Woody production plant survival in the start-up phase of complex agroforestry systems

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Abstract

Complex agroforestry systems (CAS) are an increasingly popular, low-input, and sustainable alternative to conventional food production systems, however, their implementation is hampered by low plant availability, and late and uncertain returns to high investments. CAS practitioners could make better-informed choices if more knowledge on plant survival were available, especially in the context of complex agroforestry in a temperate climate. To obtain this knowledge, a georeferenced monitoring programme was set up using QGIS, in which survival status, initial plant characteristics, time of planting, various landscape variables and management practices were collected. With over 12,000 observed plants across 7 locations in the Netherlands, this research provides the first insights into the survival of promising genera and species in the start-up phase of a complex agroforestry system. The cumulative survival probability for all plants was 91% for the first year, ranging from 30 to 100% across species, and declined to 69% in year 5, ranging from 64 to 97% across species. Among the species with high survival are Purple chokeberry (*Aronia prunifolia)* and Red currant (*Ribes rubrum),* which have a 97% probability of surviving the first 2 years, and among the low-surviving species is Raspberry (*Rubus idaeus),* with only a 30% probability of surviving the first year after planting. Additionally, this research has explored which contextual variables (nursery, price, initial size, soil type, water table, planting season, and intensity of mulching, irrigation and protection of trees) most strongly influence plant survival using generalised linear mixed models, and found planting season and initial size to be the most important factors affecting survival. To strengthen the survival analyses and further explore the drivers of plant survival, it is highly recommended to continue the monitoring and add locations, so that the dataset will include more climate, management and landscape variability.

Keywords: *Complex agroforestry; Cultivars; Food forests; Geo-referenced data; Initial plant characteristics; Landscape variables; Management practices; Monitoring programme; Rootstocks; Survival*

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Glossary

CAS – complex agroforestry systems: food production systems consisting of at least three vegetation layers, thus including herbaceous and woody species, with a high diversity of food crops and system plants (Rijksoverheid, 2018).

CAS adopters – people who have started the creation of a CAS

CAS practitioners – people who manage CAS

Cultivar – cultivated variation of a plant species that has been selected on one or more desired traits that are retained upon propagation (Brickell et al., 2009). Cultivars can differ from each other in various traits such as taste, (fruit/nut) size, (fruit) colour, disease and pest resistance, drought tolerance, growth rate, and winter hardiness.

Genus – the taxonomic rank above species, which forms the first part of the Latin species name. Species within the same genus are more related to each other than to species in other genera, and tend to have similar plant traits related to physical appearance, reproduction, growth habits, molecular compounds (Erdtman, 1963), growing requirements and susceptibilities.

Initial plant properties – properties of a plant that characterize it before it is planted, such as size, age, price, and nursery of origin. Plants can be bought in a pot, with bare roots or root-ball (Allen et al., 2017a).

Production plants – plants that produce food

Rootstock – the root system and lower part of the stem of a grafted tree (Crawford, 2010). The rootstock is a **cultivar** that is selected on root-related properties such as root growth, rooting depth, disease and pest resistance, drought tolerance, and sturdiness.

System plants – also called support plants, are plants that do not produce food but have supportive, often ecological, functions in the system.

Vegetation layers – also called strata, are the vertical layers in which plants are arranged. The vertical layers are generally described as: rhizosphere, ground cover, herbaceous layer, shrub layer, low tree layer, canopy and climbers.

1. Introduction

Our society is facing many challenges concerning our food- and ecosystems: anthropogenic climate change (IPCC, 2022), rapid biodiversity decline, soil degradation, pollution, nature fragmentation, habitat destruction, and a growing population that needs to be fed (Foley, 2011). Accounting for about 35% of the carbon dioxide, methane and nitrous oxide we emit, agriculture is the largest single source of greenhouse gas emissions (Foley, 2011). Conventional agriculture has been specialised and intensified, which has led to large-scale monocultures that require many inputs such as fertilizers and pesticides (Peyraud et al., 2014). Some of these inputs are polluting and non-renewable, and can lead to soil degradation, water pollution, biodiversity losses and increased concentrations of greenhouse gasses released. We thus have to reduce the usage of polluting and non-renewable inputs, and instead have to start using nature's ecosystem services to sustain the productivity of the land (Nair, 2007). Complex agroforestry is an alternative food production system that can be used to bridge the gap we have created between nature and agriculture.

Complex agroforestry systems (CAS) are sustainable, manmade food production systems consisting of at least three vegetation layers, thus including herbaceous and woody species, with a high diversity of food crops and system plants (Rijksoverheid, 2018). Complex agroforestry is becoming increasingly popular (Albrecht & Wiek, 2021; de Groot & Veen, 2017; Wendel et al., 2023), and includes food forests, forest gardens, syntropic farms, successional agroforestry, and diversified multi-strata agroforestry systems (Schulz & Weckenbrock, 2016). The large diversity of trees, shrubs and plants within the food ecosystem is designed to mimic the functional and ecological complexity that is characteristic of natural forests (Crawford, 2010). Complex agroforestry is more complex, biodiverse and less dependent on (chemical) inputs than conventional food systems, therefore distinguishing complex agroforestry from conventional agriculture, orchards, nut plantations and simpler forms of agroforestry like alley cropping systems (Geijer, 2023). This increased complexity can enhance: nutrient cycling (Steinfeld et al., 2023), self-regulation of soil biological processes (Cezar et al., 2015), biological pest control (Brito et al., 2019), and other self-regulatory processes. There are many reasons to encourage the creation of complex agroforestry systems, as agroforestry systems can provide healthy food, medicinal remedies (Albrecht & Wiek, 2021; Nair, 2007), spaces for education, community building and recreation (Albrecht & Wiek, 2021; Pilgrim et al., 2018), and environmental services such as soil health restoration (Fahad et al., 2022; Nair, 2007), carbon sequestration (Jose, 2009; Nair, 2007; Wendel et al., 2023), air and water quality enhancement (Jose, 2009; Nair, 2007), biodiversity enhancement (Albrecht & Wiek, 2021; Breidenbach et al., 2017; Jose, 2012; Pilgrim et al., 2018; Torralba et al., 2016) and mitigation of climate change effects (Lin, 2011).

Agroforestry research is primarily focused on system performance (Castle et al., 2022), rather than the performance of specific species, cultivars and rootstocks (Wendel et al., 2023). The research on system performance has highlighted the many benefits that agroforestry systems have on a social, ecological, and environmental level (Castle et al., 2022), such as described in the previous paragraph, and is less available for specifically complex agroforestry specifically (Albrecht & Wiek, 2021; Geijer, 2023). Since complex agroforestry is more complex and diverse than conventional agroforestry, Nationaal Monitorings Programma Voedselbossen (NMVB) and Voedsel uit het Bos have both set up a monitoring programme to obtain more knowledge of the performance of CAS in the Netherlands over time. These monitoring programmes focus on system performance, by collecting data on various soil health, biodiversity, carbon sequestration, yield parameters, and financial and social parameters (Voedsel uit het Bos, 2020; Wendel et al., 2023). Though existing literature and the first insights of the aforementioned monitoring programmes provide information on system performance, they do not inform us of the performance of specific species, cultivars and rootstocks, which is of importance in the decision-making process of CAS adopters (van Eijk, 2021; Van Eijk & Van Der Stok, 2023).

At the moment, CAS adopters can find information on plant-specific characteristics like physical characteristics, preferred growing conditions, and edibility in online databases (Notenteelt.com, 2024; Plants for a Future, n.d.; Stichting Planten Dichterbij, n.d.), books from CAS practitioners (Crawford, 2010; Jacke & Toensmeier, 2005; Oostwoud, 2019) and websites from nursery growers (De Smallekamp, 2024; Ecohoeve Den Oude Kastanje, 2024; Kwekerij Arborealis, 2024)(Daems, 2022). The information in these sources is to a large extent based on observations of pioneers, expert contributions, user contributions, literature reviews, and to a lesser extent on systematically collected field data. Besides, there rarely is any information on plant performance indicators like survival, growth rate or productivity, which would be beneficial information for the selection of which species, cultivars and rootstocks to implement in a CAS (van Eijk, 2021; Van Eijk & Van Der Stok, 2023). This results in CAS adopters currently basing their decisions in the plant selection, design and implementation process on anecdotal evidence and plant availability, rather than systematically collected field data on the performance of species.

1.1 Survival of woody species

Data on the survival of woody production species that are used in CAS, like Peach, Chestnut, and Pawpaw is available for forests, experimental fields and less complex food systems such as orchards, nut plantations, nurseries, and simple agroforestry systems in temperate climates. Research has shown that plant survival is affected by plant traits such as size, age, species, and cultivar, and many contextual variables such as climate, soil characteristics and competition, and (Allen et al., 2017b; Hilbert et al., 2019; N. McDowell et al., 2008; Vogt et al., 2015). However, plant survival has not yet been studied in the context of CAS in a temperate climate (Van Eijk & Van Der Stok, 2023). In Table 1, several contextual variables found to influence plant survival are shown for species that are also planted in CAS. These variables can be grouped into landscape variables (e.g. light availability, soil characteristics, and competition); management practices (e.g. irrigation, planting date, and tree tube usage); and initial plant characteristics (e.g. size and cultivar). In other contexts, landscape variables found to reduce survival are droughts, competition, poor soil quality (Hilbert et al., 2019; Struve, 2009), and other variables that lead to reduced water or nutrient availability (N. McDowell et al., 2008). Management practices that were found to positively affect tree survival are mulching (Adams, 1997; Chalker-Scott, 2007; Granatstein & Sanchez, 2009; Hytönen et al., 2005; Vogt et al., 2015), and watering (Vogt et al., 2015). Nursery production systems were found to impact urban tree survival through their influence on root architecture and handling of planting material (Allen et al., 2017b), and the smallest and largest tree sizes tend to have higher mortality (Hilbert et al., 2019; N. McDowell et al., 2008) Even though this existing research on drivers of survival is set in different systems and climates, it helps us hypothesize under what circumstances survival might be reduced or enhanced in complex agroforestry.

Table 1 Overview of (a)biotic drivers found to affect plant survival of the specified species in literature, with their context explained through land use system and climate type.

Species	Drivers of survival	System	Climate	Source
Apple (*Malus domestica)*	Cultivar, grafting	Orchard	Continental	(Bradshaw et al., 2016)
Chestnut (*Castanea sativa, dentata* and *mollissima*)	Water and light availability, planting date, competition, herbivory	Forest, experimental field	Temperate, subtropic, Mediterranean	(Conedera et al., 2021; Dalgleish et al., 2015; Pinchot et al., 2017; Radoglou et al., 2003)
Common hazel (*Corylus avellana*)	Sapling size, light availability	Forest	Temperate	(Moustakas & Evans, 2015)
Pawpaw (*Asimina triloba*)	Tree tube usage	Experimental field	Subtropic	(Crabtree et al., 2020)

Peach (*Prunus persica*)	Irrigation treatments, ground cover, cultivar, flooding	Orchard, experimental field	Continental, Mediterranean	(Andersen et al., 1984; Layne et al., 1994)
Pear (*Pyrus communis*)	Flooding	Experimental field	Mediterranean	(Andersen et al., 1984)

CAS practitioners have hypotheses on drivers of survival based on personal observations, experiences of other practitioners in their network, and, to a lesser extent, research from different contexts such as described in the previous paragraph. Practitioners generally see rainfall, soil characteristics and management practices as the most important drivers of survival. Irrigation, mulching and the addition of tree protectors are generally expected to positively affect survival, though some practitioners think less management creates a more resilient system. Some CAS practitioners hypothesize that plants planted in autumn have more time to adapt and root before the first growing season and will therefore have higher survival, whilst other people think that spring is more favourable because the period between possible root damage during planting and root growth will be minimized (as also mentioned by Agroforestry Vlaanderen, 2021). Practitioners also think some nurseries provide healthier planting material. Nurseries likely differ in the circumstances the plant material is accustomed to, as well as the management practices, seed sources, soil type, and time spent on managing the plants, which can affect plant quality. The purchase price is expected to be influenced by the nursery's time investment, the seed material price, and plant age, thus assumed to be a rough indicator of plant quality. Small plants are expected to suffer more from competition and grazing than larger plants, but larger plants might have more trouble adapting to their environment than smaller plants. These hypotheses affect the decisions they make, especially regarding implementation and management practices.

1.2 Wish to gain knowledge of survival at the species level

Agroforestry adopters have to deal with high investment costs, low plant material availability, and late and uncertain returns on investments. The main investment costs of CAS lie in the purchase of plants and organizing their implementation (Geijer, 2023; Sollen-Norrlin et al., 2020). Many woody plants in CAS are rather costly and scarce, and only start becoming productive after 5 to 10 years, resulting in late investment returns (Thiesmeier & Zander, 2023). Besides, not all plants survive, and thus replanting may be necessary, leading to even higher investment costs and further delay in the investment returns. Since research on plant survival in different contexts, such as experimental set-ups, (urban) forests and conventional food systems highlight the importance of context on survival (Table 1), the survival of plants is expected to be different in CAS compared to simpler, less biodiverse food systems with high inputs. Some species might benefit from the complexity within a CAS, whilst other species might perform better with less competition and higher inputs. Even between CAS, survival could differ, as CAS projects are started in a variety of environmental contexts with varying management practices aiming to increase plant survival. As mentioned in the prior research, there is no scientific knowledge of the survival of plants specifically within CAS, and thus it is unclear what percentage of plants might generate yields and in what timeframe. Following this, there is also no research on which contextual variables could positively influence plant survival in CAS, whilst reducing plant mortality could help reduce investment costs, plant scarcity and time until investments are returned. In November 2022, Stichting ReGeneratie organized a stakeholder engagement workshop, aiming to identify the knowledge gaps and research questions needed to professionalise CAS. They found a wish to monitor plant survival on the species, cultivar and rootstock level for a wide range of contextual variables that could affect plant survival (Van Eijk & Van Der Stok, 2023).

1.3 Research Objectives and Research Questions

In this research, I aim to make a start with the creation of a geo-referenced monitoring programme that will follow individual plants from varying species, cultivars and rootstocks in complex agroforestry systems in North-West Europe with a temperate climate (see Appendix 7.1). This study will focus on the survival of woody production plants in the start-up phase (up to 6 years). The research questions are:

What factors are most strongly associated with the survival probability of specific promising CAS genera, species, cultivars and rootstocks during the first years of establishment in complex agroforestry systems in the Netherlands?

1. *What is the overall survival probability for specific promising CAS genera, species, cultivars and rootstocks during the first years after planting in the field?*
2. *How does the survival probability vary among different promising CAS genera, species, cultivars and rootstocks?*
3. *What variables are most strongly associated with the survival of specific promising CAS genera?*
    a. *Initial plant characteristics: nursery, price, and initial size*
    b. *Landscape variables: soil type, water table, and previous land use*
    c. *Implementation and management practices: planting season, and mulching, irrigation, and protection intensity*
4. *What implementation and management practices are recommended due to their positive effect on woody production plant survival?*

1.4 Hypotheses

Genera, species and rootstocks are expected to differ in survival, whereas cultivars are expected to show smaller differences. Since rootstocks are selected on root-related properties such as root growth, rooting depth, disease and pest resistance, drought tolerance and sturdiness, rootstocks selected for different properties are expected to differ. Cultivars are often selected on taste and fruit/nut size, in which case they are not expected to differ in survival. Cultivars can however also be selected on traits that are more related to susceptibilities, like winter hardiness and disease resistance, and vigour, in which case, cultivars are expected to differ in survival.

The variables that are expected to be associated with survival are categorized under initial plant characteristics, landscape variables and management practices (Fig 1). It is expected that plant price, initial size, and irrigation have stronger effects than the other variables (indicated with thicker arrows in Fig 1), followed by soil type, water table, and planting season.

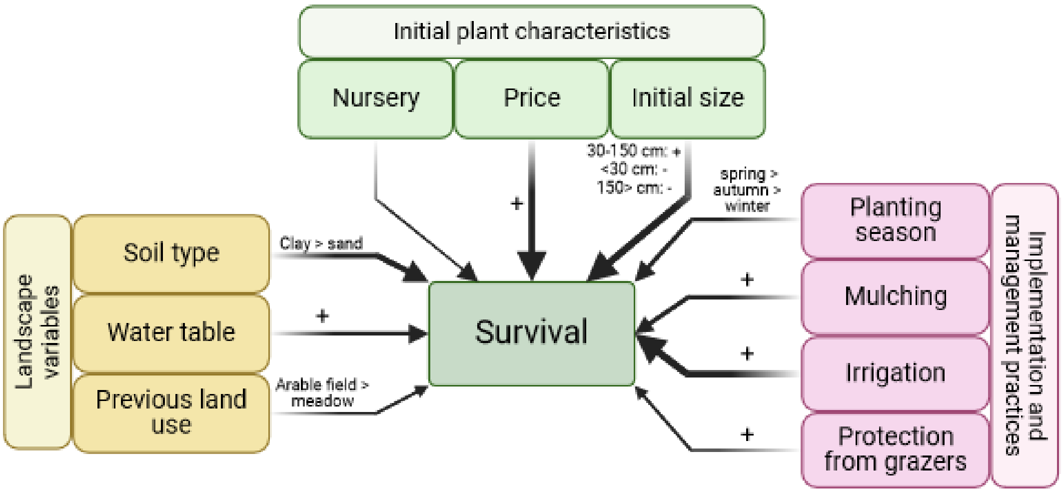

Figure 1 Expected effects of variables on survival of woody production plants in CAS. The arrow size indicates the expected relative effect size. '+' indicates an expected positive correlation. For categorical variables, which category is expected to have a higher survival is indicated. For initial size, survival is expected lowest when smaller than 30cm or higher than 150cm, but expected to increase with size between 30 and 150cm. Created with BioRender.com

2. Research Methods

2.1 CAS selection

The CAS that were selected for this research are all located in the Netherlands (Fig 2), which is one of the forerunners in terms of commercial CAS development (personal communication, Jordy van Eijk), as reflected in the increase in projects from foundations and companies such as Stichting Voedselbosbouw Nederland, Stichting ReGeneratie and Fruitzforlife.

The CAS projects were selected on several criteria:

- The project, or part thereof, is 0-6 years old and thus in the start-up phase. The woody plants that could be monitored were not older than 6 years.
- The project is larger than 0.5 hectares
- The project has commercial food production goals or aims to research commercial food production possibilities
- There is proper documentation on the species, location of plants, time of planting, and preferably also on the cultivar, nursery, price, size and survival of the initial planting material, and the project is willing to share this information
- The project is willing to participate in a monitoring programme for the coming years

To be able to investigate the influence of contextual factors, the CAS projects were also selected to:

i. Overlap in species
ii. Differ in contextual variables such as soil type or management practices

In total, I visited 7 projects (for more information, see Appendix 7.2). The locations of 6 of the projects can be seen in Figure 2; the project that is left out wanted to remain anonymous.

Figure 2 Overview of six of the seven selected complex agroforestry projects. One location wanted to remain anonymous and is thus left out. The brown, purple and green dots indicate projects located on sandy, loamy or clay soil respectively. The size of the dot is proportional to the size of the area that has been planted. Created with QGIS.

2.2 Data collection

The contextual variables that were selected are a) the nursery, purchase price and initial size as initial plant characteristics, b) soil type, groundwater table class ('grondwatertrappen', a Dutch classification system based on the average highest and average lowest groundwater table values) as landscape variables, and c) planting season and intensity of mulching, irrigation and protection of trees as management practices (Table 2, Fig 3).

Table 2 Description of the variables on which data is collected and their collection method.

