dormant stage. Chemical control usually takes a **minimum** of three years to totally eradicate Japanese knotweed. Therefore, Japanese knotweed must still be regarded as infective within this three year period, or whilst regrowth still occurs during spring. However, treatment with an appropriate herbicide can reduce the vigour of knotweed material, even if it were only treated a few weeks prior to disturbance. If a developer is in a situation where their timescale prohibits effective chemical eradication of Japanese knotweed, the plant should still be treated, if it is in leaf, at the earliest possible convenience.

Infested area isolated from disturbance whilst a chemical control programme is underway

Combined treatment methods

Site trials have shown a combined digging and spraying treatment method to be effective in reducing the time period required for chemical control. Great care is required with this method to avoid spreading plant material.

The majority of Japanese knotweed rhizome exists in the upper layers of topsoil. It has been estimated that in an infected area, 14,000 kg/ha dry weight of knotweed may exist in the top 25cm (Brock, 1994). An excavator is used to scrape surface crowns and rhizomes into a pile. The exposed ground is then cultivated to a depth of 50cm, and the piled material re-spread over the cultivated area. This process stimulates the rhizome to produce a higher density of stems, which renders it more vulnerable to herbicide treatment. Subsequent herbicide treatment has been observed to eradicate knotweed after only two applications, which may be performed within the same growing season.

Digging can be carried out during the winter months, and regrowth treated during the spring and summer. Extreme care must be taken to ensure that all equipment used on site is free of Japanese knotweed material before leaving the site to avoid contravention of the Wildlife & Countryside Act, 1981. To reduce the risk of contaminating vehicles, excavators with caterpillar tracks should be avoided.

Which herbicide should I use?

The most important questions regarding the selection of a herbicide are;

Is the site in or near water?

Do I wish to re-use the soil from the treated area for replanting, and if so, how long before I intend to landscape with it?

Wherever there is a risk of contamination to a watercourse, choice is limited to formulations of Glyphosate and 2,4-D Amine that are approved for use in or near water. **Not all herbicides containing these active ingredients are suitable for use in or near water. Use of a herbicide in or near water requires consultation with the Environment Agency.**

If the site poses no risk to a watercourse, there is a greater choice of herbicide. Where soil is intended for continued use, or immediate reuse, for landscaping purposes, a non-residual herbicide, such as Glyphosate or 2,4-D Amine would be appropriate. In the event that replanting is likely to be delayed for a period of at least six weeks, a formulation containing triclopyr may be considered. If it is the intention to cover the area in a hard surface, or delay replanting for at least two years, persistent chemicals such as picloram and imazapyr would be appropriate.

Developers are advised to seek the advice of a qualified landscape gardener or BASIS registered pesticides advisor prior to commencing a spraying programme.

When using a herbicide, always adhere to the advice given on the label.

Herbicide	Affects grasses?	Approved for use in or near water?	Persistency
Glyphosate	Yes	Yes	Non-persistent
2,4-D Amine	No	Yes	1 month
Triclopyr	No	No	6 weeks
Imazapyr	Yes	No	9 months
Picloram	No	No	2 years

First year roundup control.

Under duty of care, persistent chemicals must be included within the description of the waste if the material is being disposed of within the period of activity of that particular chemical.

Spray applications during late summer avoid damage to spring bulbs, which may re-emerge after a successful control programme.

Pin-cushion effect of third year roundup control. Regrowth occurring during the third year usually consists of tiny pointed leaves. It is essential that Japanese knotweed is not overlooked at this stage of the treatment programme if eradication is to be achieved. Broad-spectrum herbicides, such as roundup, prevent grasses from re-colonising before the treatment is complete, which can make spot-treatment of stunted regrowth easier.

Non-chemical methods of Japanese knotweed disposal and control

Where chemical control is inappropriate, or insufficient time is available to ensure eradication, it will be necessary to dispose of material contaminated with viable knotweed material. It is recommended that, wherever possible, this approach be adopted, even when a chemical control programme has been completed.

Soil containing knotweed material can be buried on site. Ideally, at least one application of herbicide will have been performed to reduce the vigour of infective material. Soil to a depth of at least 3m and within 7m of the perimeter of the knotweed should be excavated for disposal. Site managers should check the periphery of the excavation for rhizome, to ensure that an adequate volume of material has been removed to account for all of the invasive material.

On site burial should be performed to a depth of at least 5m. The material should then be covered with a geotextile layer (e.g. Lowtrak) or a heavy gauge polythene sheet prior to infilling.

If the development does not allow for burying infected soil on site, it should be disposed of at an approved landfill, having informed the site operator of the presence of knotweed within the material.

Early identification of Japanese knotweed on a site allows a developer to assess and cost options for management and disposal.

Extract from South Wales Evening Post

Mary's knotty problem is a Japanese invasion

MANY of us have a plant in the corner of the living room to brighten up the place.

Mary Lyden's home is no exception, only her's isn't the potted variety — it's an invader shooting up from under the carpet.

Japanese knotweed has migrated from a bank yards away from the side of her Swansea home, burrowing through the foundations and up through the floorboards.

"I was dumbfounded when I spotted this greenery in a corner and pulled the carpet back to find these shoots coming right through," said the 66-year-old widow, of Sway Road, Morriston.

"They were coming through between the carpet and the skirting board near a boxed-in gas meter.

"I pulled some of it out but it will keep coming back.

"It's so strong and really does get a hold. I'm worried that if it really takes root under the house it could damage the foundations."

Mrs Lyden said she had asked the council to clear overgrowth on the car park next to her house but nothing had been done.