Variable	Description	Method
Species	Plant species	Design, practitioner, labels in the field, own knowledge
Cultivar	Plant cultivar	Design, practitioner, labels in the field
Rootstock	Plant rootstock	Practitioner, order lists, labels in the field
Survival	0 (dead) or 1 (alive)	Observed in the field: absence/presence of green leaves and buds
Planting year	In between which two growing seasons the plant has been planted: 2018/2019, 2019/2020, 2020/2021, 2021/2022, 2022/2023	Practitioner, order lists
Initial plant characteristics		
Nursery	Nursery where the plant was bought from	Practitioner, order lists, labels in the field
Price	Purchase price in €	Order lists, labels in the field
Initial size	Size range in cm	Order lists, labels in the field
Landscape variables		
Soil type	Clay, loam or sand	Practitioner and BRO soil map
Water table	Grondwatertrap: based on highest and lowest water table values, ranging between 1-9	BRO 'grondwatertrappen' map
PLU	Previous land use: meadow, or arable field	Practitioner
Management and implementation practices		
Planting season	Season in which plants were planted: autumn, winter, spring, or summer	Practitioner, order lists
Mulching	Mulching intensity on a scale of 1-10	Survey
Irrigation	Irrigation intensity on a scale of 1-10	Survey
Protection	Protection intensity on a scale of 1-10, protection by tree protectors or fence	Survey

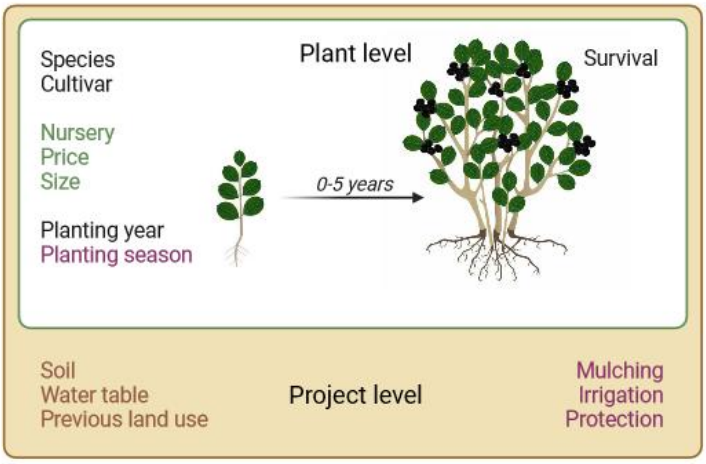

Figure 3 Visualisation of which variables were measured at what scale. The white and orange boxes show which variables were collected at the plant and project level respectively. The text colour of the variables indicates the overarching variable group with initial plant characteristics in green, landscape variables in orange and management and implementation practices in purple. Created with BioRender.com

2.2.1 Georeferencing the baseline planting schemes and plant data

I requested the CAS practitioners to send their designs, order lists, and planting lists. The designs were loaded in QGIS (version 3.30.2; QGIS Development Team, 2023), an open-source Geographical Information System (GIS) software, and used to georeference the woody production plants (Fig 4A) (for more details, see Appendix 7.3). This was done to ensure monitoring on the plant level is possible over the next few years without having to rely on tags in the field. Subsequently, I used the order and planting lists to fill in as many initial plant characteristics (Table 2) to the georeferenced plants as possible (Fig 4A). In some cases, practitioners documented their plants with their characteristics in a dedicated file, and initial plant characteristics and the time of planting could be retrieved through this. Two locations did not have available order lists or other forms of documentation, resulting in those locations lacking information on the price, initial plant size, and nursery. For roughly half the plants, at least one of the initial plant characteristics was unclear, due to missing information or uncertainties in the order lists. Additionally, the time of planting was derived from the order lists of projects that planted their planting material within two weeks after they were received.

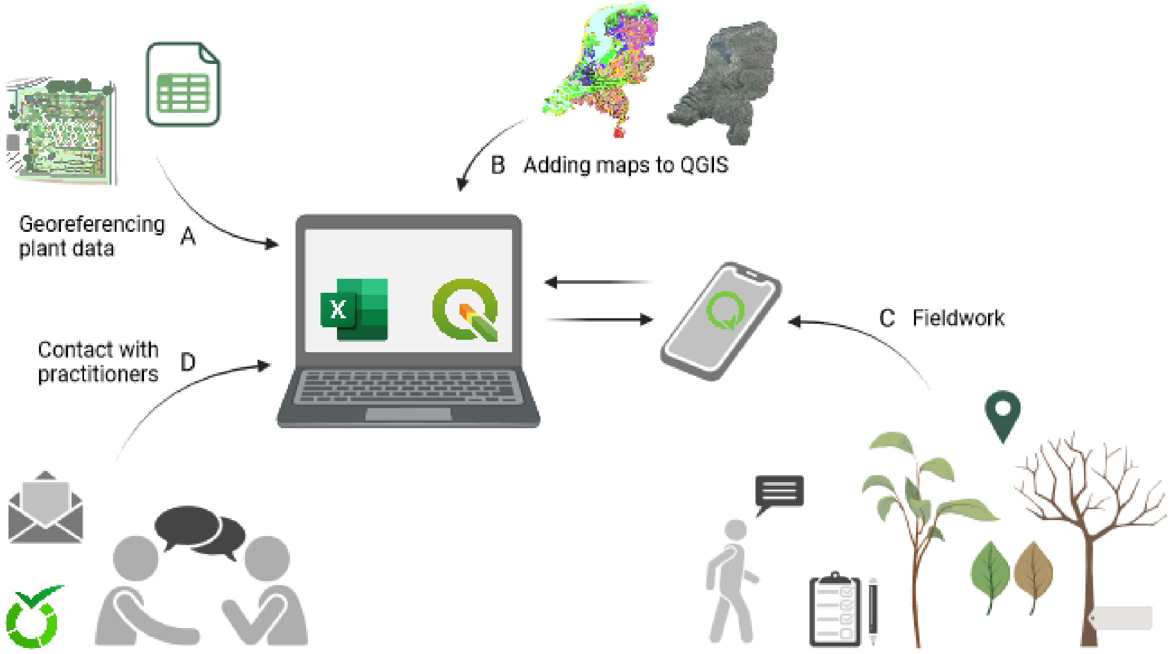

Figure 4 Visualisation of data collection. A: adding designs and data from plant and order lists to QGIS. B: adding an aerial picture, soil map and water table map to QGIS. C: undertaking fieldwork in which survival (presence of green leaves and/or buds) and other plant information retrieved through the practitioner, a label, or through observation, was collected. D: contact with practitioners through interview, survey and mail. Created with BioRender.com

2.2.2 Scoring survival in the field

In the field, I used QField (OPENGIS.ch, 2023) to further add information to the georeferenced plants (Fig 4C). I noted the survival status (dead or alive), which was based on the absence or presence of green leaves and buds; an efficient, non-destructive method that will ensure consistent data collection. For long rows featuring a single species, a plant count was conducted and the positions of deceased plants were documented (e.g. row B12 – 113 total – dead: nr 15, 64 and 109 from the roadside) to save time in the field and allow for concurrent monitoring. This was subsequently incorporated into QGIS. Any other observations were noted down, e.g.: clear damage by herbivores, having a label, being a lot larger/smaller than others, the tree protector being filled with an ant nest, etc. I adjusted plant locations in QField where necessary to ensure ease of finding the plants in future monitoring, and added observed plants missing from the design. When an entire row had to be adjusted, I only updated the geolocations of the first and last plant and adjusted the remainder of the row accordingly in QGIS. In total, 12651 plants were geo-referenced and observed in June-September 2023. In case additional information about specific plants was given by the CAS practitioner in the field this was also added in Qfield. Similarly, information on the species, cultivar, nursery, price and/or size on the sometimes remaining labels from the nursery or as added by practitioners, was also added in QField.

2.2.3 Collection of data on contextual variables

Through a plugin in QGIS that gives access to up-to-date geo-information of the Netherlands (PDOK Plugin; Duivenvoorde, 2023), I obtained aerial pictures (Het Kadaster, 2023), soil maps and water table maps (Wageningen Environmental Research, 2023b, 2023a) (Fig 4B), which were respectively used to georeference the data, confirm the soil type, and determine the groundwater table class.

Furthermore, I had contact with practitioners through a survey, an interview (Appendix 7.4) and additional communication (Fig 4D), which provided information on management practices, perceived survival of plants in the field, soil texture, previous land use, and time of planting. Additionally, I requested practitioners to further fill in initial plant characteristics still missing after incorporating data from the order lists and fieldwork, to the extent possible within the time frame of this thesis and the time availability of the practitioners.

The survey was developed to gather information on the management practices for all locations (Fig 4D), using LimeSurvey (LimeSurvey, 2023). Through this survey, I asked practitioners to numerically estimate the intensity of mulching, irrigation and tree protection (1-10), to facilitate data analysis. Given the subjective nature of scaling management practice intensity, I analysed and in two cases adjusted the responses, to ensure that observed differences between projects in the field would be reflected in the scores:

- The mulching intensity of a project that mulched nearly all rows with a weed-suppressing membrane and woodchips after having added compost with lava powder to the whole area, thus being most systematically mulched, was changed from ‘2’ to ‘9’.
- The tree protection intensity of a project that did not use tree protectors, but that had all the plots surrounded by a steady, high fence, thus being best protected against (roe)deer, hares, and other herbivores from all visited projects, was changed from ‘1’ to ‘10’.

2.3 Data analysis

A subset of 24 genera, 38 species and 32 cultivars were analysed for RQ 1 and 2. Selection was based on 1) being a woody plant whose main function is to produce food, 2) being present in at least three out of the seven selected CAS projects, with a total number of at least 20 individuals of which the planting year is known, and 3) being listed as one of the 100 promising species for CAS in (van Eijk, 2021), being a genus that entails a selected species, or being a cultivar of a selected species.

To answer the first two sub-questions, I plotted Kaplan-Meier survival curves with 95%-confidence plotted for all the selected genera, species and cultivars, using the survival package in R (T. Therneau, 2023; T. M. Therneau & Grambsch, 2000). The time steps in the analyses are in years, and each planting season they are in the field is counted as one year. E.g.: a tree planted in winter 2022 is noted as one year old, and a tree planted in spring 2021 is noted as 3 years old. This means that in reality, plants can vary in age and time in the field. Data on plant survival from previous years was not available, so for plants that were noted down as dead last summer, the exact year of death is not known (Kartsonaki, 2016). In the calculations, the survival probability is estimated based on the assumption that the plant died in the last year, though it could have died earlier. In total, 12483 plants that were identified at the species level had a known planting year, thus being part of the survival analysis (Survival data, Table 3).

Additionally, a binomial logistic regression analysis was performed to examine whether the genera (Model A) and species (Model B) differ significantly from one another. This was only done with the plants planted in 2022/2023, to remove possible effects of climate and time in de field on survival (Model A/B data, Table 3). In the generalised linear model, survival status was included as the response variable, and the genera or species as a fixed factor. The CAS project was also included as a fixed factor, to allow for comparison between locations, and to account for other variables whilst keeping the model simple. Since not all genera and species are equally represented across the projects, leaving out the projects may lead to apparent differences between genera or species that are in reality caused by other variables. The models were created with the glm function from the lme4 package in R (Bates et al., 2015), which uses the reweighted least squares (IWLS) method for fitting the model. After running the models, pairwise comparisons (Bonferroni method) were conducted using the emmeans package (Lenth, 2024) to identify significant differences ($p_{adj} < 0.05$) among genera, species and CAS projects.

A) Survival ~ Genus + CAS project

B) Survival ~ Species + CAS project

Table 3 Overview of different sub-sets of the collected data and what they were used for.

Data sub-set	Selection description	Usage	Number of plants
Raw data	All observed plants	-	12651
Survival data	All plants for which the species and planting year are identified	Survival curve of all plants combined (RQ1)	12483
Genus, species, cultivar and rootstock data	All plants from the selected genera, species, cultivars, and rootstocks for which the planting year is identified	Survival curves of genera, species and cultivars (RQ1&2)	11870, 11118, 4903, 59
Model A data	All plants from the selected genera that were planted in 2022/2023	Generalized linear model with genus and CAS project (RQ2)	10873
Model B data	All plants from the selected species that were planted in 2022/2023	Generalized linear model with species and CAS project (RQ2)	10178
Model C data	All plants from the selected genera that were planted in 2022/2023, for which the planting season is identified	Generalized linear mixed model without initial plant characteristics (RQ3)	10644
Model D data	All plants from the selected genera that were planted in 2022/2023, for which the planting season, nursery, price and initial size are identified	Generalized linear mixed model with initial plant characteristics (RQ3)	5472

The third sub-question was answered by creating generalised linear mixed models (GLMM), with survival status (0/1) as the response variable, the initial plant characteristics, landscape variables and implementation and management practices as the fixed factors, and location and genus as random factors. The models were created with the glmer function from the lme4 package (Bates et al., 2015), in which the survival was set to follow a binomial logistic regression (family = binomial, link function = logit). This again was only done with the plants planted in 2022/2023 (Model C/D data, Table 3). The number of observed plants differs per genus and project, and survival rates were expected to vary more across different genera and locations than within those groups. To account for the variability among genera or locations that may not be accounted for with the selected variables, genus and CAS project were included as random factors.

The models were optimized by performing a backward selection based on p-values: variables without a p-value lower than 0.05 were removed. Plants that had missing information for one of the variables were removed from the dataset to allow for the backward selection, resulting in 5472 observations in the dataset (Model D data, Table 3). Information on plant price was only available for 5 of the projects, resulting in less variance in landscape variables, management practices, soil type and nurseries. Therefore, another model selection was performed that excluded nursery, price and initial size, resulting in 10644 data points (Model C data, Table 3).

C) Survival ~ Soil type + PLU + Water table + Planting season + Mulching intensity + Irrigation intensity + Protection intensity + (1|Genus) + (1|CAS project)

D) Survival ~ Nursery + Price + Size + Soil type + PLU + Water table + Planting season + Mulching intensity + Irrigation intensity + Protection intensity + (1|Genus) + (1|CAS project)

All analyses were performed using R Statistical Software (version 4.3.2; R Core Team, 2023).

3. Results

3.1 Survival probability across genera, species, cultivars and rootstock

The probability of a woody production plant from the selected genera surviving the planting and part of the first growing season is 91% (Fig 5, Appendix 7.5 Table 8). The cumulative survival probability of surviving the second year drops to 74%, but does not decline much more in the following 3 years. After 5 years, the probability of plants in the selected genera surviving in the field is around 69%.

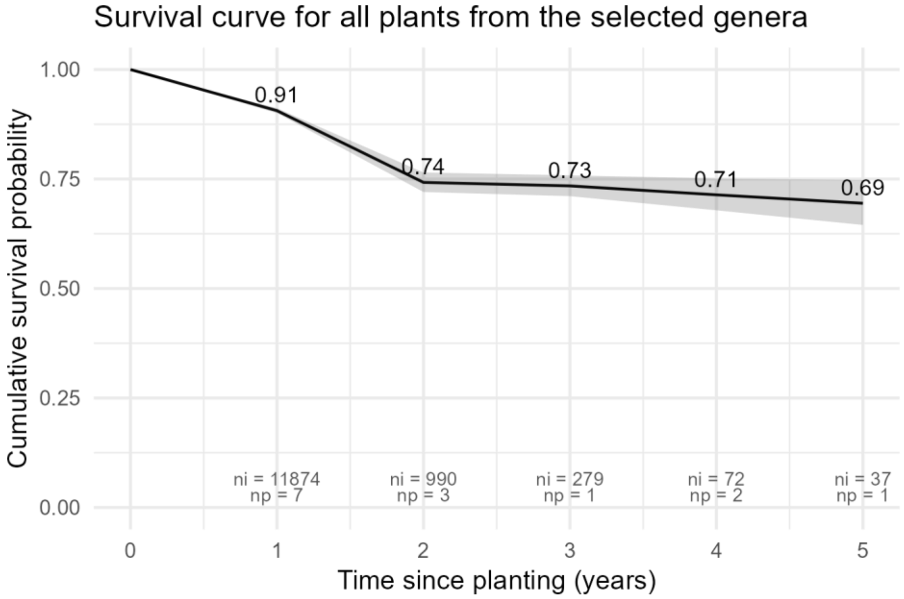

Figure 5 Kaplan-Meier survival curve for all the plants from the selected genera with the 95% confidence interval. ni = number of individual plants on which the calculations are based for that time stamp. np = number of projects in which those individuals can be found.

Genera were found to have significant differences (Model A, $p_{adj} < 0.05$) in survival probability for the first year after planting (Fig 6, Appendix 7.6.1). As can be seen in Figure 6, many apparent differences are not significant.

Most genera (17 out of 24) have a probability of surviving the first year higher than 90%. Chokeberries (*Aronia),* honeyberries (*Lonicera)*, apples (*Malus)* and currants (*Ribes)* have a survival probability of 97% or higher. Chestnut (*Castanea)*, kaki (*Diospyros),* autumn olive (*Elaeagnus),* sea buckthorn (*Hippophae),* Chinese mahogany (*Toona)*, and Szechuan pepper (*Zanthoxylum)* have a survival probability of around 70% to 80%. The genus with the lowest survival probability for year 1 is *Rubus*, which is mainly composed of Raspberries, Tayberries, Blackberries, Boysenberries and Japanese wineberries.

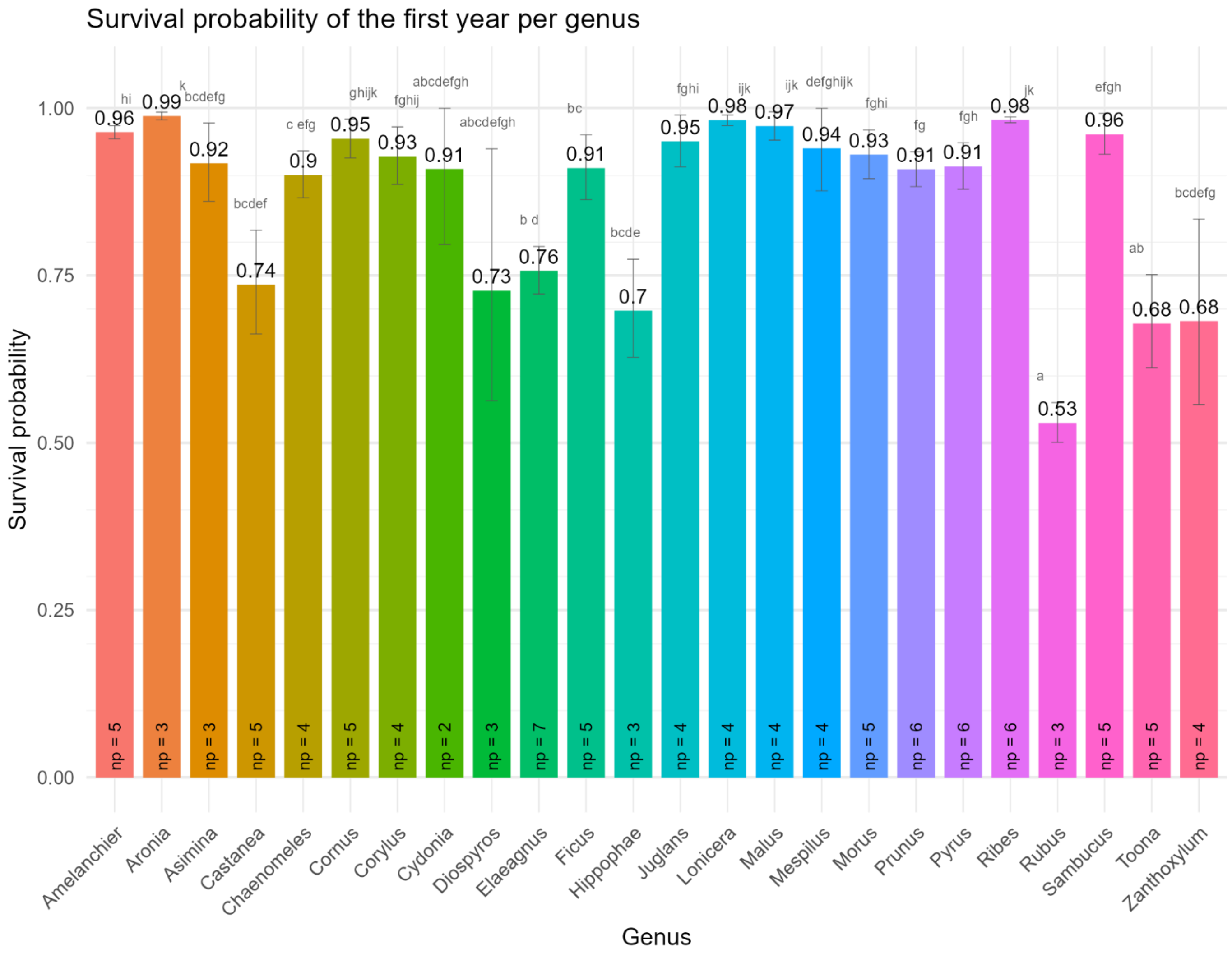

Figure 6 Survival probability of the first year for the selected genera, based on the Kaplan-Meier survival curves that were generated per genus. Error bars indicate the 95%-confidence intervals derived from the survival curves. 'np' indicates the number of projects where the individuals used in the calculations for year 1 are present. Genera not overlapping in letters above the upper confidence interval are significantly different by the Bonferroni test based on Model A ($p_{adj} < 0.05$). The letters were assigned using the multcomp package (Hothorn et al., 2008).

For over half (13 out of 22) of the genera, the cumulative probability of surviving the second year is less than 20% lower compared to the first year (Appendix 7.5.1), with *Aronia, Chaenomeles, Elaeagnus, Hippophae, Lonicera, Malus, Mespilus* and *Zanthoxylum* declining with less than 5%. *Asimina, Castanea, Cydonia, Ficus, Juglans, Morus, Prunus, Sambucus and Toona* see a decline in cumulative survival probability greater than 20% between the first and second year (Fig 7, Appendix 7.5.1).

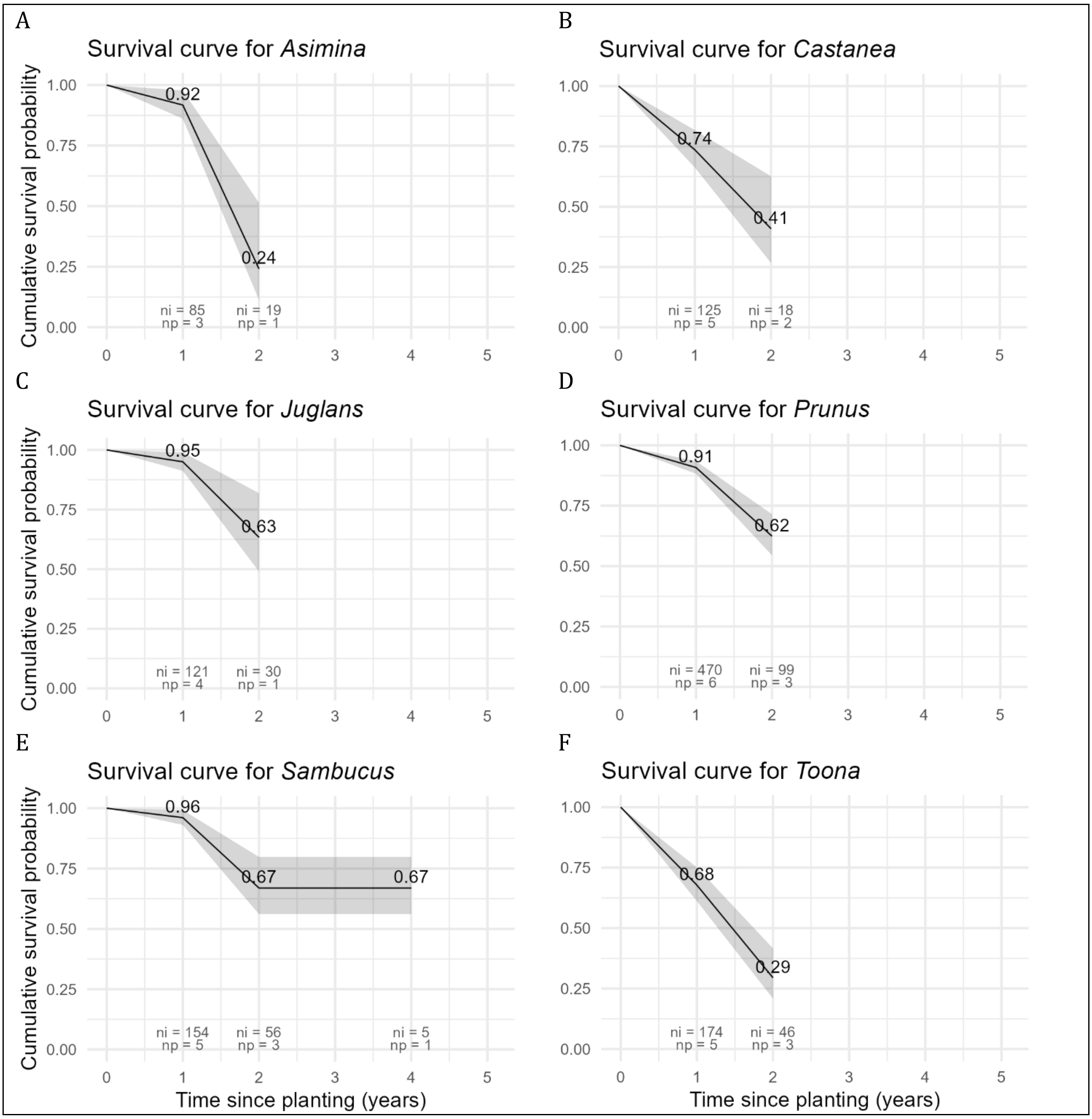

Figure 7 Kaplan-Meier survival curves with their 95% confidence intervals of some of the genera that show a drop in cumulative survival probability after year 1. ni = number of individual plants on which the calculations are based for that time stamp. np = number of projects in which those individuals can be found.

Rubus had the lowest probability of surviving the first year (Fig 6), making it an intriguing genus to further explore. Since *Rubus* featured only one species that was present in at least 3 locations (out of the 5 species that had at least 20 individuals), an exception was made so that species present in two locations were included in the survival curve as well.

Species were found to have significant differences (Model B, $p_{adj} < 0.05$) in survival probability for the first year after planting (Table 4, Appendix 7.6.2).

Most species (27 out of 38) have a probability of surviving the first year after planting higher than 90% (Fig 8). Purple chokeberry (*Aronia prunifolia),* Common walnut (*Juglans regia),* Honeyberry (*Lonicera caerulea)*, Mulberry hybrid (*Morus alba x rubra)*, Plum (*Prunus domestica)*, European pear (*Pyrus communis),* Worcesterberry (*Ribes divaricatum),* Black currant (*Ribes nigrum)*, Red currant (*Ribes rubrum),* and Tayberry (*Rubus fruticosus x idaeus)* have a survival probability of 98% or higher. Three species have a survival probability of the first year lower than 60%: Peach (*Prunus persica),* Raspberry (*Rubus idaeus)* and Boysenberry (*Rubus loganobaccus x idaeus)*.

For over half (15 out of 29) of the species, the cumulative probability of surviving the second year is less than 20% lower compared to the first year (Appendix 7.5.2), with Purple chokeberry, Common hazel (*Corylus avellana)*, Autumn olive (*Elaeagnus umbellata)*, Sea buckthorn (*Hippophae rhamnoides)*, Common walnut, Honeyberry, Apple (*Malus domestica)*, Medlar (*Mespilus germanica)*, Russian plum (*Prunus salicina x cerasifera)*, Worcesterberry, Red currant, Gooseberry (*Ribes uva-crispa)*, Boysenberry and Japanese wineberry (*Rubus phoenicolasius)* declining with less than 5%. Pawpaw (*Asimina triloba),* Sweet chestnut and its hybrid with Japanese chestnut (*Castanea sativa* and *sativa x crenata),* Quince (*Cydonia oblonga),* Fig (*Ficus carica),* Japanese walnut (*Juglans ailantifolia),* Mulberry hybrid, Plum, Apricot (*Prunus armeniaca),* Nashi pear (*Pyrus pyrifolia),* Black currant, Jostaberry (*Ribes nigrum x uva-crispa)*, European elderberry (*Sambucus nigra),* and Chinese mahogany (*Toona sinensis)* see a decline in cumulative survival probability greater than 20% between the first and second year (Appendix 7.5.2).

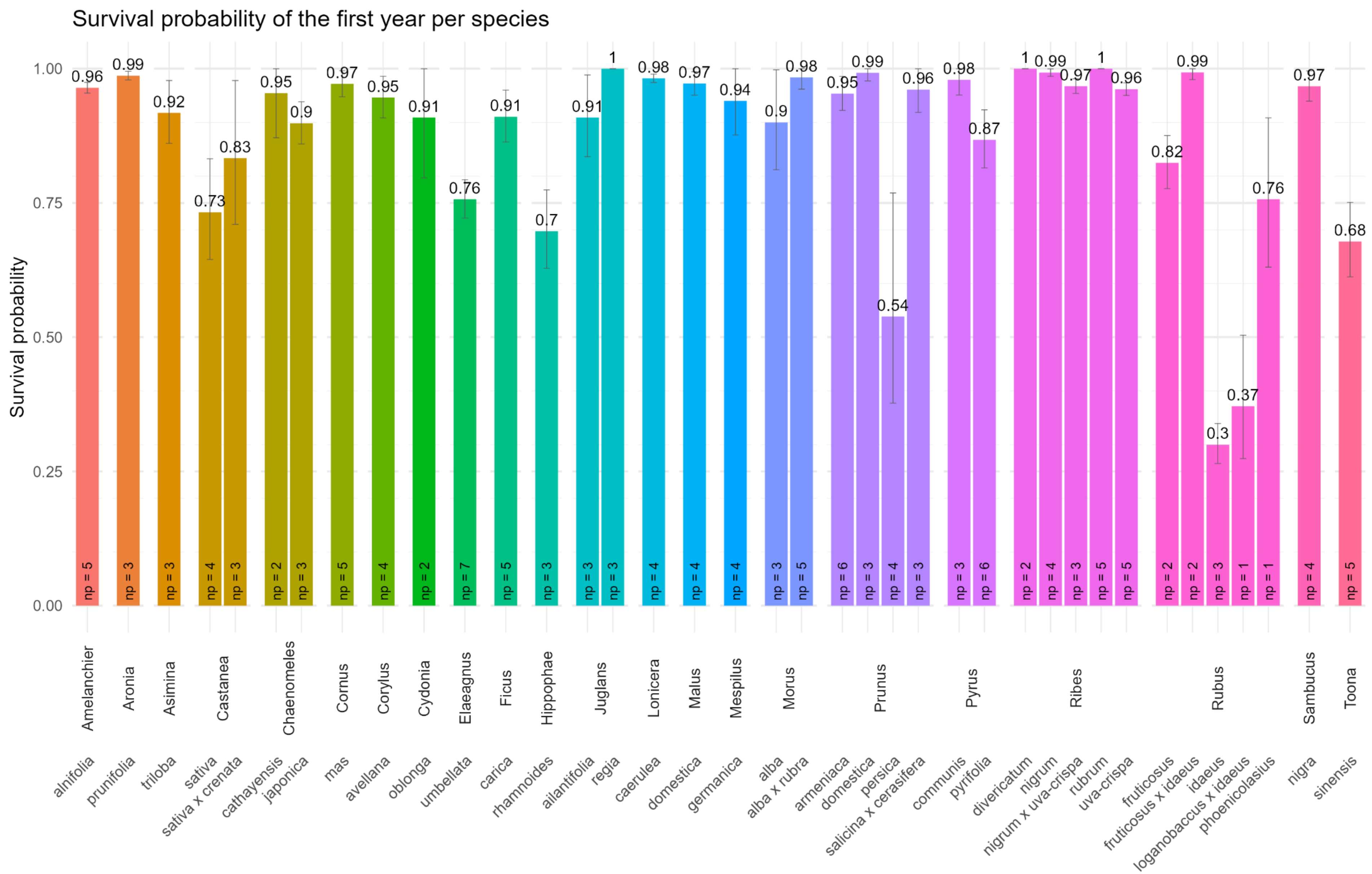

Figure 8 Survival probability of the first year for the selected species, based on the Kaplan-Meier survival curves. Bars are grouped per genus. Error bars indicate the 95%-confidence intervals. 'np' indicates the number of projects where the individuals used in the calculations for year 1 are present.

Table 4 Grouping of the selected species based on the pairwise comparisons resulting from model B. The pairwise comparisons are based on the estimated marginal means with the Bonferroni adjustment method, using the emmeans and multcomp package (Hothorn et al., 2008; Lenth, 2024)*. Species that have no overlapping letters in the 'Group' column differ significantly from each other (*$p_{adj} < 0.05$*).*

Genus	**Species**	**Estimated marginal means**	**Standard error**	**Group**
Rubus	*idaeus*	-1,105	0,120	a
Rubus	*loganobaccus x idaeus*	-0,396	0,275	ab
Prunus	*persica*	0,074	0,411	abcd
Toona	*sinensis*	0,269	0,165	bc
Ficus	*carica*	0,734	0,196	bcde
Hippophae	*rhamnoides*	0,844	0,188	bcde
Elaeagnus	*umbellata*	1,047	0,110	def
Rubus	*fruticosus*	1,094	0,194	cdefg
Castanea	*sativa*	1,182	0,246	cdefgh
Asimina	*triloba*	1,358	0,272	cdefghi
Rubus	*phoenicolasius*	1,475	0,398	cdefghijkl
Cydonia	*oblonga*	1,530	0,490	bcdefghijklm
Pyrus	*pyrifolia*	1,644	0,239	defghi
Chaenomeles	*japonica*	1,764	0,235	defghij
Sambucus	*nigra*	1,811	0,235	defghij
Prunus	*domestica*	1,811	0,246	defghijk
Castanea	*sativa x crenata*	1,885	0,468	cdefghijklmn
Juglans	*ailantifolia*	2,159	0,377	defghijklmn
Morus	*alba*	2,268	0,539	cdefghijklmno
Corylus	*avellana*	2,549	0,349	ghijklmno
Prunus	*armeniaca*	2,785	0,350	hijklmno
Ribes	*nigrum x uva-crispa*	2,804	0,181	jklmno
Amelanchier	*alnifolia*	2,932	0,171	klmno
Prunus	*salicina x cerasifera*	3,010	0,595	efghijklmnop
Cornus	*mas*	3,022	0,390	ijklmno
Mespilus	*germanica*	3,085	0,603	efghijklmnop
Chaenomeles	*cathayensis*	3,091	1,028	bcdefghijklmnop
Ribes	*uva-crispa*	3,109	0,174	lmno
Morus	*alba x rubra*	3,400	0,591	ghijklmnop
Pyrus	*communis*	3,498	0,720	efghijklmnop
Ribes	*nigrum*	3,642	0,287	mnop
Lonicera	*caerulea*	3,693	0,227	nop
Malus	*domestica*	3,855	0,422	mnop
Aronia	*prunifolia*	4,005	0,280	op
Rubus	*fruticosus x idaeus*	4,861	1,008	fghijklmnop
Ribes	*rubrum*	6,426	0,710	p
Juglans	*regia*	16,137	307,407	abcdefghijklmnop
Ribes	*divericatum*	16,154	209,704	abcdefghijklmnop

For three out of the eight genera with multiple observed species (Fig 9), species barely differ in survival, whereas for other genera some differences can be seen (Fig 10-12) (Table 4, Appendix 7.5.2). The Flowering quinces (*Chaenomeles cathayensis* and *japonica)*, chestnuts, and Mulberries (*Morus alba* and *alba x rubra)* have a large overlap in their 95% confidence interval (Fig 9), and do not differ significantly in the probability of surviving the first year (Table 4).

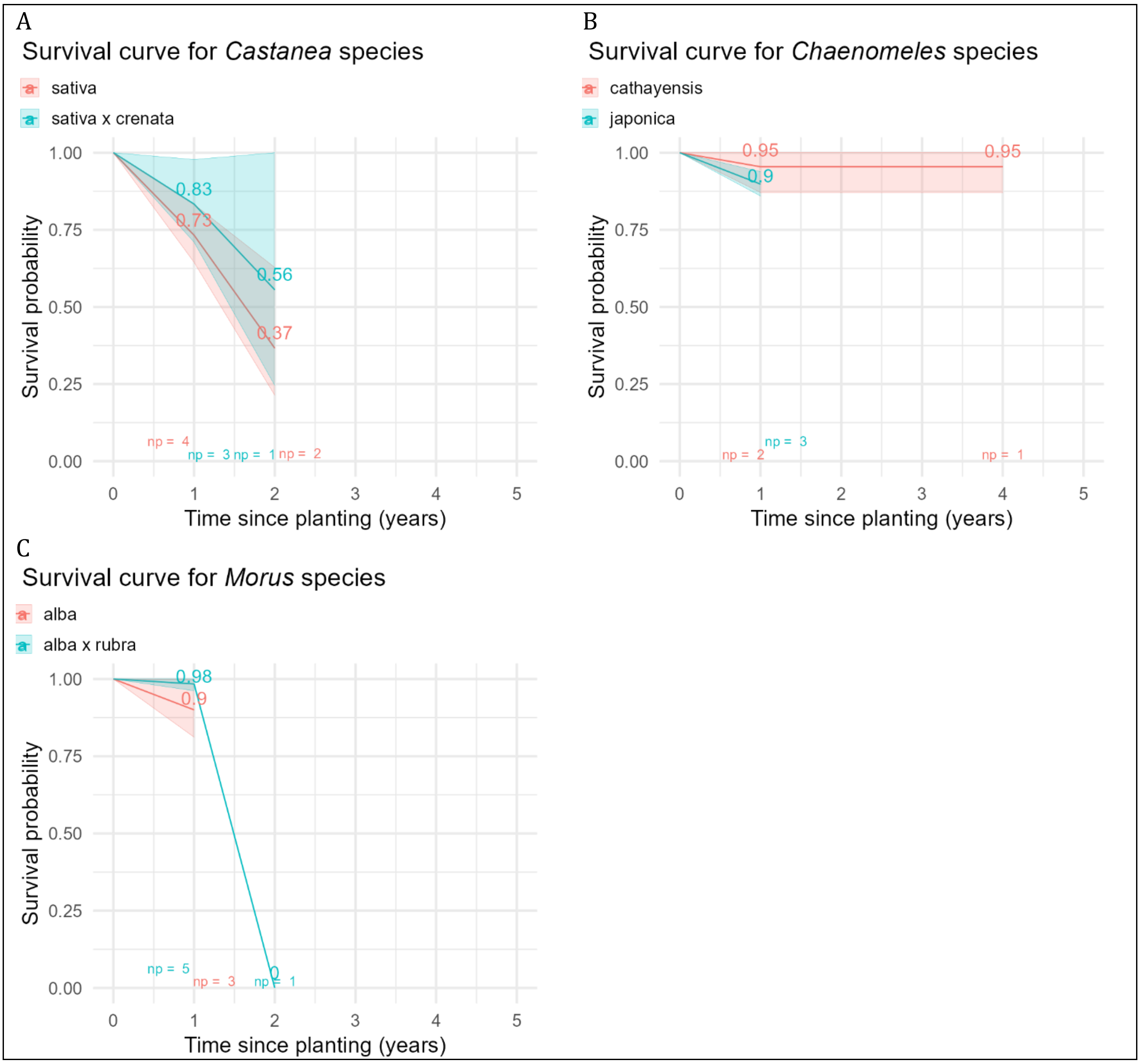

Figure 9 Kaplan-Meier survival curves with their 95% confidence intervals for the genera in which species do not differ significantly. ni = number of individual plants on which the calculations are based for that time stamp. np = number of projects in which those individuals can be found.

Juglans and *Ribes* species do not differ much when looking at the first year (Fig 8), but seem to differ more in survival probability for the second year (Fig 10A). In the second year Japanese walnut (*J. ailantifolia)* has a lower cumulative survival probability than Common walnut (*J. regia)*, though this is based on 10 and 4 individuals respectively. Within the genus *Ribes*, Red currant (*R. rubrum)* was found to differ significantly from Gooseberry and Jostaberry (resp. *R. uva-crispa* and *nigrum x uva-crispa)* in the first year (Model B, $p_{adj} < 0.05$, Table 4) with survival probabilities of 1.0, 0.96 and 0.97 respectively. In the second year, Black currant (*R. nigrum)* and Jostaberry have a seemingly lower cumulative survival probability than the other *Ribes* species (Fig 10B).