"There's a lot of knotweed on the bank close to my home and this has obviously spread under my fence and got into the foundations," she said.

Mrs Lyden reported her Japanese invasion to Swansea Council two weeks ago and environmental health officer called at her home.

"Nothing's been done and I'm getting very concerned," she said.

"I want urgent action from the council to stop this weed before it spreads any further."

LIVING ROOM: The weed growing in the lounge of Mary Lyden's home in Morriston, Swansea.

We wish to thank the International Centre of Landscape Ecology Loughborough University for the use of their research and photographs in the production of this leaflet and South Wales Evening Post.

Remember

Failure to manage and dispose of Japanese knotweed responsibly may lead to prosecution.

Spreading Japanese knotweed is harmful to native plants and animals.

Failure to manage Japanese knotweed on a development site may result in eventual structural damage, especially to tarmac surfaces.

For specific advice concerning Japanese knotweed management and disposal, contact either the Environment Agency or your local Council.

ENVIRONMENT AGENCY

For Further Information Contact
The Environment Agency,
Sir John Moore House, Victoria House,
Victoria Square, Bodmin, Cornwall, PL31 1EB
Tel (01208) 78301

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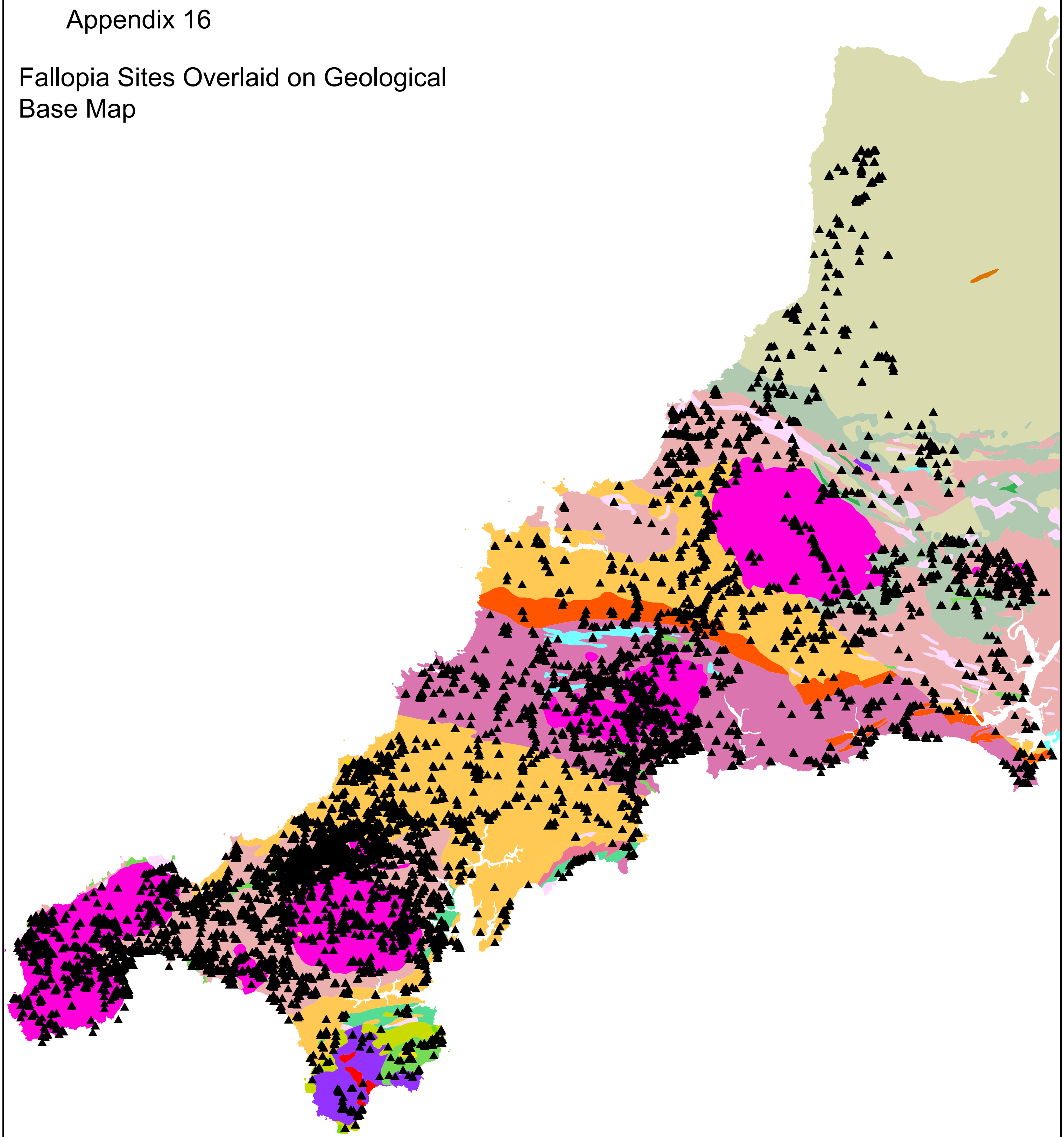
Designed and produced by
Technical Services, Planning, Cornwall County Council
May 2000