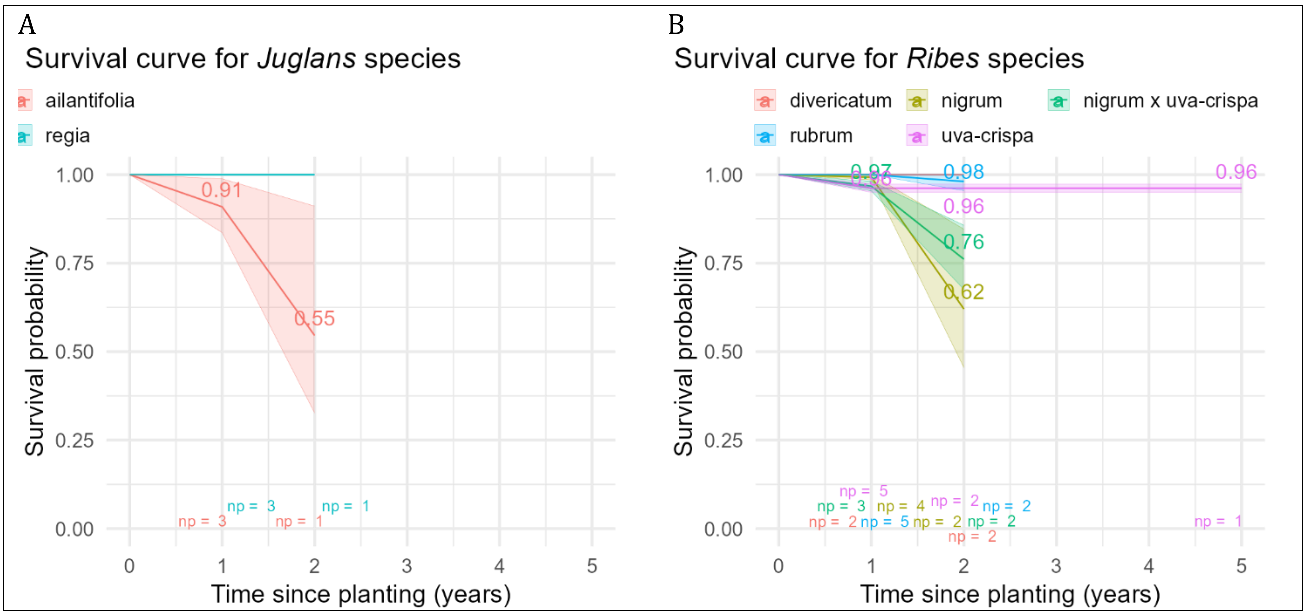

Figure 10 Kaplan-Meier survival curves with their 95% confidence intervals of the genera for which the survival probability in the first year does not differ much, but differences seem to appear in year 2. np = number of projects in which the plants were observed.

In *Prunus,* Peach (*P. persica)* has a significantly lower survival (Model B, $p_{adj} < 0.05$, Table 4) than Apricot and Russian plum (resp. *P. armeniaca,* and *salicina x cerasifera)* for the first year (Fig 8 and 11A). However, in the second year Apricot drops in survival, and the 95% confidence intervals overlap greatly with that of Peach (Fig 11A). Important to note is that the number of observed individuals for Apricot and Peach in year 2 is 3. The cumulative survival probability for year 2 seems highest for the Russian plum.

European pear (*Pyrus communis)* and Nashi pear (*Pyrus pyrifolia)* seem to differ in survival probability for the first year (Fig 8), though not significant (Table 4), with Nashi pear seeing a further decline in survival for the second year and no data available for European Pear (Fig 11B).

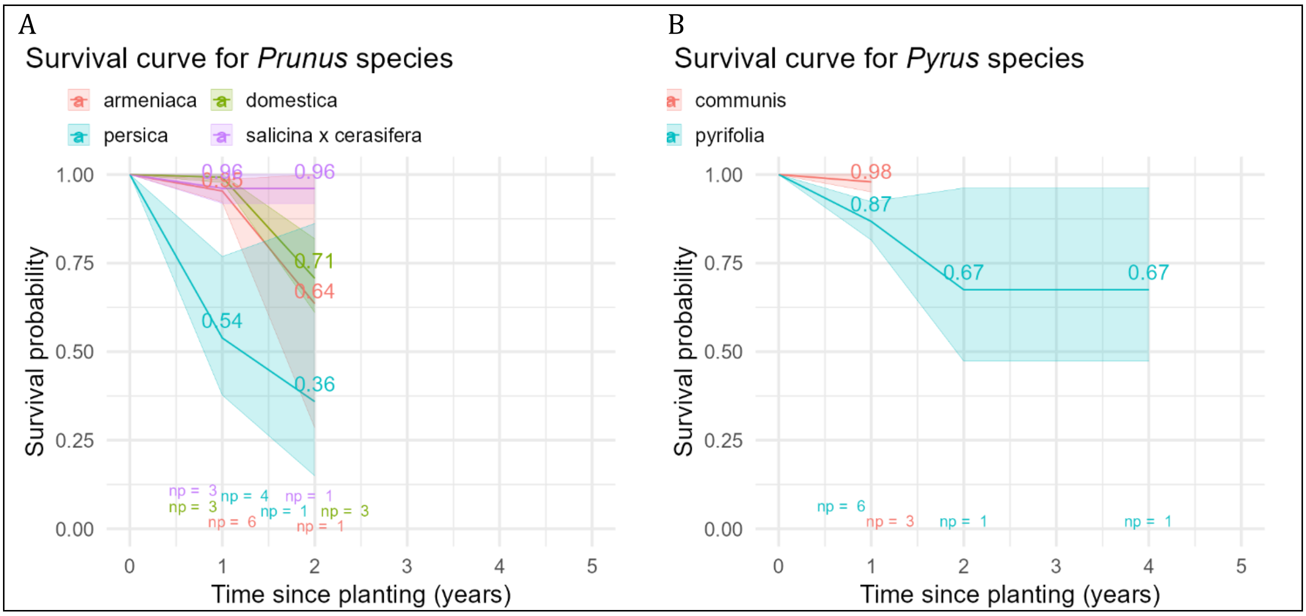

Figure 11 Kaplan-Meier survival curves with their 95% confidence intervals of the genera for which the survival probability seems to increasingly differ. np = number of projects in which the plants were observed.

In *Rubus,* Raspberry and Boysenberry (resp. *R. idaeus* and *loganobaccus x idaeus)* have a lower survival than Blackberry, Tayberry and Japanese wineberry (resp. *R. fruticosus, fruticosus x ideaus,* and *phoenicolasius)* for the first, as well as the second year (Fig 8 and Fig 12). This also corresponds with the results from the pairwise comparisons, in which Blackberry, Tayberry and Japanese wineberry were found to differ significantly from Raspberry and Boysenberry in year 1 (Model B, $p_{adj} < 0.05$, see Table 4).

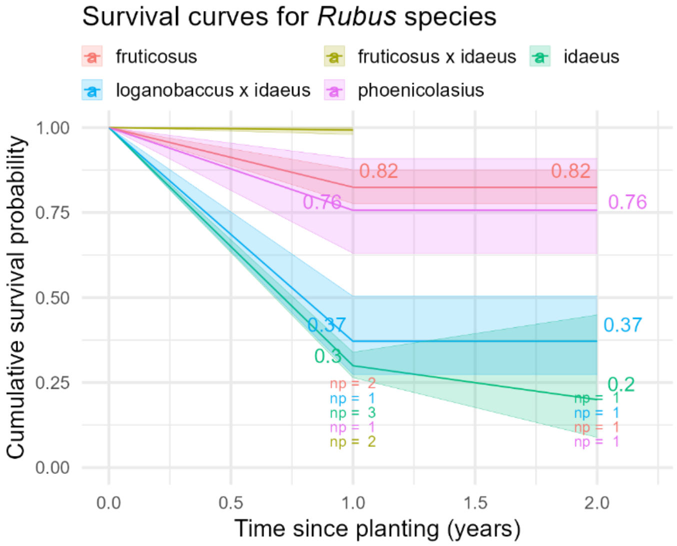

Figure 12 Kaplan-Meier survival curves with their 95% confidence intervals for the selected Rubus *species. np = number of projects in which the plants were observed.*

Of the 14 species that had a selected cultivar, 8 species had multiple selected cultivars, thus making comparing cultivars within a species possible (Appendix 7.5.4). Of these eight, only Autumn olive (*Elaeagnus umbellata)* seemed to have a difference between cultivars (Fig 13), with Red Cascade seemingly doing less well than Amber, Big Red and Sweet 'n Tart.

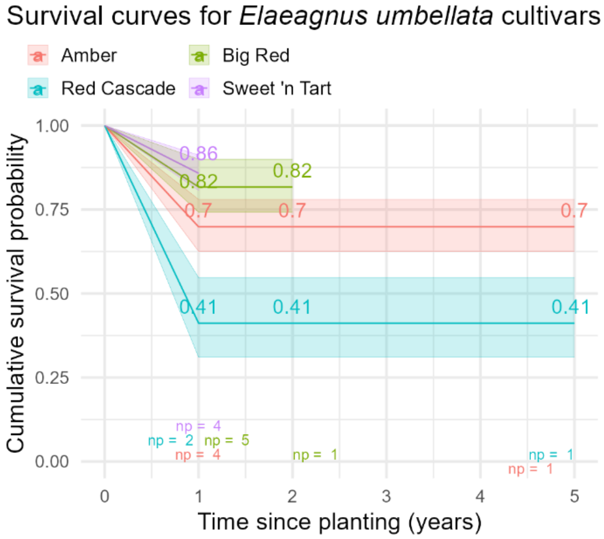

Figure 13 Kaplan-Meier survival curves with their 95% confidence intervals for the selected Elaeagnus umbellata *cultivars. np = number of projects in which the plants were observed.*

For less than 60 grafted plants across 2 locations, it was clear what rootstock was used, thus not making it possible to analyse the survival of specific rootstock cultivars.

3.2 Drivers of woody production plant survival

Adding CAS project as a random effect to the models resulted in singular fits. Therefore, CAS project was removed from the models.

The backward selection on Model C, in which the initial plant characteristics are not included, using the p-value approach resulted in the removal of previous land use, water table, and protection intensity. Looking at the differences between planting seasons, plants planted in summer showed a significantly lower survival (β = -1.98, p = 0.014), and plants planted in winter (β = 0.497, p = 0.003) and spring (β = 0.389, n.s.) had higher survival compared to those planted autumn (Table 5), with only winter being significantly different. Compared to clay soils, plants on loam had a higher survival (β = 0.167, ns) and plants on sandy soil had a lower survival (β = -0.569, p = 0.004) (Table 5). Mulching (with values ranging from 1 to 9) positively affected survival (β = 0.276, p ≈ 0.000), and irrigation (with values ranging from 1 to 6) negatively affected survival (β = -0.124, p = 0.022) (Table 5).

*Table 5 Estimated regression parameters, standard errors, z-values and p-values for the binomial GLMM resulting from the backward selection of Model C. *'s indicate p-values < 0.05.*

	Estimate	Standard error	z value	p-value
Intercept	1.011	0.408	2.479	0.013*
Soil type: loam	0.167	0.225	0.743	0.456
Soil type: sand	-0.569	0.195	-2.915	0.004*
Mulching	0.276	0.073	3,755	0.000*
Irrigation	-0.124	0.054	-2.279	0.022*
Planting season: spring	0.389	0.432	0.901	0.368
Planting season: winter	0.497	0.172	2.884	0.004*
Planting season: summer	-1.984	0.808	-2.456	0.014*

The backward selection on Model D, in which all variables were included, using the p-value approach resulted in the removal of the variables: nursery, mulching intensity, irrigation intensity, previous land use, protection intensity, and initial price. The resulting model (intercept estimate = 8.580) found a significant effect of water table (β = -1.044, p = 0.002) and soil type (β = 5.782, p = 0.006), but failed to converge and had VIF values higher than 5 for water table and soil type. Since the water table was derived from a map whereas soil type was confirmed by the practitioners, water table was removed from the model. However, this led to soil type not having a significant estimate, and the model failed to converge. So instead, soil type was removed, and water table was added back in. Subsequently, the model was able to converge, and the VIF values were lower than 5. However, water table was not significant anymore, and thus also removed.

Looking at the planting seasons, plants planted in winter (β = 0.102, p = 0.858) and spring (β = 0.965, p = 0.013) had higher survival compared to autumn, with only spring being significantly different (Table 6). Compared to plants that are 10-30 cm in size, plants that were larger than 125cm had a higher survival (β = 1.547 & 1.493, p = 0.046 & 0.022, for plants of 125-150 cm and 150-200 cm respectively) (Table 6).

*Table 6 Estimated regression parameters, standard errors, z-values and p-values for the binomial GLMM resulting from the backward selection of Model D. *'s indicate p-values < 0.05.*

	Estimate	Standard error	z value	p-value
Intercept	1.691	0.662	2.554	0.011*
Planting season: spring	1.238	0.343	3.612	0.000*
Planting season: winter	0.798	0.354	2.252	0.024*
Size: 30-60 cm	0.257	0.356	0.720	0.471
Size: 60-100 cm	-0.059	0.438	-0.133	0.893
Size: 100-125 cm	-0.109	1.276	-0.085	0.932
Size: 125-150 cm	1.547	0.775	1.996	0.046*
Size: 150- 200	1.493	0.648	2.304	0.022*

The largest effect sizes in the two models are found for categories of planting season, with summer having the largest estimate in Model B, and spring and winter having relatively large estimates in Model D, for categories of initial size, with 125-150 cm and 150-200 cm having the largest estimates in Model D. In Model C, a high mulching intensity also results in a high survival estimate (e.g. a mulching intensity of 9 results in an estimate of 2.484).

4. Discussion

Complex agroforestry systems (CAS) are an increasingly popular, low-input, sustainable alternative to conventional food production systems (Albrecht & Wiek, 2021; Daems, 2022; de Groot & Veen, 2017; Wendel et al., 2023), however, their implementation is hampered by a low plant availability, and late and uncertain returns to high initial investments (Thiesmeier & Zander, 2023). Gaining and sharing knowledge on woody production plant survival could help CAS practitioners to make more informed decisions (van Eijk, 2021; Van Eijk & Van Der Stok, 2023), and can contribute to the economic viability and thus competitiveness of complex agroforestry with other, less sustainable food systems (Albrecht & Wiek, 2021; Thiesmeier & Zander, 2023).

This research provides the first insights into woody production plant survival. The cumulative survival probability for all plants was 91% for the first year, ranging from 30 to 100% across species, and declined to 69% in the fifth, ranging from 64 to 97% across all species. I found differences in survival among and across genera. Additionally, I explored which contextual variables (nursery, price, initial size, soil type, water table, planting season, and intensity of mulching, irrigation and protection of trees) most strongly influence survival, and found that the planting season and initial size seem to be the most important factors affecting survival in 2023. In the following paragraphs, the findings of this research are further explored and discussed in light of previous research and field observations, and recommendations for practitioners, and for future research are formulated.

4.1 Survival probability of woody production plants over time

The cumulative survival probability was shown to be around 91% in the first year, flattening off towards 69% after 5 years (Fig 5). This is similar to findings in a literature review on urban tree mortality, which found a median annual survival rate of 93 to 93.4% for the first five years, which would result in survival of ~70% for the first five years (Hilbert et al., 2019). In Serbia, the average first-year survival of trees planted across 90 reforestation sites was 78%, ranging from 68% in afforestation to 85% in assisted natural regeneration sites (Ivetić, 2015). Other reforestation studies also mention lower survival percentages than what was found in this study, ranging from 52 to 88% after 1.5 years in (Preece et al., 2023), and averaging to 82% after 1 year, and 56% after 5 years in (Banin et al., 2023). For mature canopy trees in natural forests, an annual mortality of 1 to 3% is typically described (Hilbert et al., 2019). Estimates of survival in temperate complex agroforestry systems that were found are <60% in ~2 years in a low-management project (Schoutsen et al., 2022), ~70% in the first year in a small project near Breda (Klimaatslim Bos- en Natuurbeheer, 2021), ~90% in the first year in several other projects (Gemeente Lanaken, 2023; Trees for All, 2022), and an overall estimate of 90% for the first year (Agroforestry Vlaanderen, 2021b). In one project that was visited, almost all plants that were planted in 2018 died within a year (personal communication, 2023). These varying survival estimates are primarily based on observations by practitioners from different projects initiated in different years, highlighting the contextual dependency of survival. This study established a 70% cumulative survival probability through systematic monitoring across diverse projects rather than single-project observations, but the practitioner estimates and the variation in survival across projects in this study (Fig 16 and 17 in Appendix 7.5.3) emphasize that survival rates of projects outside this study are also likely to vary due to contextual parameters.

The most notable change in survival probability over time is the drop in cumulative survival probability from year 1 to year 2. The survival probability of the first year was 91% for all plants, with 71% of genera and 71% of species demonstrating a survival of 90% or higher. However, the cumulative survival probability drops to 74% in year 2, with only 21% of genera and 28% of species maintaining a cumulative survival of 90% or higher. Since tree death is not caused by genetically programmed plant death, but by an external agent that the plant is not resistant to (Piovesan & Biondi, 2021), the survival in the first year is considered to have been relatively high due to the contextual parameters being within the tolerances of most of the plants. Because the survival status of preceding years was missing, the year in which observed dead plants died cannot be retrieved from the data. So, regardless of in which year a plant died, in the calculations, it was assumed that plants died in the last year in the field. Consequently, the calculations for years 1 and 2 are mainly based on plants planted in resp. 2022/2023 and 2021/2022, and the change in cumulative survival probability from year 1 towards year 2 informs us on the survival of the 2-year-old plants in both years they were in the field. The cumulative survival probability dropped with over 20% in year 2 for 14 out of 29 species: Pawpaw (*Asimina triloba),* Sweet chestnut and its hybrid with Japanese chestnut (*Castanea sativa* and *sativa x crenata),* Quince (*Cydonia oblonga),* Fig (*Ficus carica),* Japanese walnut (*Juglans ailantifolia),* Mulberry hybrid (*Morus alba x rubra),* Plum (*Prunus domestica)*, Apricot (*Prunus armeniaca),* Nashi pear (*Pyrus pyrifolia),* Black currant (*Ribes nigrum),* Jostaberry (*Ribes nigrum x uva-crispa)*, European elderberry (*Sambucus nigra),* and Chinese mahogany (*Toona sinensis)* (Appendix 7.5.2). Pawpaw, chestnuts, Quince, Japanese walnut, Mulberry hybrid, Apricot and Nashi pear had less than 20 observed 2-year-old plants, so finding conclusive drivers of their survival by examining the collected variable data was not possible. Fig, Plum, Black currant, Jostaberry, European elderberry, and Chinese mahogany are present in higher numbers, and except for Fig, their 2-year-old plants are present in 2 locations. All but one of the 2-year-old Figs died, whilst the 1-year-old Figs had a 78% survival. The 2-year-old Figs were planted in spring, but so were some of the 1-year-old Figs, which had a 79% survival. The projects with 1-year-old Figs and the project with 2-year-old Figs overlap in soil type, water table, previous land use and management practices, so what caused the higher mortality in year 2 remains inconclusive. For Plum, Black currant, European elderberry, and Chinese mahogany, also no clear patterns were found that could explain differences in survival over time. Notably, 2-year-old Jostaberry plants at project F exhibited differences in survival between plants bought from different nurseries (63 vs 90%), which could mean the planting material from one nursery was healthier upon planting or more tolerant to the contextual parameters in the field because the nursery had similar conditions. Overall, the collected variables do not seem to explain the decline in cumulative survival probability from year 1 to year 2. In light of this, I propose a different variable as the explanatory driver of survival: precipitation.

When comparing the weather conditions in the years 2022 and 2023, notable differences in precipitation can be observed, especially during the summer, despite both experiencing a relatively warm and sunny autumn, winter and spring. The average total precipitation from autumn through spring was 511 mm for 2021/2022 and 667 mm for 2022/2023 (Koninklijk Nederlands Meteorologisch Instituut, n.d.). The summer of 2022 was very dry, especially in July and August, with a 7-day heatwave in August. This led to a precipitation deficit of 300 mm at the end of summer, far higher than the typical 100 mm deficit. June 2023 started very dry, but was followed by substantial rainfall in July in August, resulting in a lesser precipitation deficit of 130 mm at the end of summer (Koninklijk Nederlands Meteorologisch Instituut, n.d.). The overall drier conditions, coupled with more frequent dry spells, are likely to have increased plant mortality caused by water deficits (Kijowska-Oberc et al., 2020; N. G. McDowell et al., 2022), especially in more water-demanding, less competitive, and/or shallow-rooting species. Except for chestnuts, all species that declined with over 20%+ in survival probability are known to prefer moist soil (Ecopedia, 2024; Plants for a Future, n.d.). Sweet chestnut, Pawpaw, Apricot, and European Elderberry were found to exhibit higher mortality when growing under drier conditions in previous studies (Beloiu et al., 2022; Conedera et al., 2021; Fathi et al., 1999; Machado, 2023), suggesting these species might indeed have suffered from the dry summer in 2022. Chinese mahogany and White mulberry were among the low-surviving species in an afforestation trial under dry conditions (Chen et al., 2019). While literature on the effect of dry conditions on the other species is lacking, plant characteristics can be found that suggest vulnerabilities to droughts, such as Black currant preferring wet soil (Ecopedia, 2024), Quince having a shallow rooting system (Hussain et al., 2021), and being a slow grower (Ecopedia, 2024), thus taking longer to establish after planting, and Chinese mahogany not tolerating a dry soil (Ecopedia, 2024).