Appendix 16

Fallopia Sites Overlaid on Geological Base Map

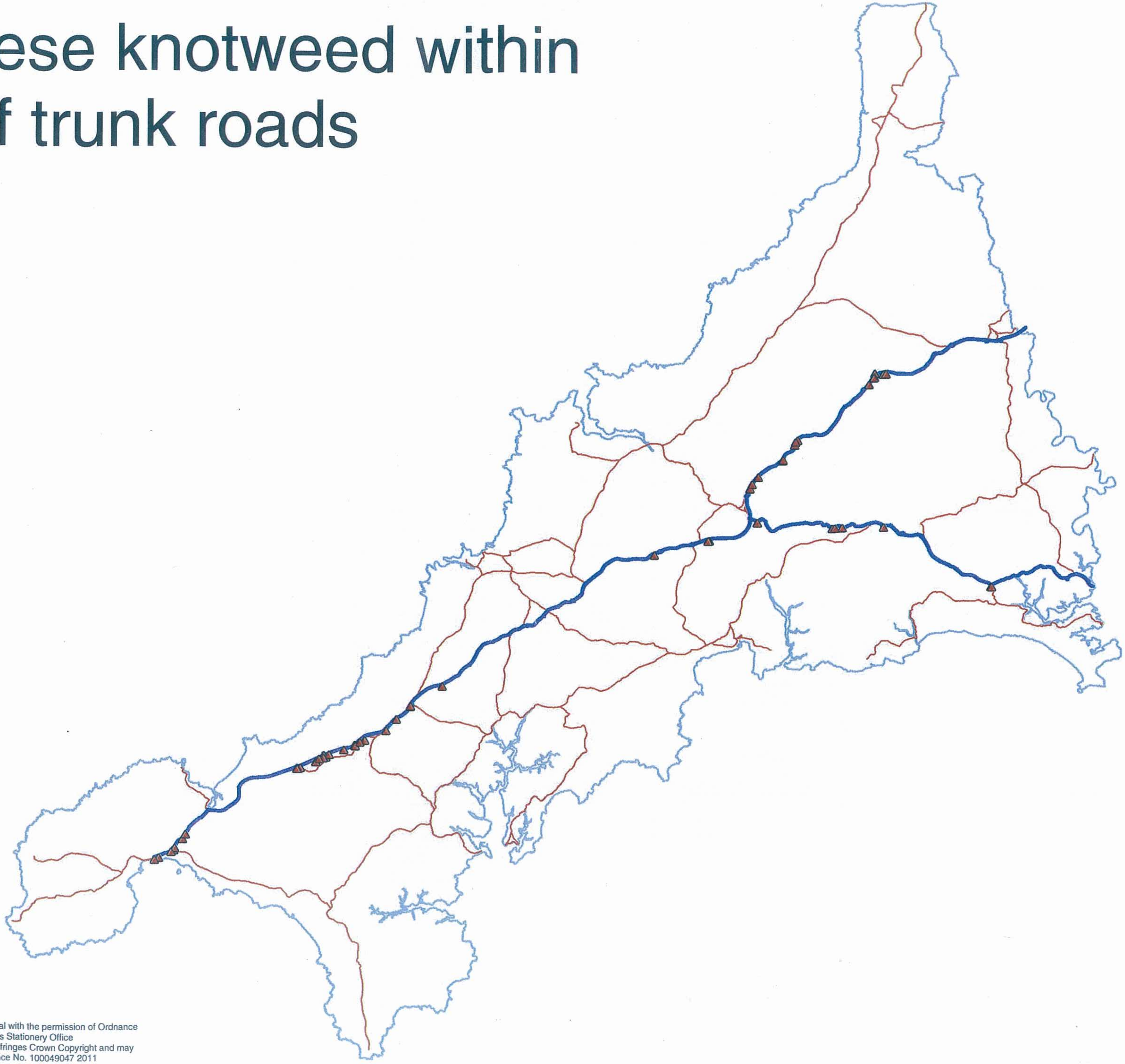


Legend

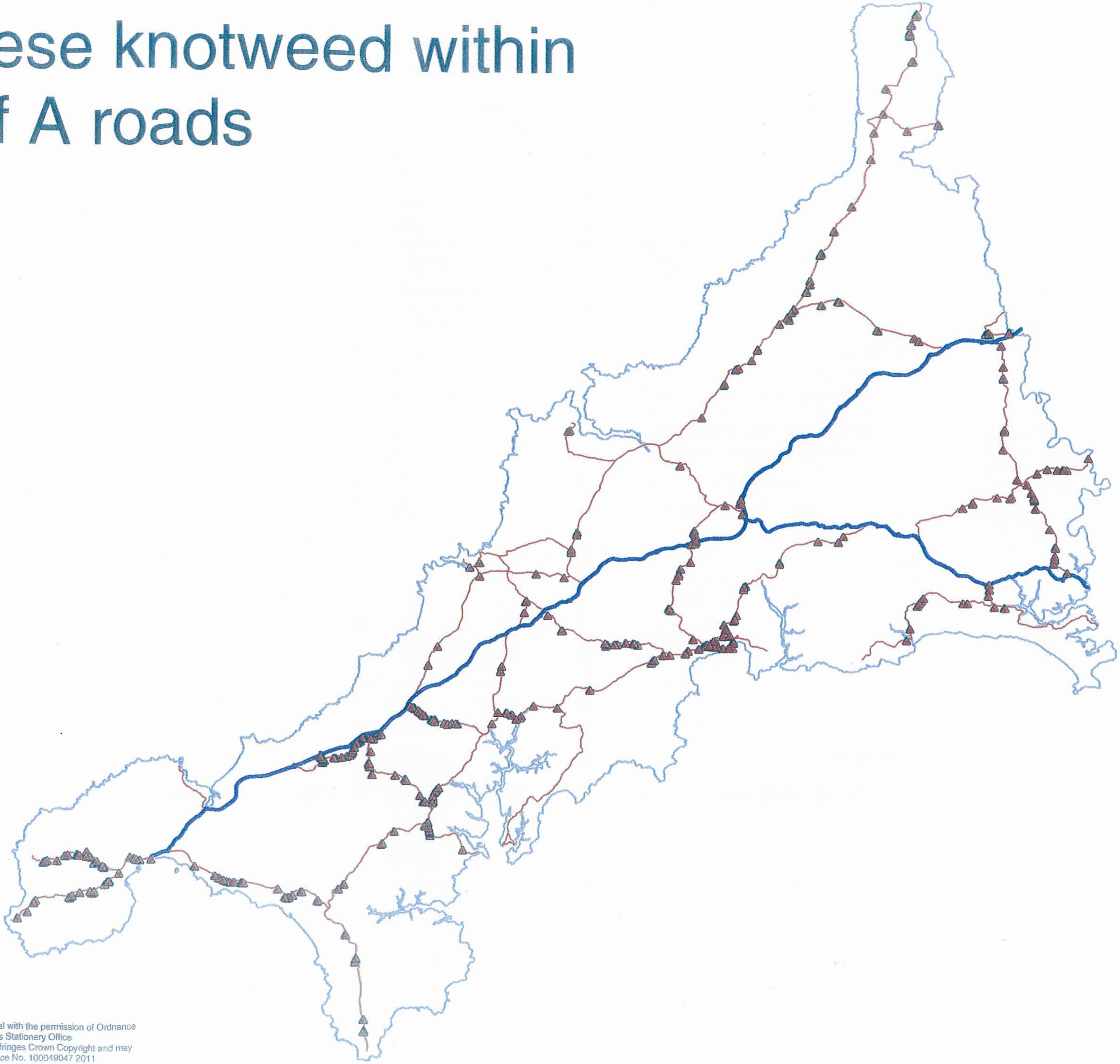
Geological bedrock

- NEOGENE ROCKS (UNDIFFERENTIATED) - GRAVEL, SAND, SILT AND CLAY
- EOCENE TO MIOCENE ROCKS (UNDIFFERENTIATED) - CLAY, SILT, SAND AND GRAVEL
- PERMIAN ROCKS (UNDIFFERENTIATED) - SANDSTONE AND CONGLOMERATE, INTERBEDDED
- UNNAMED EXTRUSIVE ROCKS, PERMIAN - FELSIC LAVA
- HOLSWORTHY GROUP - MUDSTONE, SILTSTONE AND SANDSTONE
- UNNAMED EXTRUSIVE ROCKS, CARBONIFEROUS - MAFIC LAVA AND MAFIC TUFF
- UNNAMED EXTRUSIVE ROCKS, CARBONIFEROUS - MAFIC LAVA
- UNNAMED EXTRUSIVE ROCKS, CARBONIFEROUS - MAFIC TUFF
- UNNAMED IGNEOUS INTRUSION, CARBONIFEROUS TO PERMIAN - FELSIC-ROCK
- UNNAMED IGNEOUS INTRUSION, CARBONIFEROUS TO PERMIAN - MAFIC IGNEOUS-ROCK
- TEIGN VALLEY GROUP - MUDSTONE, SILTSTONE AND SANDSTONE
- UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - BRECCIA AND METABRECCIA
- UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE
- UPPER DEVONIAN ROCKS (UNDIFFERENTIATED) - SANDSTONE AND CONGLOMERATE, INTERBEDDED
- MIDDLE DEVONIAN (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE
- MIDDLE DEVONIAN (UNDIFFERENTIATED) - SANDSTONE AND CONGLOMERATE, INTERBEDDED
- LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - MUDSTONE, SILTSTONE AND SANDSTONE
- LOWER DEVONIAN ROCKS (UNDIFFERENTIATED) - SANDSTONE AND CONGLOMERATE, INTERBEDDED
- DEVONIAN ROCKS (UNDIFFERENTIATED) - HORNBLENDE SCHIST
- DEVONIAN ROCKS (UNDIFFERENTIATED) - LIMESTONE, MUDSTONE AND CALCAREOUS MUDSTONE
- DEVONIAN ROCKS (UNDIFFERENTIATED) - MICA SCHIST
- UNNAMED EXTRUSIVE ROCKS, DEVONIAN - MAFIC LAVA AND MAFIC TUFF
- UNNAMED EXTRUSIVE ROCKS, DEVONIAN - MAFIC LAVA
- UNNAMED IGNEOUS INTRUSION, DEVONIAN - FELSIC-ROCK
- UNNAMED IGNEOUS INTRUSION, DEVONIAN - MAFIC IGNEOUS-ROCK
- UNNAMED IGNEOUS INTRUSION, DEVONIAN - ULTRAMAFITITE
- UNNAMED EXTRUSIVE ROCKS, NEOPROTEROZOIC - FELSIC TUFF