Additionally, the 2-year-old plants of the aforementioned species were mainly present in project F, which showed the lowest survival in year 2, and the largest drop in cumulative survival probability (Fig 16 in Appendix 7.5.3). Project F had less precipitation in 2022 than the other projects with 2-year-old plants (D and E), with 113 mm of precipitation measured at the nearest weather station, compared to 119 (D) and 124 mm (E)(Koninklijk Nederlands Meterologisch Instituut, 2024). Projects D and E started in 2019 from an orchard and arable field respectively, and were observed to have a greater proportion of herbs in the surrounding vegetation, than project F, which started in 2022 from a meadow. The greater proportion of grasses in the surrounding vegetation at project F likely resulted in more water competition (Kiær et al., 2013), creating more drought stress. To conclude, the dry summer of 2022 may have reduced the survival of plants planted in 2021/2022, especially for species that seem vulnerable to droughts during their establishment and plants in the project that likely had the lowest water availability, resulting in the drop in cumulative survival probability in year 2.

4.2 Identifying the highest- and lowest-surviving species

Survival significantly differed among and across genera, emphasizing the importance of monitoring at the species level. However, since plant genera and species were not equally distributed among the projects (e.g. one location had 953 Honeyberry plants, another location had only 9, and 5 locations had none), drawing conclusions from the survival curves should be done with caution. This is increasingly so towards the right side of the curves, which is based on fewer individuals and projects (Table 11), resulting in less accurate survival estimates, as can be seen in the increasing 95%-confidence intervals (Appendix 7.5.2).

For the first year, Purple chokeberry (*Aronia prunifolia),* Common walnut (*Juglans regia),* Honeyberry (*Lonicera caerulea)*, Mulberry hybrid, Plum, European pear (*Pyrus communis),* Worcesterberry (*Ribes divaricatum),* Black currant, Red currant (*Ribes rubrum),* and Tayberry (*Rubus fruticosus x idaeus)* have the highest survival probability (98% or higher) (Fig 8). However, Tayberry and Worcesterberry only occur in 2 projects for year 1, and the calculations for Common walnut and Worcesterberry are based on less than 50 individuals. Though these species had high survival, more observations, in different locations, are necessary to conclude that they are high survivors with certainty. Looking at year 2, of which there is no data for European pear and Tayberry, the cumulative survival probability drops below 90% for Mulberry, Plum, and Black currant (Appendix 7.5.2). As mentioned earlier, these species are expected to have suffered from the dry summer of 2022. Honeyberry, Red currant, Purple chokeberry and Apple have a 97%+ survival probability for year 2, with calculations being based on respectively 21, 104, 245 and 13 individuals present in 2, 2, 2 and 1 projects. Due to these species having a high survival in both the first and second year, these species can be concluded as high-survivors with more certainty. This is in line with the perceptions of the CAS practitioners, who also mentioned these species as high-survivors (Appendix 7.4.1). Especially Purple chokeberry and Red currant stand out, with both species having a cumulative survival probability higher than 97% at year 2, with over 100 plants being observed in at least 2 locations for year 2, thus being concluded to be high-surviving species in the first two years of a complex agroforestry system in a temperate climate based on this research.

As mentioned earlier, plant death happens when the plant cannot tolerate an external factor or disturbance (Piovesan & Biondi, 2021), suggesting the high-surviving Red currant and Purple chokeberry were not often faced with conditions leading to plant death and that these species tolerate circumstances that lower-surviving species might not. Red currant is a common native species in the Netherlands, and Purple chokeberry is considered an invasive species by the Netherlands Food and Consumer Product Safety Authority (van Valkenburg et al., 2022), suggesting both can establish well in the current Dutch climate. Scientific data on the survival of these species is lacking, however, in a study on Black chokeberry (*Aronia melanocarpa),* one of the species that Purple chokeberry is a hybrid of, planted on cut-over peatlands in Canada, Black chokeberry was found to have a 95% survival after the first growing season, which declined to 48% after six growing seasons (Bussiè et al., 2008). Though this study is set in a different context, based on a different (but closely related) species, the difference in survival between the first and later growing seasons does suggest longer monitoring is needed to prove that Purple chokeberry is a high-surviving species in the long term.

In the first year, Peach (*Prunus persica)*, Boysenberry *(Rubus loganobaccus x idaeus),* and Raspberry (*Rubus idaeus)* had the lowest survival probability (54, 37 and 30% respectively) (Fig 8). Boysenberry was only present in 1 project, and for Peach only 26 individuals were observed, so concluding these as low-surviving is considered too soon. Though these species had a low survival, more observations, in different locations, are necessary to conclude that they are low-survivors with certainty. In year 2, 8 other species have a cumulative survival probability lower than 60%: Mulberry hybrid, Fig, Pawpaw, Chinese mahogany, Sweet chestnut, Quince and Japanese walnut. These all saw a 20%+ decline in cumulative survival probability from the first to the second year, and have been discussed in the previous sub-chapter. For Peach, Boysenberry and Raspberry, plants that were in the field for two years were only observed in one location, with 3, 2 and 3 individuals respectively. Survival of these species beyond the first year thus remains uncertain.

The practitioners from the two CAS projects that planted Raspberries in high numbers (380 at project B and 200 at project C) both named Raspberry first when asked which species they perceived to have a high mortality. One of them mentioned that the Raspberries seemed to suffer from competition with grass, or that they might have trouble establishing in clay. One of the projects (B) is on sandy soil, has drip irrigation, mulched some of the rows with cardboard after planting, and the other project (C) is on heavy clay soil, waters less regularly and did not mulch the Raspberries initially. Both projects primarily have grass competition and did not mulch the Raspberries before or directly after planting. Since the Raspberries seemed to suffer from grass competition, project B started mulching with cardboard, but they mentioned that this should have been done before the warmer summer days because the mulched Raspberries now suffered from sun damage. Project C started planting comfrey (*Symphytum spp.)* to suppress the grass. In the field, the Raspberries generally seemed to have sun damage (red pigmentation on the leaves) and water stress (dried-out leaves), whereas other *Rubus* species did not or to a lesser extent. In these same locations, Blackberry (*Rubus fruticosus)*, Tayberry and Japanese wineberry (*Rubus phoenicolasius)*, species from the same genus, had much higher survival, with a survival of 29% for Raspberry, 96% for Blackberry and 99% for Tayberry in project B, and survival of 30% for Raspberry, 100% for Tayberry and 69% for Japanese wineberry in project C. The practitioner of CAS project C indicated that at least one out of two rows of Raspberries, was planted by paid workers who handled and planted the plants with little care, and that she thought the plants in that row must have suffered from it. The handling of planting material, method of planting and planter technique have been found to affect plant establishment and survival in the first few years after planting (Preece et al., 2023; Struve, 2009), so this could indeed have affected survival. Unfortunately, which plants were planted by these paid workers is unclear, so comparing plants that were planted by the workers and by the practitioner or volunteers is not possible. So though the exact reason why Raspberry had a low survival remains unclear, the Raspberries are hypothesized to be negatively impacted by factors limiting their water uptake that related species are impacted by less.

4.3 Drivers of survival

The variables that were shown to be most strongly associated with the survival of woody plant production species are planting season, initial size, mulching intensity, and irrigation intensity (Tables 5 and 6). Survival of plants in summer was found to be significantly lower. Both models showed a higher survival when plants were planted in winter and spring compared to autumn, though not significant in both. Overall, the results do suggest that winter and spring are the best moments to plant, followed by spring.

Survival also seemed to increase with increased initial size, though only plants larger than 125 cm showed significantly higher survival estimates. This corresponds with the perceptions of the practitioners, with 4 out of 5 practitioners mentioning plant size to be a driver of survival. The practitioners mainly highlighted that the small plants, generally delivered in P9 pot size, had a low survival. This was also something that stood out during fieldwork, with especially many Autumn olives (*Elaeagnus umbellata)* being planted in a small size, and those plants seeing a high mortality. McDowell, 2008, and Hilbert, 2019, mention that trees on both ends of the size spectrum are more likely to die. This study did not find larger plants to have a higher mortality, but I hypothesize that this is because practitioners tend to irrigate and mulch trees more frequently than berry bushes that are of a smaller size, and because practitioners might plant bigger planting material with more care since bigger planting material is generally more expensive.

Mulching and irrigation were both found to influence survival (Model C). Though a positive effect of mulching was expected (Adams, 1997; Granatstein & Sanchez, 2009; Hytönen et al., 2005), the negative effect of irrigation came as a surprise. Looking into the scores given by the practitioners, irrigation and mulching intensity seem to be somewhat positively correlated. Filling in the mulching and irrigation scores with the estimates resulting from the model, results in estimates varying between 0.152 and 1.74, with the lowest score for the project with the lowest management intensity and the highest score for the project with the highest management intensity. Combined, mulching and irrigation thus seem to have a positive impact on survival.

4.4 Recommendations for CAS practitioners

This study showed that species differ in survival, emphasizing the importance of selecting species as a way to positively affect the survival of the system as a whole. CAS practitioners are advised to start with plants that are likely to survive, and invest in plants with a lower survival probability when the first returns of investment are coming in, or conditions might be more suitable for these plants. Especially Purple chokeberry and Red currant are recommended species when practitioners want to keep mortality low in the initial years. Other species that seem to have a high survival are Honeyberry and Apple, though their 2-year survival is less substantiated. Survival of Raspberry in the first year is expected to be low based on this study, whereas Tayberry, Blackberry and Japanese wineberry are expected to do better. For a wish to plant *Rubus* species, the latter are thus recommended. Overall, it is important to select species that are likely to tolerate the conditions specific to the CAS site.

Practitioners are advised to avoid buying and planting plants that are small (<30 cm), which generally come in P9 pots. Additionally, planting in winter or spring is expected to be beneficial.

Mulching and irrigation are expected to increase plant survival. Especially in dry years such as the summer of 2022, management practices that enhance water availability are recommended. When time is a limiting factor for practitioners, I advise focusing on irrigating during dry spells, and mulching drought-sensitive plants to reduce grass competition and increase the water-holding capacity of the soil.

4.5 Recommendations for future research

Continuing this research presents a valuable opportunity to get a more accurate understanding of the survival of woody production plants in CAS. First of all, continuation will correct for inaccuracies encountered in this study. The survival curves in this research were based on a singular observation moment rather than annual observations, and the absence of survival data from preceding years can result in very different results, especially for earlier years. If many plants died in an earlier year, the resulting survival curves will overestimate the survival of earlier years, and possibly underestimate the survival of later years. For example, the cumulative survival probabilities of Pawpaw for years 1 and 2 were estimated to be 0.92 and 0.24 respectively. If half of the 2-year-old plants died in the first year, the survival probabilities would be 0.82 and 0.29. Additionally, the potential oversight of plants that died in earlier years that now go undocumented also suggests an overestimation of the survival in earlier years, though they would lead to an underestimation of the survival probability in this research if documented. On the other hand, plants that were seemingly dead during the monitoring could have had living roots, which could have reduced the estimated survival. Subsequent monitoring can correct for inaccuracies such as overseeing dead plants and noting alive plants down as dead, and overestimation of survival due to missing data from previous years, thus strengthening the accuracy of the survival curves.

In addition to strengthening the survival curves, introducing plants from the current and coming planting seasons, and monitoring their survival in addition to the already-monitored plants will introduce greater variability in climate variables. While the exact impact of the dry summer of 2022 on plant mortality in this study remains uncertain, it is expected that a large portion of the observed mortality among two-year-old plants occurred in 2022. Unfortunately, statistical analysis on the effect of the dry summer of 2022 was not within the scope of this study, but the continuation of this research combined with the collection of climate data will provide the opportunity to test the influence of climate variables on survival.

Furthermore, continuation will broaden the variability in landscape parameters and management practices for the years beyond the first. Currently, the survival calculations beyond the first year are primarily derived from 3 projects, with data for years 3-5 based on only 2 out of the 7 projects. Continuing the monitoring of survival in the locations of this research will expand the survival data for the second year to encompass 7 projects instead of 3, and 4 projects for the third year instead of 1. This can be further enhanced by adding projects that overlap in characteristics with those in this research, but that have different combinations of those characteristics. This will result in a broader data set that provides a more comprehensive foundation for statistical analysis. Overall, the larger variability in variables will make for a more accurate depiction of survival trends in complex agroforestry systems.

To be able to test which plant characteristics affect survival more accurately, plant data must be documented properly as soon as possible. The longer it has been since planting, the less likely it seemed to get accurate information on the number of plants in a row, on cultivar names, and on initial plant characteristics (nursery, price and size). Additionally, for most locations, not all plants could be found back in the order lists, because

1) certain species or cultivars were bought from different nurseries and it is unclear which were bought from which nursery,
2) certain species or cultivars were delivered in different sizes with different prices, and it is unclear which sizes were planted where,
3) certain species or cultivars were planted at different moments and it is unclear which were planted when,
4) certain species or cultivars were not delivered and a replacement species or cultivar was sent of which the size and price are not mentioned on the order list, or
5) plants were gifts.

Due to these uncertainties, not all initial plant characteristics could be traced down, resulting in over half of the selected plants being excluded from statistical analysis (Model D, Table 3). Due to the missing data on cultivars, and especially rootstocks, gaining insights into the survival of varying cultivars within the same species was minimized (with only a difference in Autumn olive), and gaining insights into the survival of rootstocks was impossible. Because order lists use different measures of size (pot size, size range, or no information on size is given), it is advised to write down the approximate initial size per row and species right after planting, The size categories used in this study are recommended since these are frequently used on order lists. To prevent the loss of data in the coming years, participating CAS practitioners are strongly recommended to document 1) the planting dates of species, plant batches and/or regions in their CAS system, 2) the location (e.g. row number or region), and nursery and/or size of species or cultivars that came from different nurseries and/or in different sizes, and 3) the location, nursery, price and size of plants that were sent as a replacement. To ensure that this will happen, participating projects could be requested to document this in advance, but since most practitioners have indicated to have a busy schedule this might result in fewer projects being willing to participate.

Besides plant characteristics, documentation of management practices can be improved. First of all, the documentation of mulching should be done at the plant level. Most projects that mulched, did not mulch all plants, but due to mulching intensity being included in the model at the project level, this could not be taken into account in the data analysis. I hypothesize that larger, possibly more expensive plants are more likely to be mulched, thus enhancing their survival. Monitoring mulching at the plant level can reveal whether this is true, as well as whether some groups of plants could benefit more from mulching. Secondly, I propose adding the way of planting as a management practice that should be monitored and included in the analyses. Additionally, management practices are recommended to be monitored per year, so that possible changes in management practices over time can also be incorporated into the analyses on drivers of survival.

The dataset created during research could also be used to analyse variable effects on specific genera or species, rather than on all plants combined. Some variables could vary in their effects among species, such as soil type, water table and previous land use, which affect water and nutrient availability. Plants that have superficial roots and that grow slowly might have a relatively lower survival with more grass competition, which is common in plots that used to be meadows, and with less water availability, which is affected by soil type and water table. These plants might also benefit more from mulching and irrigation, especially in dry years. A large set of variables could thus have a larger effect on less competitive plants, and by combining all species, these effects might be cancelled out by more competitive plants. In addition to this, some species were shown to have lower survival, and further investigating which variables affect them and in what way could provide insight into how we can increase their survival. It is thus recommended to investigate variable effects on the survival of low-surviving genera and species, to gain knowledge of what circumstances could increase their survival.

To summarise, monitoring over a longer period, including more climate, landscape and management variability, can further strengthen the dataset so that eventually it can be used to get an estimate of the survival of woody production species in specific circumstances, which can help CAS practitioners make more informed choices. CAS practitioners are recommended to document plant location, initial plant properties, cultivars and planting moments more precisely, because this facilitates future data collection, and makes statistical analysis easier and more accurate. Analysing variable effects for low-surviving genera and species provides an opportunity to gain insight into which management practices might be beneficial for the survival of these genera and species.

5. Conclusion

This research pioneers in exploring the survival of woody production species in complex agroforestry systems in a temperate climate, so that CAS practitioners can make better-informed decisions in the design and implementation of CAS, thus contributing to the professionalisation of complex agroforestry. Though further monitoring will provide more accurate results, this singular monitoring moment has already provided many interesting insights. The survival curves of the selected genera and species showed differences between and among genera, with survival probabilities for the first year ranging from 30 to 100% across species, highlighting the importance of species selection and monitoring at the species level. The dry summer of 2022 is considered to have negatively affected survival, thus contributing to the drop in cumulative survival probability from 91% in year 1 to 74% in year 2. Species that stand out are Purple chokeberry (*Aronia prunifolia)* and Red currant (*Ribes rubrum),* which have a 97% probability of surviving the first 2 years, and Raspberry (*Rubus idaeus),* which has a 30% probability of surviving the first year after planting.

In the start-up phase, CAS practitioners are recommended to 1) select high-surviving species or species expected to tolerate the conditions specific to their site, 2) avoid planting plants smaller than 30 cm, 3) plant in winter or spring, 4) irrigate during dry spells, and 5) mulch drought-sensitive plants.

Monitoring over a longer period, and including more climate, landscape and management variability through the addition of more CAS projects will strengthen the survival analyses and will allow for further exploration of the drivers of survival. Documenting plant location, initial plant properties, cultivars, rootstocks, and planting moments more precisely can facilitate future data collection. Adding the way of planting as a management practice, collecting data on mulching intensity at the plant level, and collecting management practices per year are recommended to gain more insight into how practitioners can enhance plant survival. For CAS practitioners to be able to get a more accurate estimation of the survival of woody production plants in their complex agroforestry system, the continuation and further development of this research is highly recommended.

6. Literature

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7. Appendix

7.1 Start of a monitoring programme

To make complex agroforestry systems more economically viable and thus a more attractive alternative to conventional food production systems, gaining insight into what species, cultivars and rootstocks have a high likelihood to survive and perform well under what circumstances can play an important role (Jose et al., 2004; Thiesmeier & Zander, 2023). Currently, Stichting ReGeneratie and Stichting Voedselbosbouw Nederland are creating an open plant database that will allow designers of CAS to make more informed choices. Since scientific data to fill in the open plant database is lacking, there is a need for a long-term monitoring plan that will follow individual plants from varying species, cultivars and rootstocks (Van Eijk & Van Der Stok, 2023). In this research, a start for the creation of a geo-referenced monitoring programme was made.

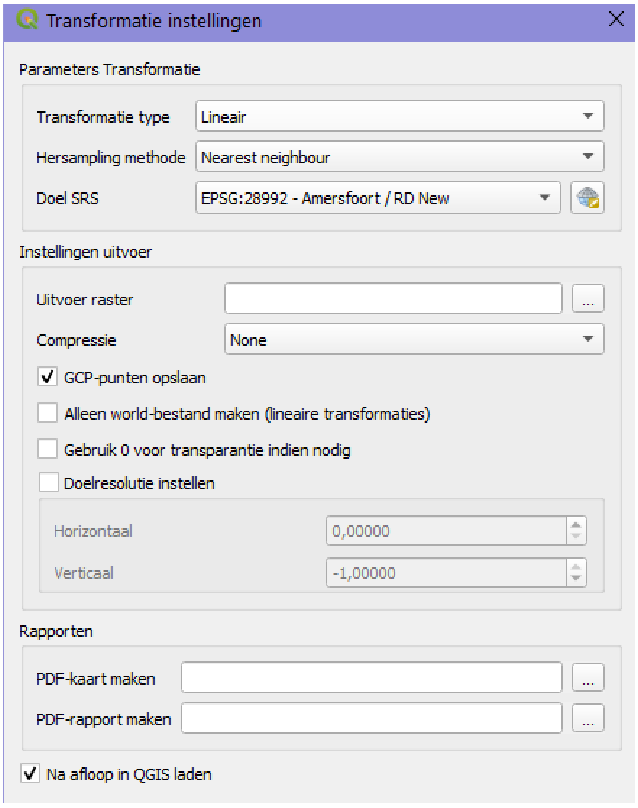
7.2 CAS projects

Table 7 Overview of the selected CAS projects showing their size, age, and landscape variables and showing whether the order lists and thus the initial plant characteristics were available.

Project	Province	Size (ha)	Age (#growing seasons)	Soil type	Grondwatertrap	Previous land use	Order lists available
A	FL	30	6	Clay	VIIo	Arable field	4
B	GD	3,5	1	Sand	IVc	Meadow	9
C	UT	4,4	3	Clay	Ib	Meadow	3
D	GD	1	5	Sand	VIIo	Orchard	7
E	NB	4	5	Sand	Ib	Arable field	1
F	NB	6,3	2	Sand	IVc	Meadow	5
G	LB	5	1	Loam	VIIId	Meadow	3

7.3 Georeferencing the data

The CAS designs were loaded in QGIS (in PDF or JPEG format) and calibrated to aerial pictures or cadastral maps that were obtained through the PDOK plug-in (Duivenvoorde, 2023) using the 'Geo-referencer' function. The coordinate reference system (CRS) that is used in QGIS is Amersfoort RD New. At least 5 ground control points (GCPs) were selected to ensure that the transformation is accurate. The transformation settings can be found in Fig 14. After the CAS maps were transformed, a visual check was done to make sure the CAS map fit the aerial picture. If there seemed to be too much deviation, more GCPs were added until the resulting georeferenced map seemed fitting.



Transformatie instellingen

Parameters Transformatie

Transformatie type: Lineair
Hersampling methode: Nearest neighbour
Doel SRS: EPSG:28992 - Amersfoort / RD New

Instellingen uitvoer

Uitvoer raster:
Compressie: None
☑ GCP-punten opslaan
☐ Alleen world-bestand maken (lineaire transformaties)
☐ Gebruik 0 voor transparantie indien nodig
☐ Doelresolutie instellen
Horizontaal: 0,00000
Verticaal: -1,00000

Rapporten

PDF-kaart maken:
PDF-rapport maken:

☑ Na afloop in QGIS laden

Figure 14 Transformation settings used in QGIS for calibrating the CAS maps to the Amersfoort RD New CRS.

The locations of the plants were added in QGIS by adding point data and assigning plant IDs to the points that represent individual plants. For designs with rows, instead of adding each plant separately, the rows were added first as line data. Sometimes these rows were visible in the aerial pictures, in which case the row data was fitted onto the aerial picture rather than the transformed map. Each row was given data on the distance between plants so that the 'add points to row' function could be used. The resulting points were then added to a geopackage with point data and assigned unique plant IDs. The plant IDs are necessary to be able to denote which plant is which.

7.4 Interview planten overleving

Deze vragenlijst focust zich op de overleving van houtige productiesoorten in complexe agroforestry systemen in de eerste 5 jaar na aanplanten. Systeemplanten en meerjarige kruidige planten worden dus niet meegenomen. Antwoord op basis van uw eigen ervaringen in het complexe agroforestry systeem waar u bij betrokken bent.

1. Welke soorten of groepen soorten hebben een hoge overleving?
2. Welke soorten of groepen soorten hebben een hoge sterfte?
3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen,)
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?

7.4.1 Interview results

Project B

1. Welke soorten of groepen soorten hebben een hoge overleving?
   a. Ribessen, appels, peren, honingbessen. Van het kleine wortelgoed: ribessen. Moerbeien overleven wel maar zien er iets minder goed uit.
2. Welke soorten of groepen soorten hebben een hoge sterfte?
   a. Frambozen en olijfwilg.
3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
   a. Braam
   b. Krent
   c. Aalbes
   d. Honingbes
   e. Olijfwilg
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen)
   a. In vak D is er veel vraat, vooral aan de kornoeljes en krenten, door hazen en reeën. Over het hele veld is er wel schade van hazen, vooral aan de kornoelje en pruim. In vak A is het vrij nat, en in vak B en C is het soms erg droog.
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)
   a. Boombeschermers zijn essentieel, vooral de eerste 3 maanden. Ook mulchen, maar dat moet wel vóór de droogte gedaan zijn. Verder is irrigatie essentieel.
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)

   a. De staat van de plant bij aankoop. Door het gebruiken van worteldoek is de hoogte hier minder van invloed.
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
   a. De pawpaws hebben baat bij de tipi's (bescherming tegen zonne schade en uitdroging)
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
   a. In vak C lijkt er meer uitval te zijn, het vak waar eerst een gemeente depot was waardoor er hoogteverschil is. Op sommige delen is er erg hoog gras wat lijdt tot verstikking. Op andere delen is de bodem erg verdicht en is er dus minder gras, maar hier lijken planten last te hebben van zonneschade. Dit vak lijkt vrij droog.
9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?

Project C

1. Welke soorten of groepen soorten hebben een hoge overleving?
   a. Honingbes, rozen, kruisbes, appelbes, ribessen en taybes lijken het goed te doen. Ook de noten, die waren al iets groter. Vooral walnoten doen het goed.
2. Welke soorten of groepen soorten hebben een hoge sterfte?
   a. Frambozen vallen erg tegen. Die lijken last te hebben van concurrentie met het gras, of het lastig te hebben op klei. Amandel, perzik, kweepeer en moerbei (vooral de kleine planten) doen het ook minder goed. Boysenbes en loganbes doen het een stuk minder goed dan taybes. Verder valt de japanse wijnbes ook een beetje tegen. Kweepeer, noten en mispel hadden last van de late nachtvorst.
3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
   a. Taybes,
   b. Appelbes
   c. Aalbes en honingbes
   d. Framboos
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen)
   a. Vraatschade en schuur schade van reeën, muizen, de zware klei die kan gaan scheuren bij droogte, de wind (die er veel is) die zorgt voor verdamping. Verder is de bodem nog erg compact. Er is ook veel gras competitie, maar het gras zorgt ook voor beschutting.
   b. De omgevingseigenschappen hebben meer invloed dan de beheersmaatregelen en initiële plant eigenschappen.
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)
   a. Boombeschermers (vooral tegen het schuren) en het planten van smeerwortel
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)
   a. Het hebben van een goede wortelkluit om concurrentie tegen te gaan en door de klei heen te komen. Kleine planten (P9 potjes) doen het slecht.
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
   a. Niet echt ervaren

9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?
    a. Het kan erg verschillen hoe het er bovengronds uitziet over tijd, het kan lijken alsof iets dood is, maar dat het dan onder de grond nog leeft.

Project D

1. Welke soorten of groepen soorten hebben een hoge overleving?
    a. Meeste productiesoorten hebben redelijk hoge overleving.
    b. Van systeemplanten lijsterbes, zware els en linde opvallend hoog.
2. Welke soorten of groepen soorten hebben een hoge sterfte?
    a. kruidachtigen en lage planten laag, bv cranberries bijna allemaal dood. Moerbeien en olijfwilgen redelijk laag. Hoop systeemplanten in de eerste paar jaar ook laag ivm droge lentes (bv vlieren, duindoorn, wilg)
3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
    a. Blauwe bes
    b. Rode bes
    c. Zwarte bes
    d. Honingbes
    e. Framboos
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen,)
    a. Droogte lente en zomer icm competitie gras
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)
    a. Irrigeren en mulchen
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)
    a. Allen van invloed, grootte en prijs het meest denk
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
    a. Blauwe bessen bij mulchen
    b. Moerbei bij irrigatie, mulchen en boombeschermers
    c. Prunus bij boombeschermers
    d. Pawpaw bij irrigatie
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
    a. Niet per se
9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?

Project F

1. Welke soorten of groepen soorten hebben een hoge overleving?
    a. Het meeste doet het eigenlijk wel goed.
2. Welke soorten of groepen soorten hebben een hoge sterfte?
    a. Vijgen

3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
    a. Alle ribes soorten en honingbes. Tussen de ribessen zit weinig verschil in overleving, misschien wel in de grootte.
    b. Appel (bijna niks dood)
    c. Pruim (~10% dood)
    d. Pawpaw enten (15-20% dood).
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen)
    a. Op vochtigere plekken lijkt de overleving hoger.
    b. Er is wel veegschade, maar daar gaan de planten niet aan dood
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)
    a. Mulchen (hoe groter de plant, hoe meer mulch lijkt goed te werken)
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)
    a. Grootte is by far het belangrijkst: groter slaat beter aan, heeft minder last van vraat en veegschade. Verder doen zaailingen het beter dan enten. En overleven planten uit kleinere potjes minder.
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
    a. Ja, geen idee waarom
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
    a. Nee niet echt.
9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?
    a. Mijn verwachtingen van hoe planten het gaan doen zijn slecht. Veel dingen gaan tegen mijn intuïtie in.

Project G

1. Welke soorten of groepen soorten hebben een hoge overleving?
    a. Bessen, vooral de ribessen
2. Welke soorten of groepen soorten hebben een hoge sterfte?
    a. Wat duindoorns, misschien de zwarte moerbei, mahonia (slecht opgekuild) en gele kornoelje
3. Wat zijn de 5 meest voorkomende soorten in het systeem waar u bij betrokken bent? Zet ze in volgorde van grootste kans om te overleven naar kleinste kans om te overleven.
    a. Josta & zwarte bes
    b. Rode bes
    c. Kruisbes
    d. Shipova’s
    e. Hazelaars
    f. Zwarte moerbei
    g. Duindoorn
4. Welke omgevingseigenschappen lijken het meest van invloed te zijn op de overleving? (Bodem textuur, zomer droogte, wind, begrazing door hazen)
    a. Droogte periode in combinatie met de wind. Er zijn ook grintkoppen in de bodem, op die plekken is de overleving van alles lager.
5. Welke beheersmaatregelen lijken het meest van invloed te zijn op de overleving? (Denk aan mulchen, irrigeren, maaien, manier en moment van planten, wieden, boombeschermers plaatsen)

    a. Water geven
6. Welke initiële plant eigenschappen lijken het meest van invloed te zijn op de overleving? (Grootte, prijs, kweker, soort, cultivar, onderstam)
    a. Als eerst de grootte: groter dan iets minder beheer nodig, als het te groot is dan is het verplaatsen en aanplanten een te grote klap, planten uit P9 potjes zijn moeilijker om te laten aanslaan.
    b. Als tweede zijn de soorten: sommige planten doen het minder goed of groeien trager, bijvoorbeeld gele kornoelje
    c. Als derde de kweker: sommige planten doen het beter bij bepaalde kwekers, het wisselt per plant soort
7. Zijn er soorten of groepen soorten die meer baat lijken te hebben bij specifieke beheersmaatregelen?
    a. Geënte planten hebben meer baat bij boombeschermers, door vraat en veegschade kan de onderstam gaan uitlopen.
8. Zijn er bepaalde delen in het systeem waar meer uitval lijkt te zijn? Zo ja, waar denkt u dat dit door komt?
    a. Ja, bij de grintkoppen. Hier zit veel steen in de bodem.
9. Zijn u nog dingen opgevallen die hierboven niet aan bod zijn gekomen?
    a. Productiesoorten in het 1^e jaar aanplanten is vrij vroeg, die hebben dan wel echt irrigatie nodig. In het 2^e jaar aanplanten is al beter. In het 1^e jaar is het handiger vooral pioniers te planten.

7.5 Additional survival analysis results

Table 8 Survival curve fit summary for all plants from the selected genera

Time since planting	Total number of individuals	Number of event times	Survival probability	Standard error	Lower 95% CI	Upper 95% CI
1	11874	1115	0.906	0.00268	0.901	0.911
2	990	179	0.742	0.01130	0.720	0.765
3	279	3	0.734	0.01209	0.711	0.758
4	72	2	0.714	0.01844	0.679	0.751
5	37	1	0.695	0.02616	0.645	0.748

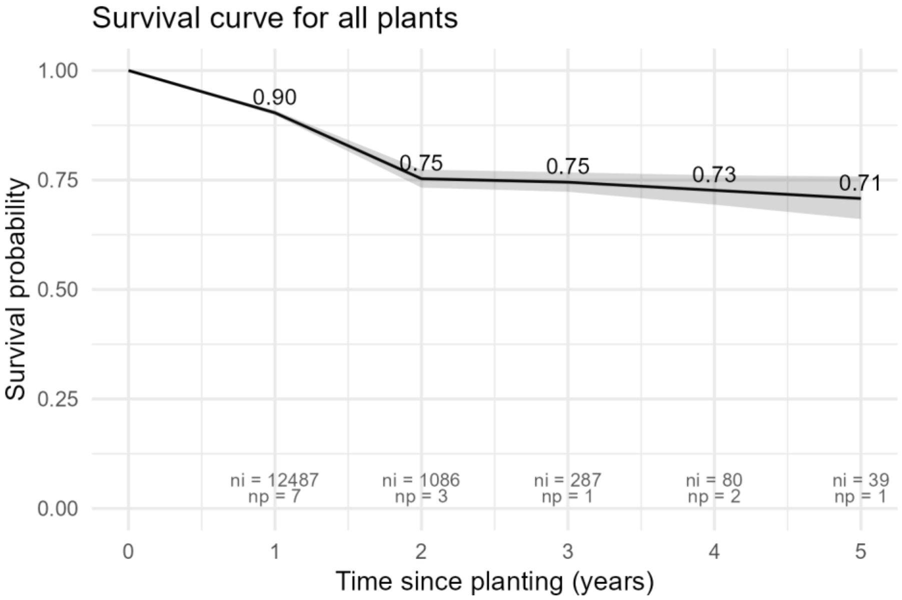


Figure 15 Kaplan-Meier survival curve for all plants with the 95% confidence interval. ni = number of individual plants on which the calculations are based for that time stamp. np = number of projects in which those individuals can be found.

Table 9 Survival curve fit summary for all plants.

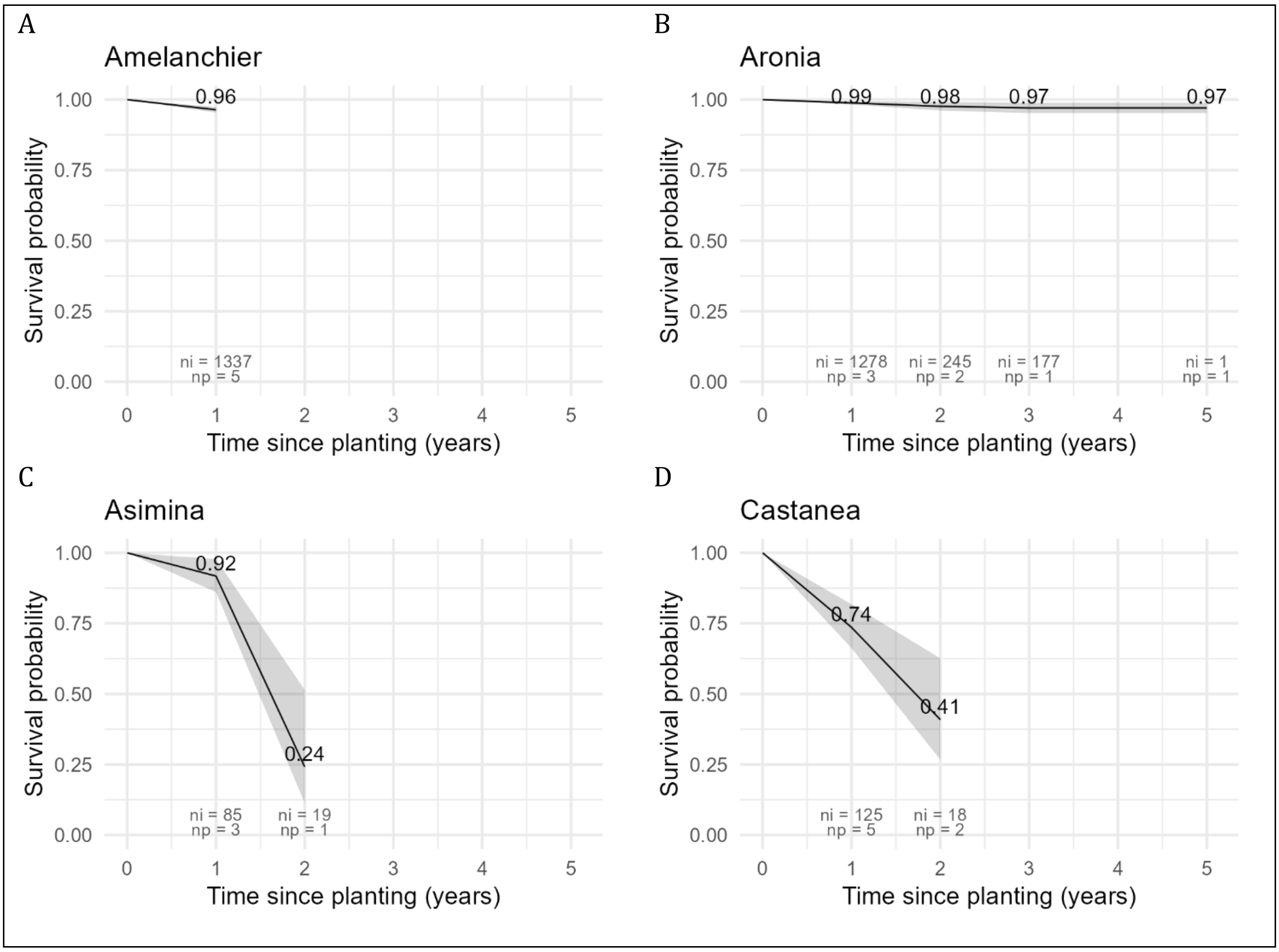
Time since planting	Total number of individuals	Number of event times	Survival probability	Standard error	Lower 95% CI	Upper 95% CI
1	12487	1205	0.903	0.00264	0.898	0.909
2	1086	181	0.753	0.01045	0.733	0.774
3	287	3	0.745	0.01129	0.723	0.768
4	80	2	0.726	0.01704	0.694	0.761
5	39	1	0.707	0.02477	0.661	0.758