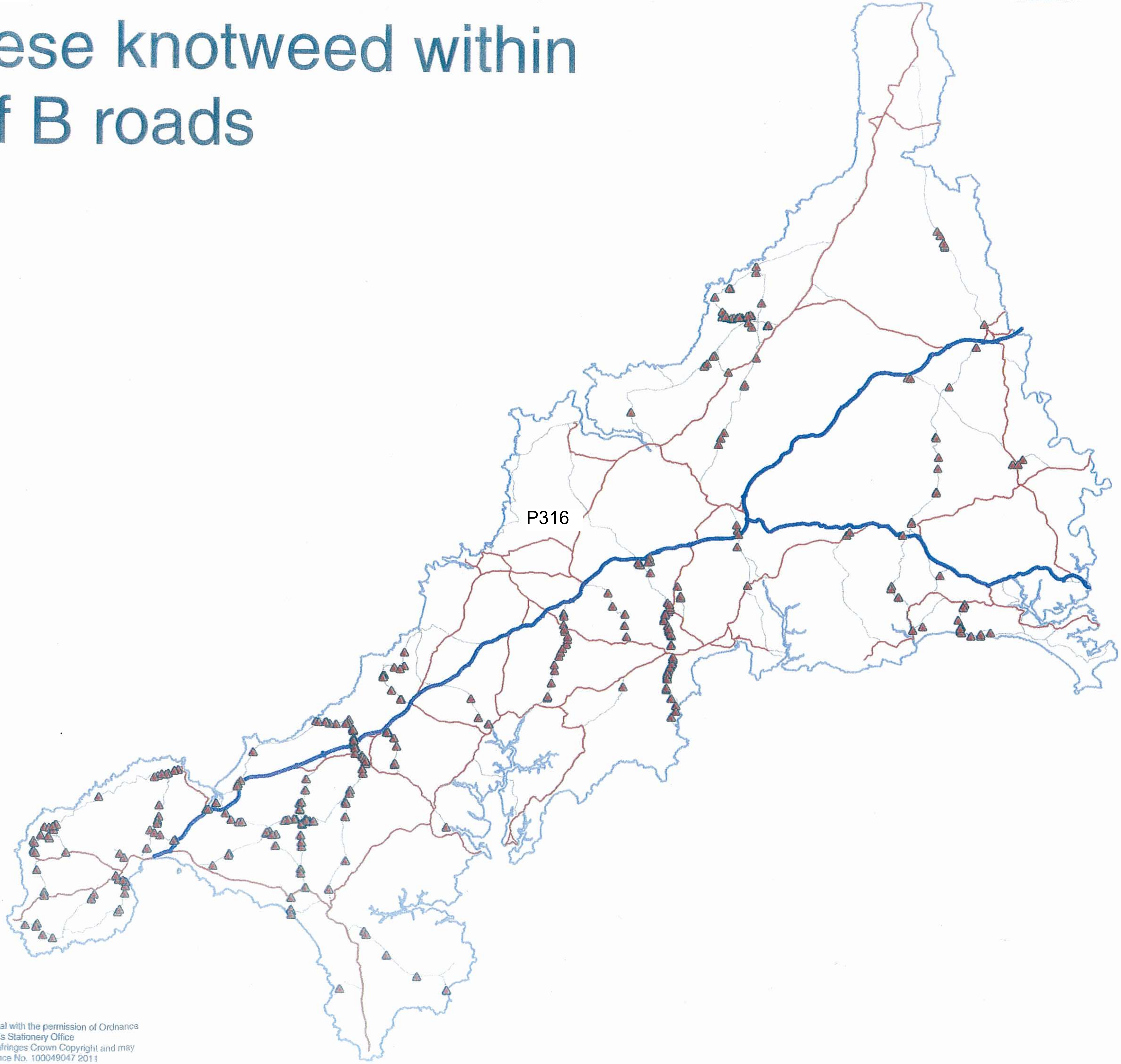
Japanese knotweed within 20m of trunk roads