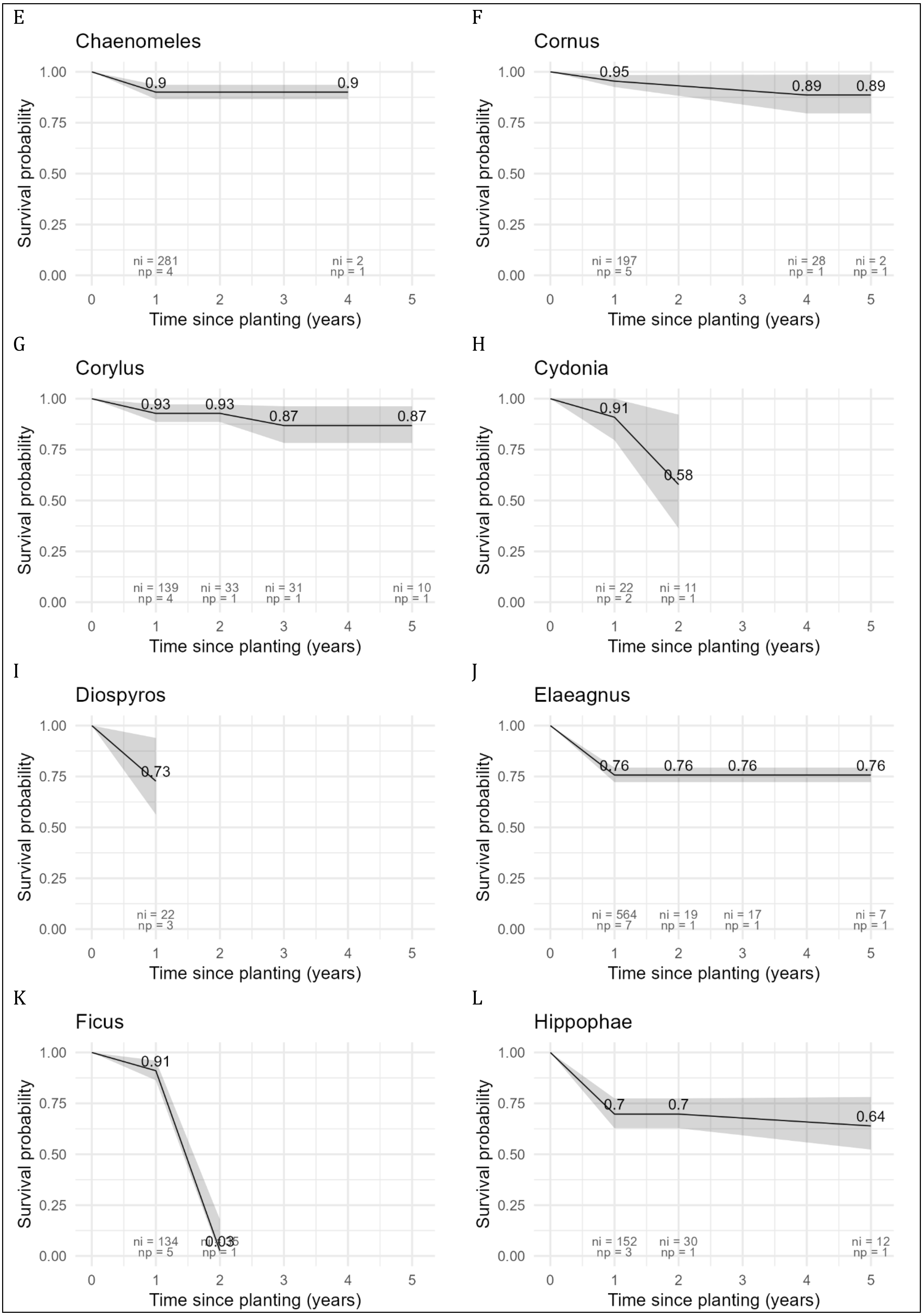
7.5.1 Survival per genus

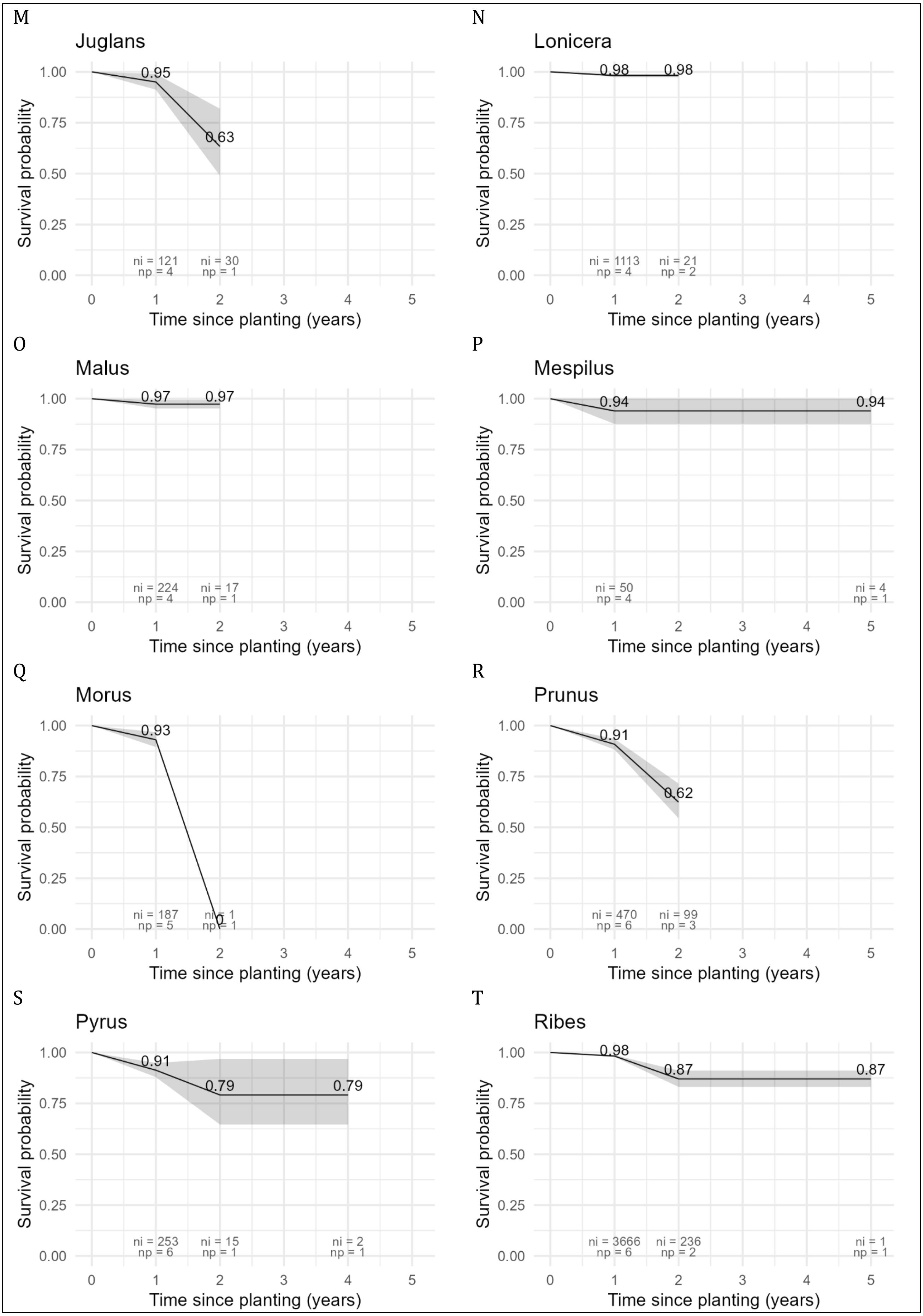
Table 10 Overview of the survival probability of the selected genera per year. Only the years for which data was collected are included. The standard error, number of plants and number of projects are also shown.

Genus	Years since planting	Cumulative survival probability	Standard Error	Number of individuals	Number of projects
Amelanchier	1	0,96	0,0051	1337	5
Aronia	1	0,99	0,0030	1278	3
	2	0,98	0,0076	245	2
	3	0,97	0,0093	177	1
	5	0,97	0,0093	1	1
Asimina	1	0,92	0,0298	85	3
	2	0,24	0,0930	19	1
Castanea	1	0,74	0,0394	125	5
	2	0,41	0,0889	18	2
Chaenomeles	1	0,90	0,0179	281	4
	4	0,90	0,0179	2	1
Cornus	1	0,95	0,0149	197	5
	4	0,89	0,0485	28	1
	5	0,89	0,0485	2	1
Corylus	1	0,93	0,0219	139	4
	2	0,93	0,0219	33	1
	3	0,87	0,0458	31	1
	5	0,87	0,0458	10	1
Cydonia	1	0,91	0,0613	22	2
	2	0,58	0,1375	11	1
Diospyros	1	0,73	0,0950	22	3
Elaeagnus	1	0,76	0,0181	564	7
	2	0,76	0,0181	19	1
	3	0,76	0,0181	17	1
	5	0,76	0,0181	7	1
Ficus	1	0,91	0,0247	134	5
	2	0,03	0,0256	35	1
Hippophae	1	0,70	0,0373	152	33
	2	0,70	0,0373	30	1
	5	0,64	0,0653	12	1
Juglans	1	0,95	0,0197	121	4
	2	0,63	0,0828	30	1
Lonicera	1	0,98	0,0040	1113	4
	2	0,98	0,0040	21	2
Malus	1	0,97	0,0108	224	4
	2	0,97	0,0108	17	1
Mespilus	1	0,94	0,0336	50	4
	5	0,94	0,0336	4	1
Morus	1	0,93	0,0186	187	5
	2	0,00	*NA*	1	1

Prunus	1	0,91	0,0133	470	6
	2	0,62	0,0433	99	3
Pyrus	1	0,91	0,0177	253	6
	2	0,79	0,0816	15	1
	4	0,79	0,0816	2	1
Ribes	1	0,98	0,0022	3666	6
	2	0,87	0,0204	236	2
	5	0,87	0,0204	1	1
Rubus	1	0,53	0,0152	1082	3
	2	0,48	0,0341	23	2
Sambucus	1	0,96	0,0156	154	5
	2	0,67	0,0600	56	3
	4	0,67	0,0600	5	1
Toona	1	0,68	0,0354	174	5
	2	0,29	0,0519	46	3
Zanthoxylum	1	0,68	0,0702	44	4
	2	0,68	0,0702	2	1




E
Chaenomeles
Survival probability
1.00
0.75
0.50
0.25
0.00
0.9
0.9
ni = 281
np = 4
ni = 2
np = 1
0
1
2
3
4
5
Time since planting (years)
F
Cornus
Survival probability
1.00
0.75
0.50
0.25
0.00
0.95
0.89
0.89
ni = 197
np = 5
ni = 28
np = 1
ni = 2
np = 1
0
1
2
3
4
5
Time since planting (years)
G
Corylus
Survival probability
1.00
0.75
0.50
0.25
0.00
0.93
0.93
0.87
0.87
ni = 139
np = 4
ni = 33
np = 1
ni = 31
np = 1
ni = 10
np = 1
0
1
2
3
4
5
Time since planting (years)
H
Cydonia
Survival probability
1.00
0.75
0.50
0.25
0.00
0.91
0.58
ni = 22
np = 2
ni = 11
np = 1
0
1
2
3
4
5
Time since planting (years)
I
Diospyros
Survival probability
1.00
0.75
0.50
0.25
0.00
0.73
ni = 22
np = 3
0
1
2
3
4
5
Time since planting (years)
J
Elaeagnus
Survival probability
1.00
0.75
0.50
0.25
0.00
0.76
0.76
0.76
0.76
ni = 564
np = 7
ni = 19
np = 1
ni = 17
np = 1
ni = 7
np = 1
0
1
2
3
4
5
Time since planting (years)
K
Ficus
Survival probability
1.00
0.75
0.50
0.25
0.00
0.91
0.03
ni = 134
np = 5
ni = 35
np = 1
0
1
2
3
4
5
Time since planting (years)
L
Hippophae
Survival probability
1.00
0.75
0.50
0.25
0.00
0.7
0.7
0.64
ni = 152
np = 3
ni = 30
np = 1
ni = 12
np = 1
0
1
2
3
4
5
Time since planting (years)


M
Juglans
0.95
0.63
ni = 121
np = 4
ni = 30
np = 1
N
Lonicera
0.98
0.98
ni = 1113
np = 4
ni = 21
np = 2
O
Malus
0.97
0.97
ni = 224
np = 4
ni = 17
np = 1
P
Mespilus
0.94
0.94
ni = 50
np = 4
ni = 4
np = 1
Q
Morus
0.93
0
ni = 187
np = 5
ni = 1
np = 1
R
Prunus
0.91
0.62
ni = 470
np = 6
ni = 99
np = 3
S
Pyrus
0.91
0.79
0.79
ni = 253
np = 6
ni = 15
np = 1
ni = 2
np = 1
T
Ribes
0.98
0.87
0.87
ni = 3666
np = 6
ni = 236
np = 2
ni = 1
np = 1
Survival probability
1.00
0.75
0.50
0.25
0.00
Time since planting (years)
0
1
2
3
4
5

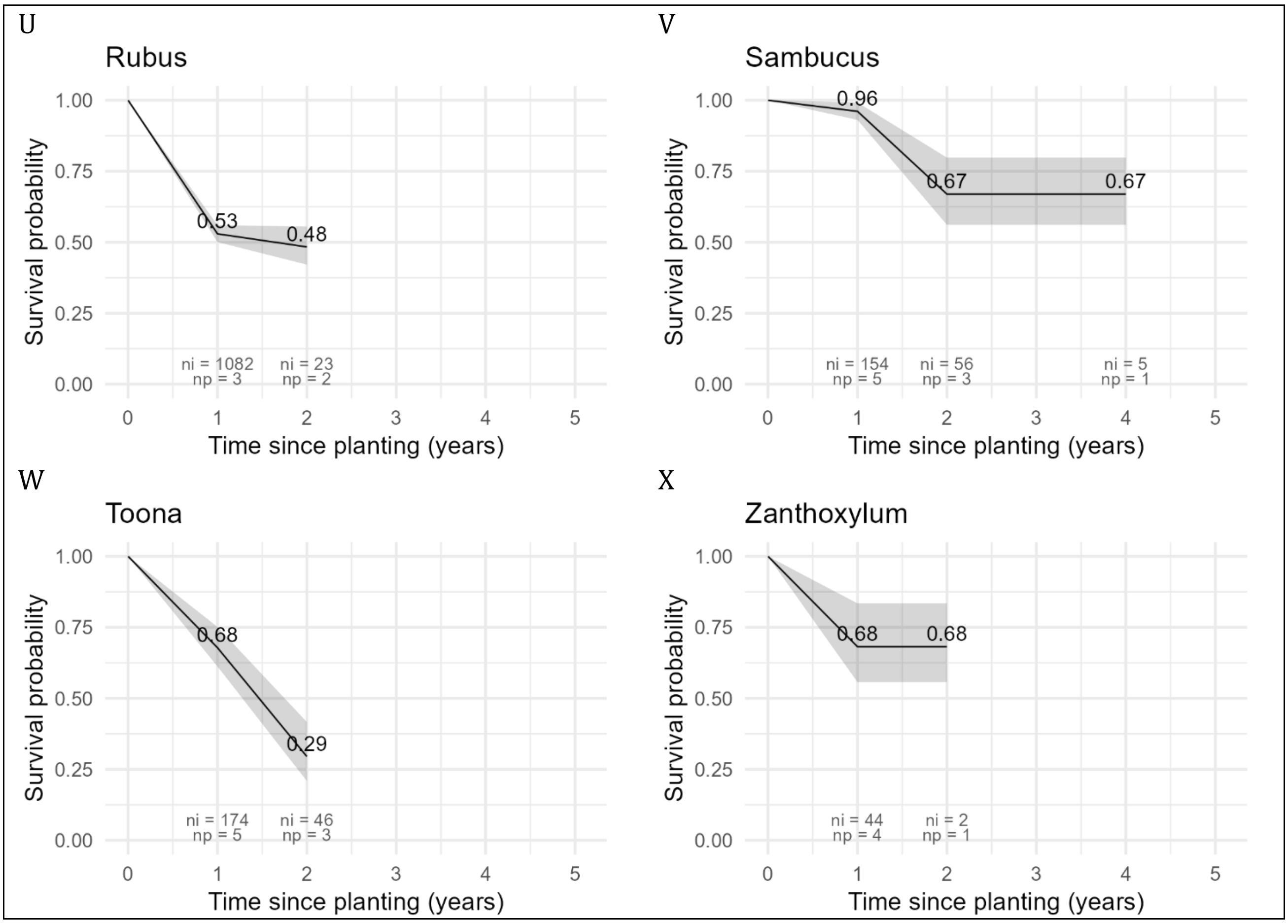


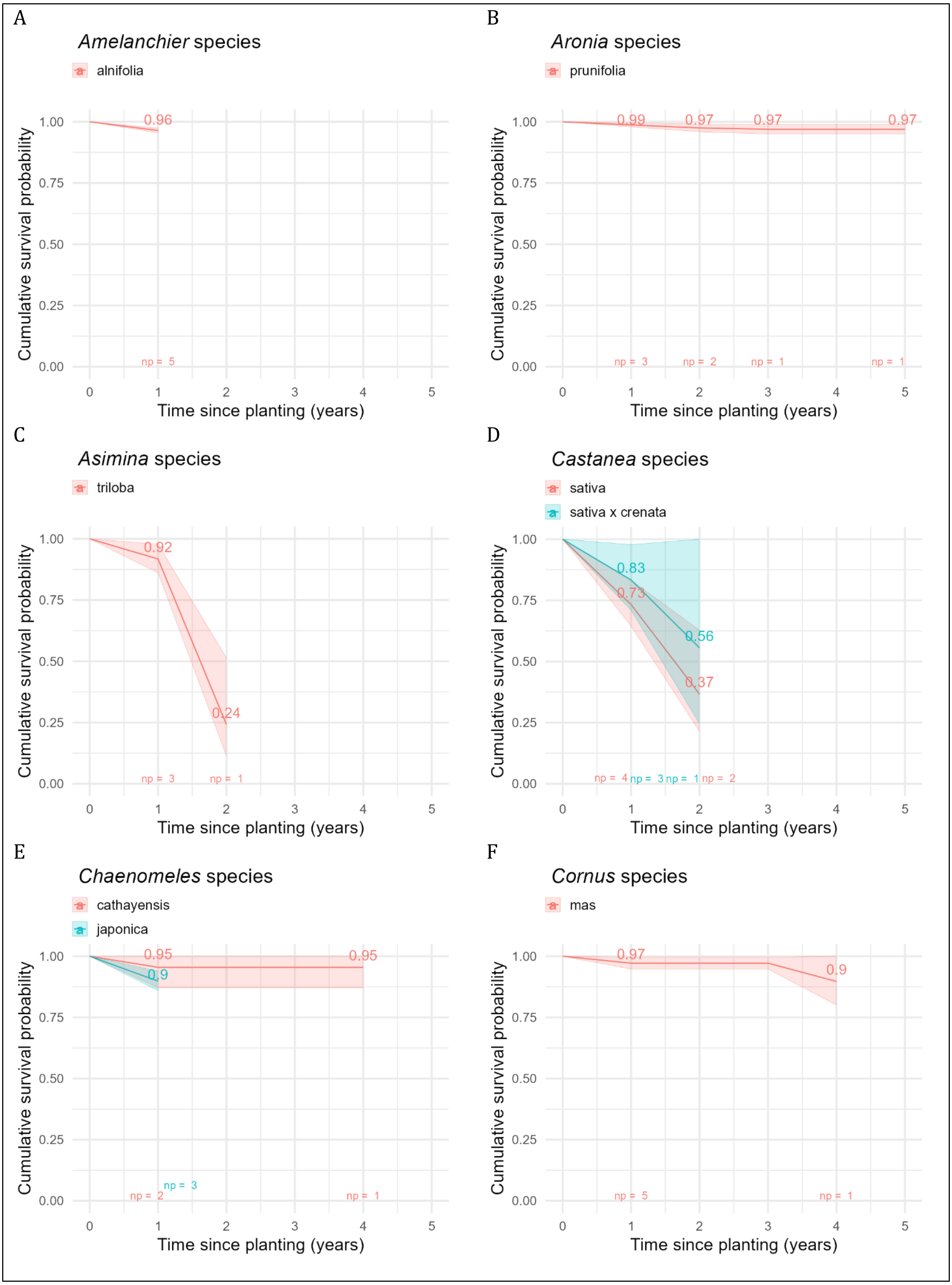
Figure 16 Kaplan-Meier survival curves with their 95% confidence intervals of all selected genera. ni = number of individual plants on which the calculations are based for that time stamp. np = number of projects in which those individuals can be found.