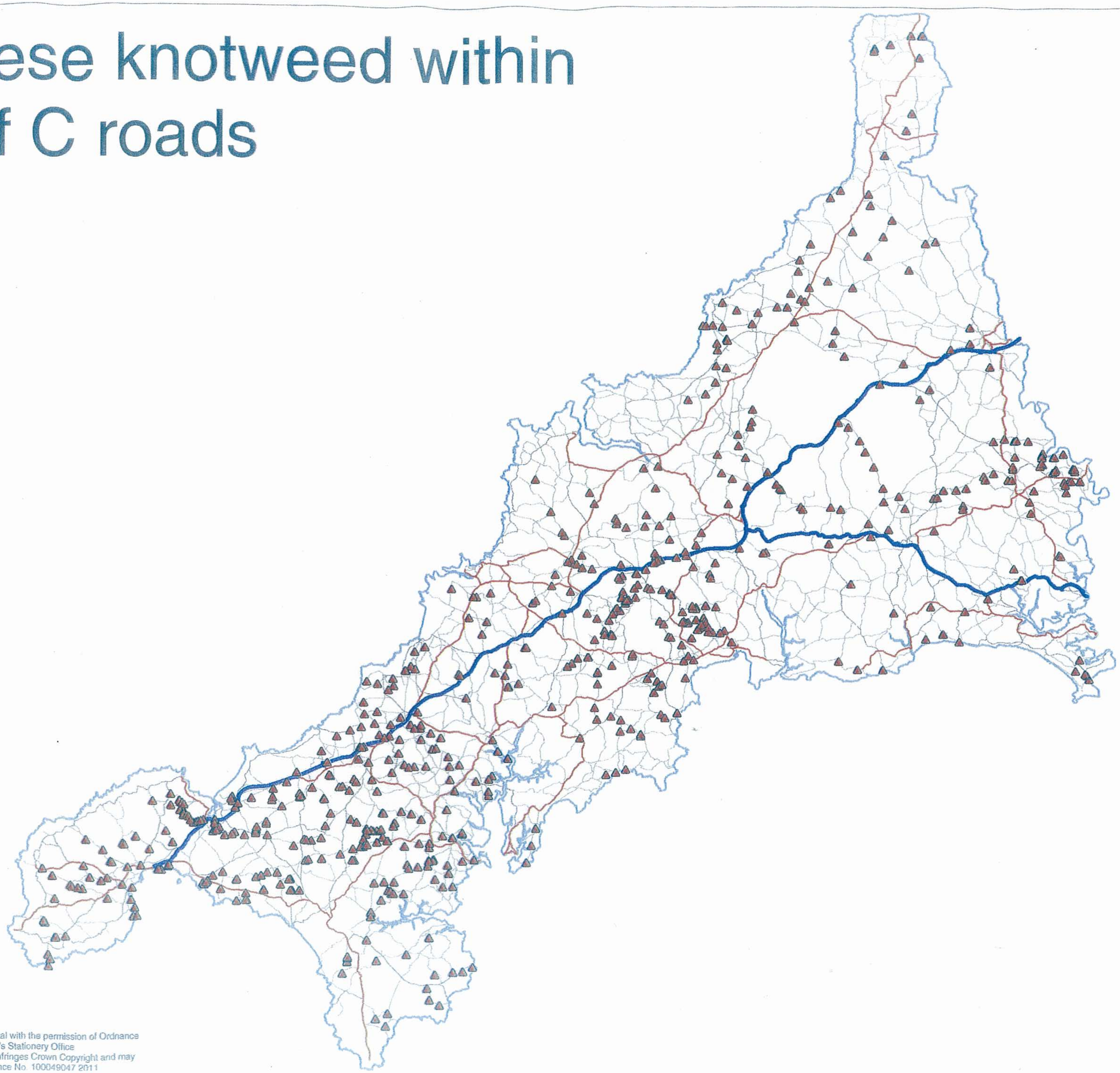
Japanese knotweed within 20m of A roads



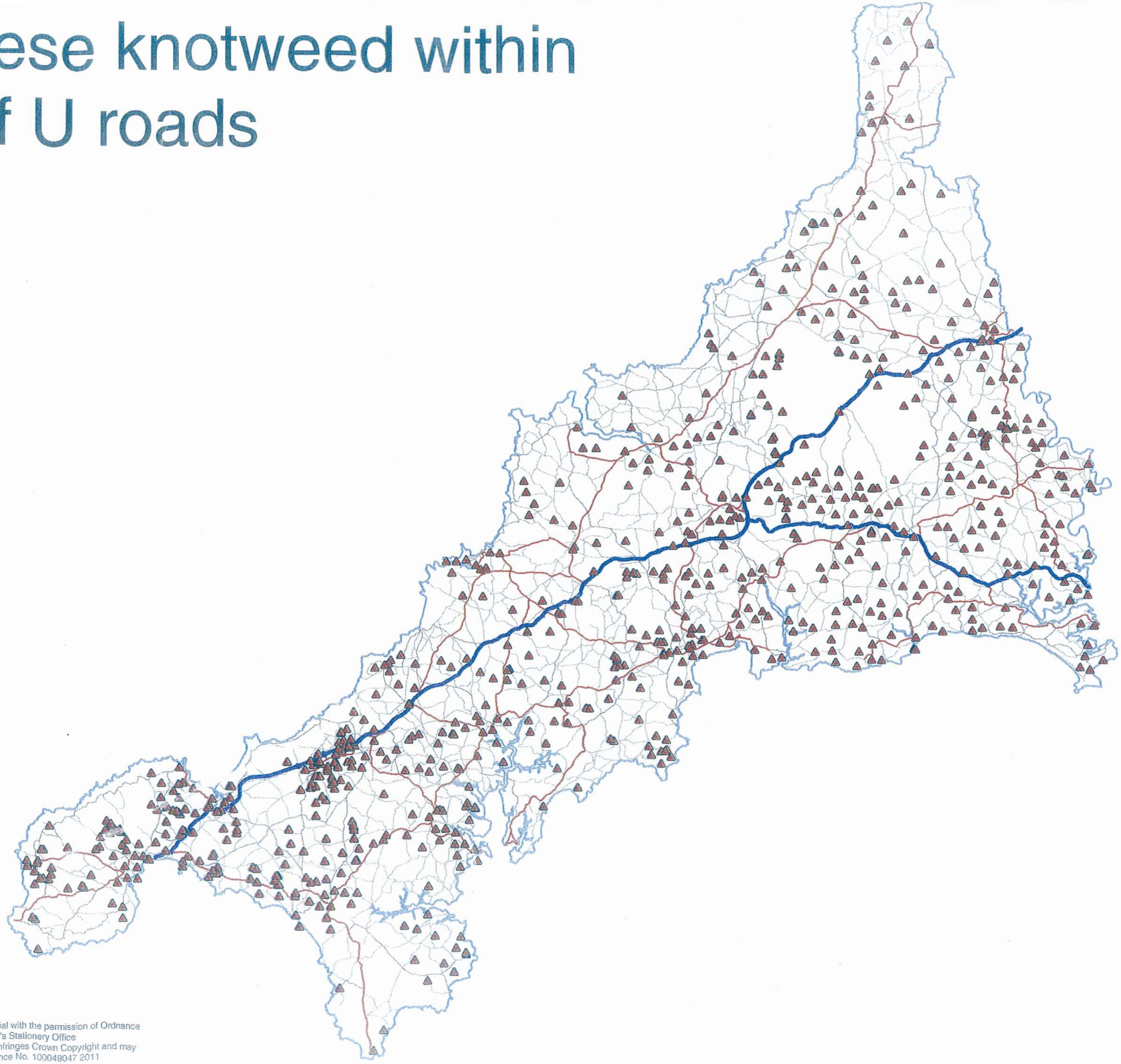
Japanese knotweed within 20m of B roads



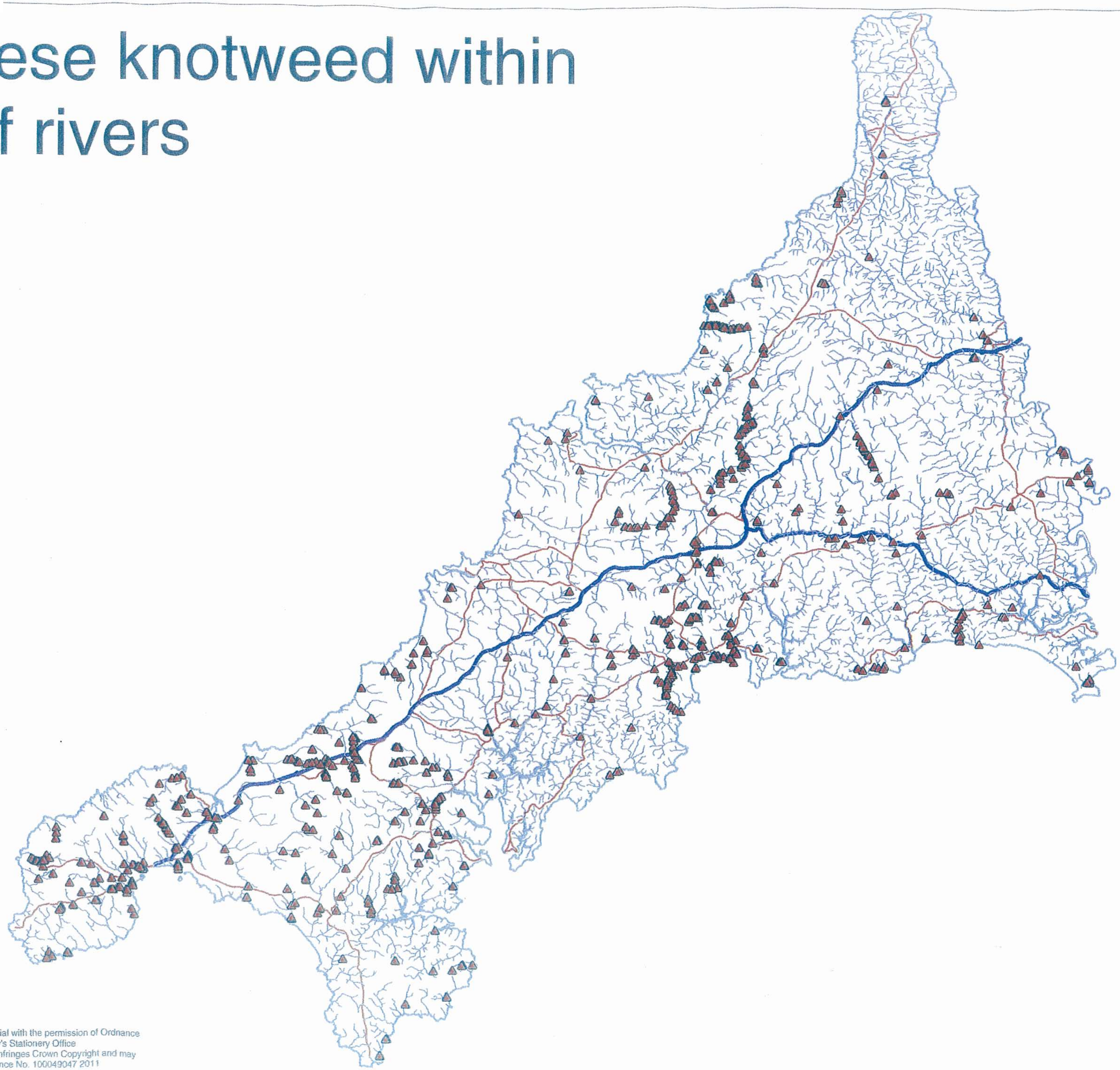
Japanese knotweed within 20m of C roads



Japanese knotweed within 20m of U roads



Japanese knotweed within 20m of rivers



Stem filling technique methodology

Equipment:-

Spot gun applicator and reservoir capable of delivering a measured dose of 10ml to 20 ml suitable for use with herbicide and fitted with solid cone nozzle.
Long handled cutters or secateurs
Screwdriver with minimum 225 mm shaft
Measuring cylinder between 1000ml and 250ml in 10 ml stages dependent on dilute container size

Protective clothing:-

Nitrile gloves, coverall, face shield, rubber boots.

Materials:-

Herbicide:- Roundup pro Biactive.
Appropriate approved dye
Adequate source of clean, preferably mains, water

Dilution rate:

1:5

Timing:-

After mid August but before leaf fall.

Maps of distribution of Japanese knotweed in Cornwall

Minimum stem size for treatment:-

8 mm diameter

Target:-

All stems cleanly cut. All stems more than 8mm in external diameter treated with 10 ml of diluted herbicide.
Cut stumps to be treated within 15 minutes of cutting.

Technique:-

Methodology will be dependent on the scale of operations.

When dealing with large areas, it is preferable to have two people working together, one cutting and setting cane aside, one injecting.
Plan the work so as to deal with corridors 1.2 metres wide
Start at one end and work logically
Work uphill rather than along a slope.
When working in a situation where the cut stems cannot be put back on cut stems and thus out of contact with the soil e.g. on a Cornish Hedge, the stems should be kept clear of the ground ideally at right angles to the corrugations on corrugated sheets so that they will dry out.

Operator 1

Erects signs to inform, where necessary, of the work in progress. Cuts all stems at approximately 200mm above base of cane, preferably approximately 40mm above a node (this should limit any potential shattering of the stem) puts them to the left and, with all stems more than 8 mm in diameter, ruptures the septum within the stem with the screwdriver down to make contact with solid tissue in the crown. Following the herbicide application, he/she then works up the next 1.2m laying the material from the second corridor over the first. When on a slope, work should be started again from the bottom and the process repeated until the area is completed. The first cane to be cut should be laid back on the material from which it was cut, resulting in a double layer on the first strip. This will mean that the last corridor is not covered down. Where there is

s try to work so as to cover over the cut stems in closest proximity to
ıblic are anticipated.

ırbicide at the correct concentration with the addition of an approved dye. sed in order to ensure both that all stems are treated and that stems do not icate treatment. Preferred technique is to treat the stems furthest away first back towards the operator. The nozzle should be inserted into the stem to vel of the ruptured septum before the dose is delivered. The face should be ne with the stem to avoid contact in the unlikely event of liquid splashing

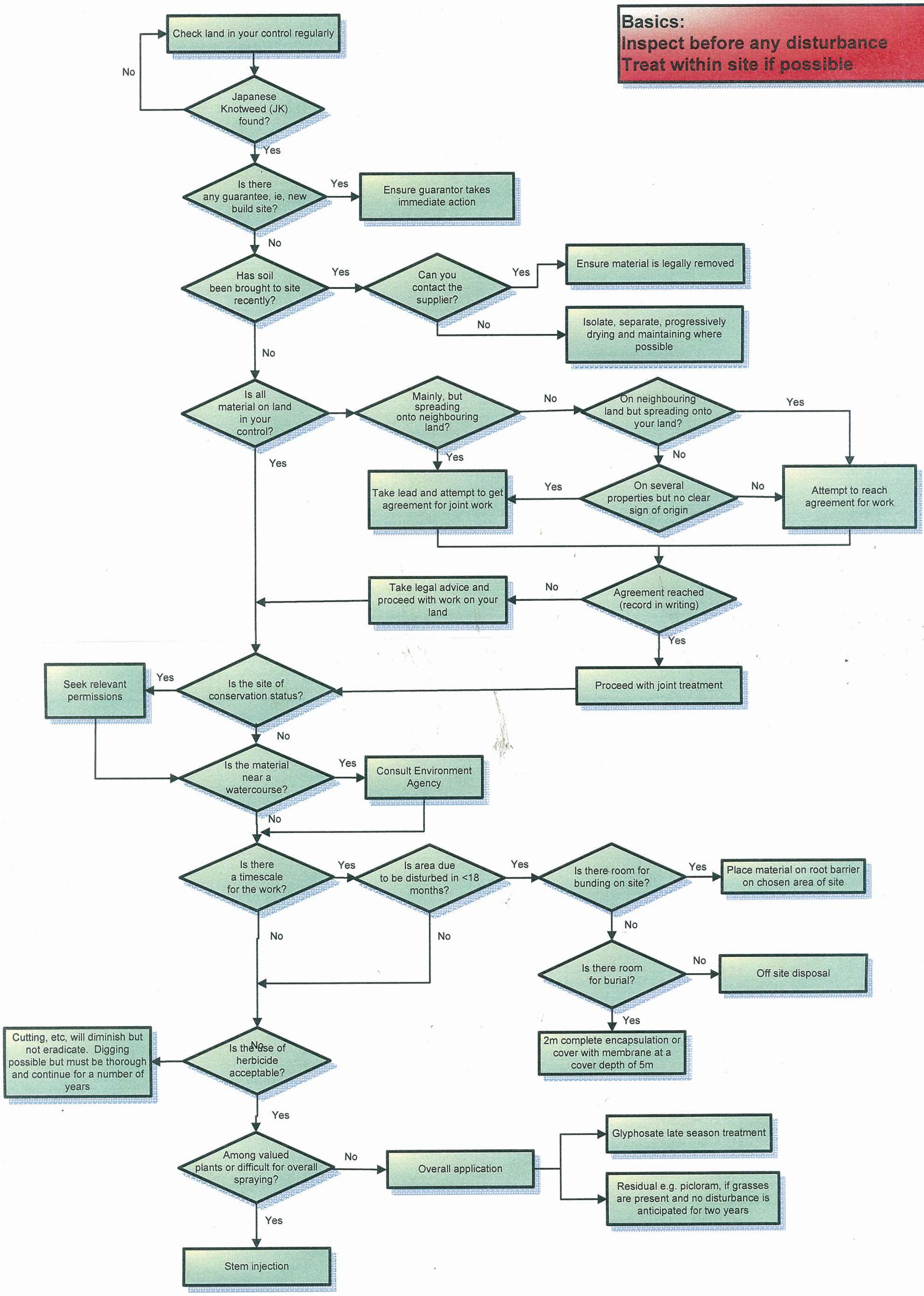
/ork:-

nt years, it is likely that stems will not be sufficiently large to inject. Spot ıf glyphosate, using an appropriate spray, rather than solid jet, nozzle. Use iper may be an appropriate alternative.

ɔses of herbicide may induce dormancy. Treatment sites should be ıring the growing season for at least three years after the last material ıd is observed. Even after this period, disturbance may result in renewed

Treatment of Japanese Knotweed

Basics:
Inspect before any disturbance
Treat within site if possible



All control techniques are likely to require follow up and the site should be monitored for at least 5 years after the last above ground material is noted.

Japanese knotweed through the seasons

Appendix 21

CORNWALL COUNCIL