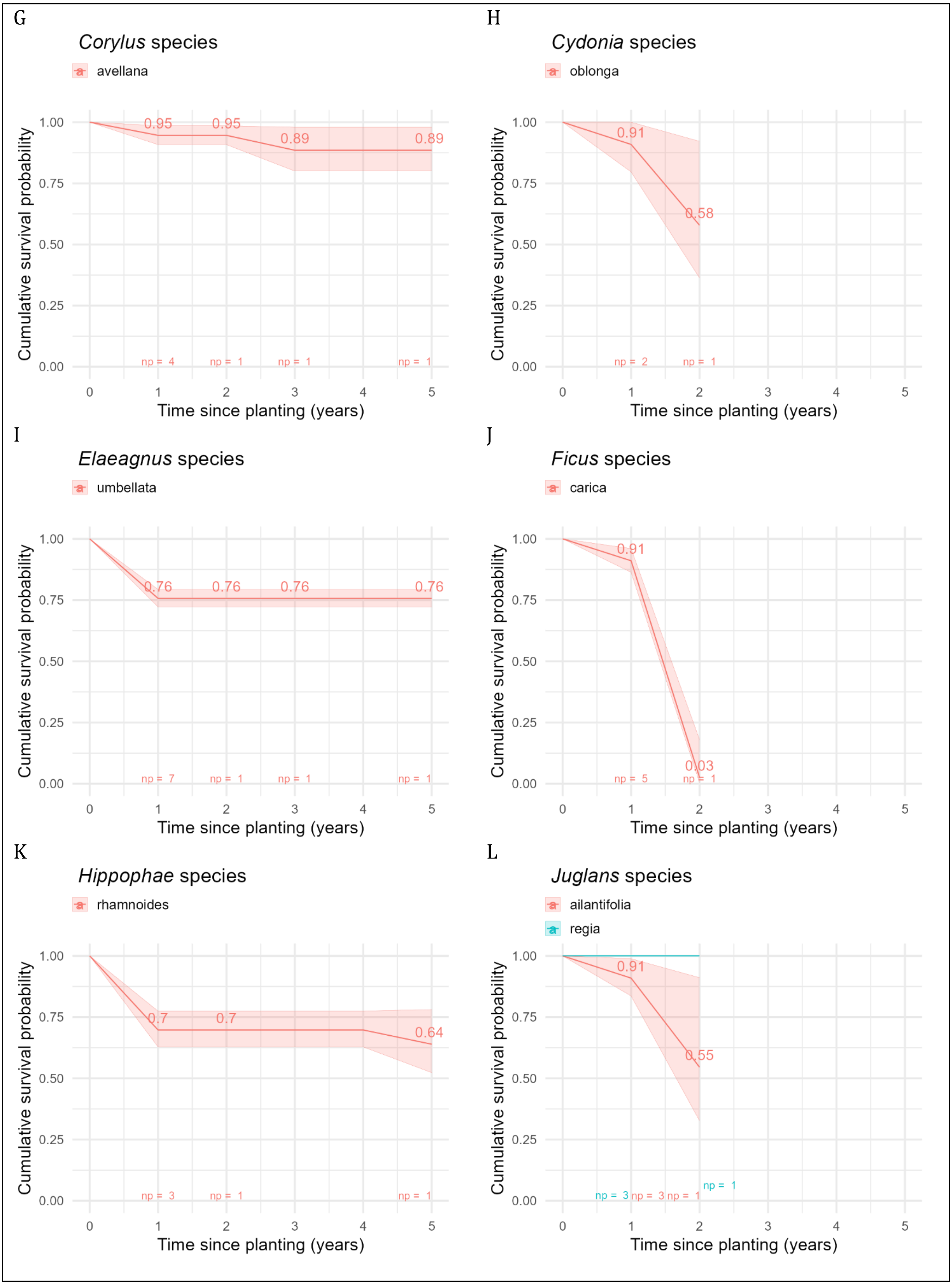
7.5.2 Survival per species

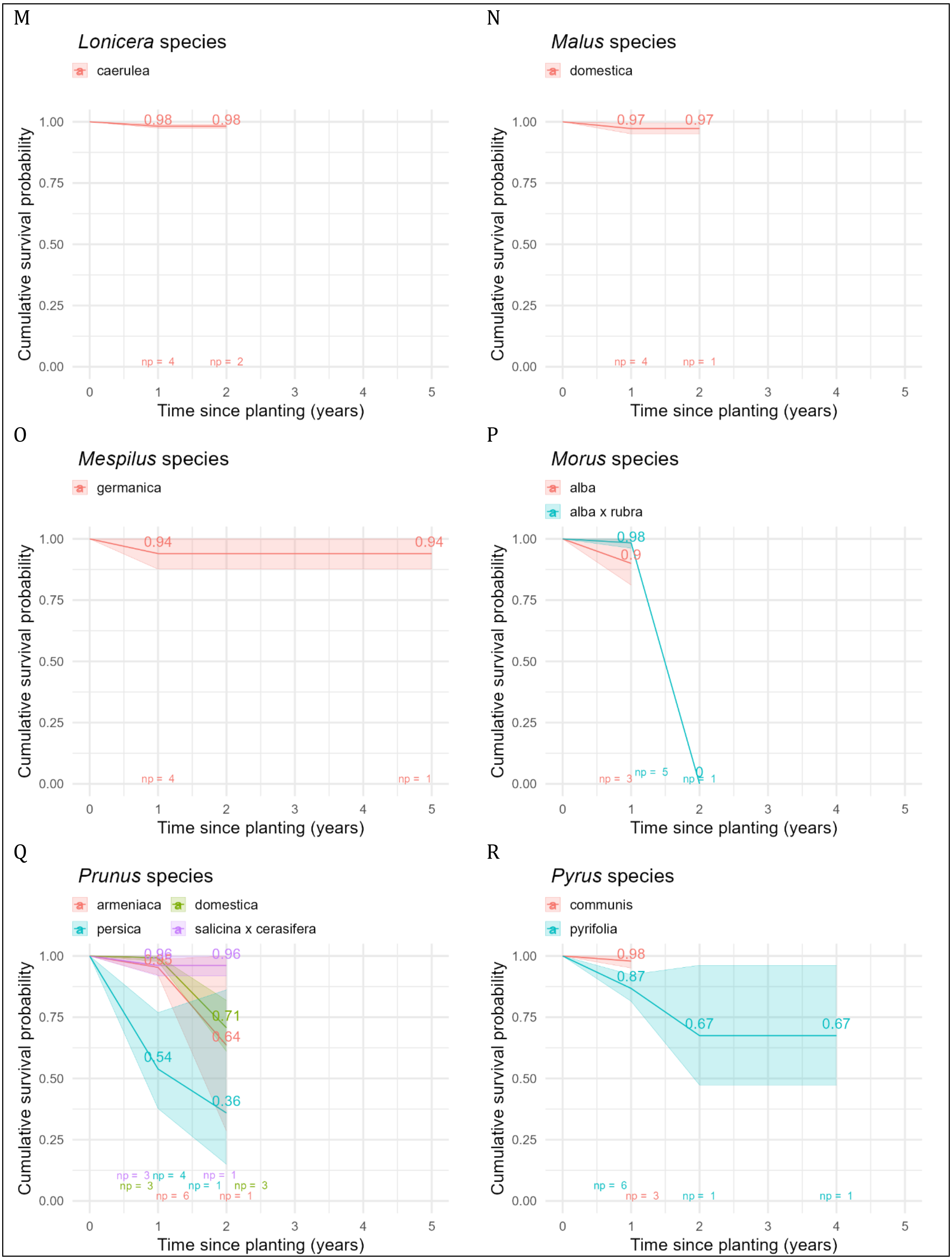
Table 11 Overview of the survival probability of the selected species per year. Only the years for which data was collected are included. The standard error, number of plants and number of projects are also shown.

Genus	Species	Years since planting	Cumulative survival probability	Standard Error	Number of individuals	Number of projects
Amelanchier	alnifolia	1	0,96	0,0051	1325	5
Aronia	prunifolia	1	0,99	0,0041	770	3
		2	0,97	0,0080	245	2
		3	0,97	0,0097	177	1
		5	0,97	0,0097	1	1
Asimina	triloba	1	0,92	0,0298	85	3
		2	0,24	0,0930	19	1
Castanea	sativa	1	0,73	0,0477	86	4
		2	0,37	0,1008	14	2
	sativa x crenata	1	0,83	0,0680	30	3
		2	0,56	0,2313	3	1
Chaenomeles	cathayensis	1	0,95	0,0444	22	2
		4	0,95	0,0444	2	1
	japonica	1	0,90	0,0201	226	3
Cornus	mas	1	0,97	0,0125	177	5
		4	0,90	0,0521	26	1
Corylus	avellana	1	0,95	0,0198	130	4
		2	0,95	0,0198	33	1
		3	0,89	0,0457	31	1
		5	0,89	0,0457	10	1
Cydonia	oblonga	1	0,91	0,0613	22	2
		2	0,58	0,1375	11	1
Elaeagnus	umbellata	1	0,76	0,0182	555	7
		2	0,76	0,0182	19	1
		3	0,76	0,0182	17	1
		5	0,76	0,0182	7	1
Ficus	carica	1	0,91	0,0247	134	5
		2	0,03	0,0256	35	1
Hippophae	rhamnoides	1	0,70	0,0373	152	3
		2	0,70	0,0373	30	1
		5	0,64	0,0653	12	1
Juglans	ailantifolia	1	0,91	0,0388	55	3
		2	0,55	0,1427	10	1
	regia	1	1,0	0	22	3
		2	1,0	0	4	1
Lonicera	caerulea	1	0,98	0,0040	1113	4
		2	0,98	0,0040	21	2
Malus	domestica	1	0,97	0,0111	217	4
		2	0,97	0,0111	13	1
Mespilus	germanica	1	0,94	0,0336	50	4

		5	0,94	0,0336	4	1
Morus	alba	1	0,90	0,0474	40	3
	alba x rubra	1	0,98	0,0113	124	5
		2	0,0	*NA*	1	1
Prunus	armeniaca	1	0,95	0,016	172	6
		2	0,64	0,260	3	1
	domestica	1	0,99	0,008	130	3
		2	0,71	0,053	73	3
	persica	1	0,54	0,098	26	4
		2	0,36	0,160	3	1
	salicina x cerasifera	1	0,96	0,022	77	3
		2	0,96	0,022	1	1
Pyrus	communis	1	0,98	0,015	96	3
	pyrifolia	1	0,87	0,028	151	6
		2	0,67	0,122	9	1
		4	0,67	0,122	2	1
Ribes	divericatum	1	1,0	0	47	2
		2	1,0	0	3	2
	nigrum	1	0,99	0,004	552	4
		2	0,62	0,098	24	2
	nigrum x uva-crispa	1	0,97	0,007	646	3
		2	0,76	0,046	75	2
	rubrum	1	1,0	0	1380	5
		2	0,98	0,013	104	2
	uva-crispa	1	0,96	0,006	1021	5
		2	0,96	0,006	30	2
		5	0,96	0,006	1	1
Rubus	fruticosus	1	0,82	0,025	228	2
		2	0,82	0,025	3	1
	fruticosus x idaeus	1	0,99	0,007	145	2
	idaeus	1	0,30	0,019	584	3
		2	0,20	0,083	3	1
	loganobaccus x idaeus	1	0,37	0,058	70	1
		2	0,37	0,058	2	1
	phoenicolasius	1	0,76	0,071	37	1
		2	0,76	0,071	8	1
Sambucus	nigra	1	0,97	0,014	153	4
		2	0,67	0,060	56	3
		4	0,67	0,060	5	1
Toona	sinensis	1	0,68	0,035	174	5
		2	0,29	0,052	46	3


A
Amelanchier species
alnifolia
0.96
np = 5
Cumulative survival probability
1.00
0.75
0.50
0.25
0.00
0
1
2
3
4
5
Time since planting (years)
B
Aronia species
prunifolia
0.99
0.97
0.97
0.97
np = 3
np = 2
np = 1
np = 1
Cumulative survival probability
Time since planting (years)
C
Asimina species
triloba
0.92
0.24
np = 3
np = 1
Cumulative survival probability
Time since planting (years)
D
Castanea species
sativa
sativa x crenata
0.83
0.73
0.56
0.37
np = 4
np = 3
np = 1
np = 2
Cumulative survival probability
Time since planting (years)
E
Chaenomeles species
cathayensis
japonica
0.95
0.95
0.9
np = 3
np = 2
np = 1
Cumulative survival probability
Time since planting (years)
F
Cornus species
mas
0.97
0.9
np = 5
np = 1
Cumulative survival probability
Time since planting (years)


G
Corylus species
avellana
1.00
0.75
0.50
0.25
0.00
Cumulative survival probability
0.95
0.95
0.89
0.89
np = 4
np = 1
np = 1
np = 1
0
1
2
3
4
5
Time since planting (years)
H
Cydonia species
oblonga
0.91
0.58
np = 2
np = 1
Cumulative survival probability
Time since planting (years)
I
Elaeagnus species
umbellata
0.76
0.76
0.76
0.76
np = 7
np = 1
np = 1
np = 1
Cumulative survival probability
Time since planting (years)
J
Ficus species
carica
0.91
0.03
np = 5
np = 1
Cumulative survival probability
Time since planting (years)
K
Hippophae species
rhamnoides
0.7
0.7
0.64
np = 3
np = 1
np = 1
Cumulative survival probability
Time since planting (years)
L
Juglans species
ailantifolia
regia
0.91
0.55
np = 3
np = 3
np = 1
np = 1
Cumulative survival probability
Time since planting (years)


M
Lonicera species
caerulea
0.98
0.98
np = 4
np = 2
N
Malus species
domestica
0.97
0.97
np = 4
np = 1
O
Mespilus species
germanica
0.94
0.94
np = 4
np = 1
P
Morus species
alba
alba x rubra
0.98
0.9
0
np = 3
np = 5
np = 1
Q
Prunus species
armeniaca
domestica
persica
salicina x cerasifera
0.96
0.95
0.96
0.71
0.64
0.54
0.36
np = 3
np = 4
np = 1
np = 3
np = 1
np = 3
np = 6
np = 1
R
Pyrus species
communis
pyrifolia
0.98
0.87
0.67
0.67
np = 6
np = 3
np = 1
np = 1
Cumulative survival probability
1.00
0.75
0.50
0.25
0.00
0
1
2
3
4
5
Time since planting (years)

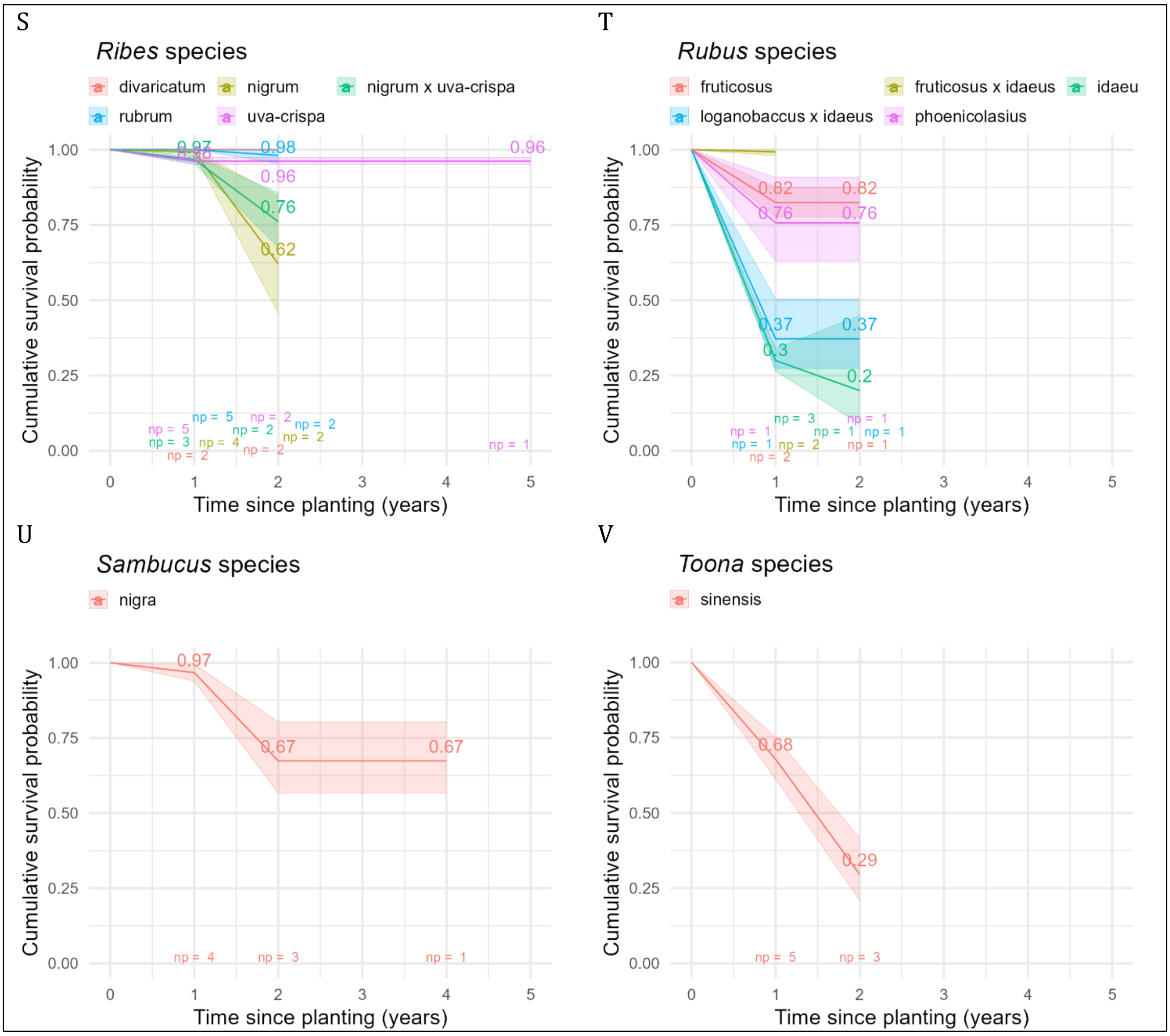


Figure 17 Kaplan-Meier survival curves with their 95% confidence intervals of all selected species per genus. np = number of projects in which the plants can be found.

7.5.3 Survival per CAS project

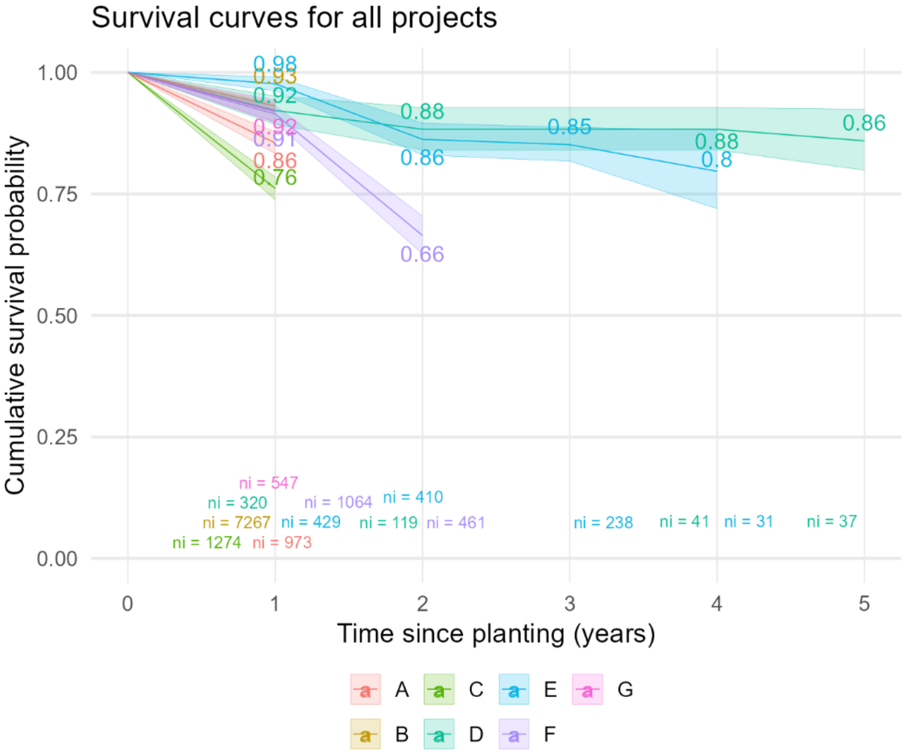


Figure 18 Kaplan-Meier survival curves with their 95% confidence intervals of all selected species per genus. ni = number of individuals used in the calculations.

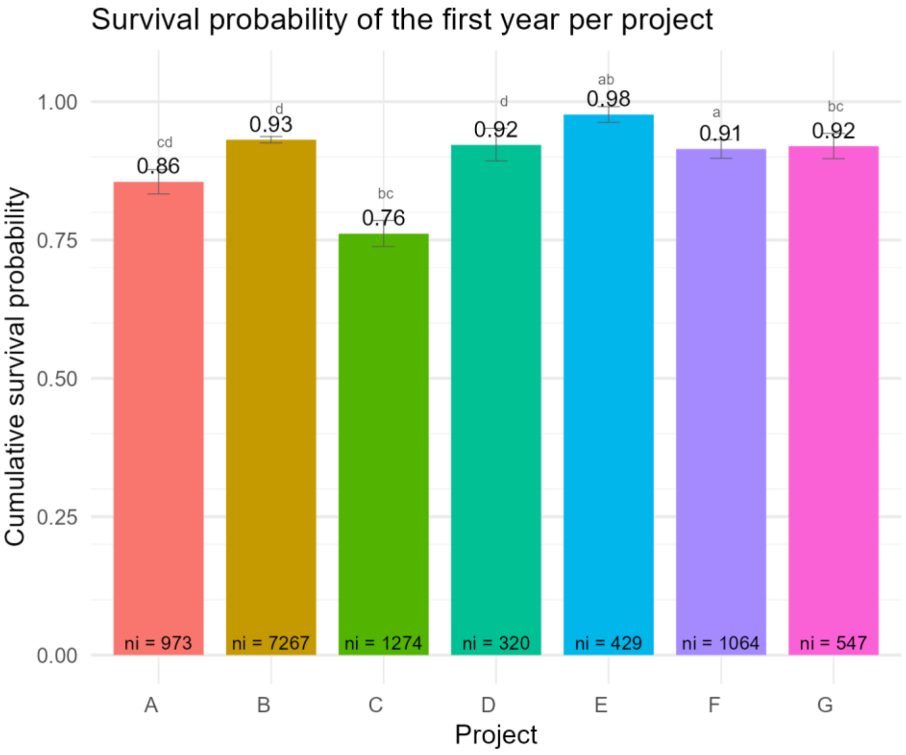


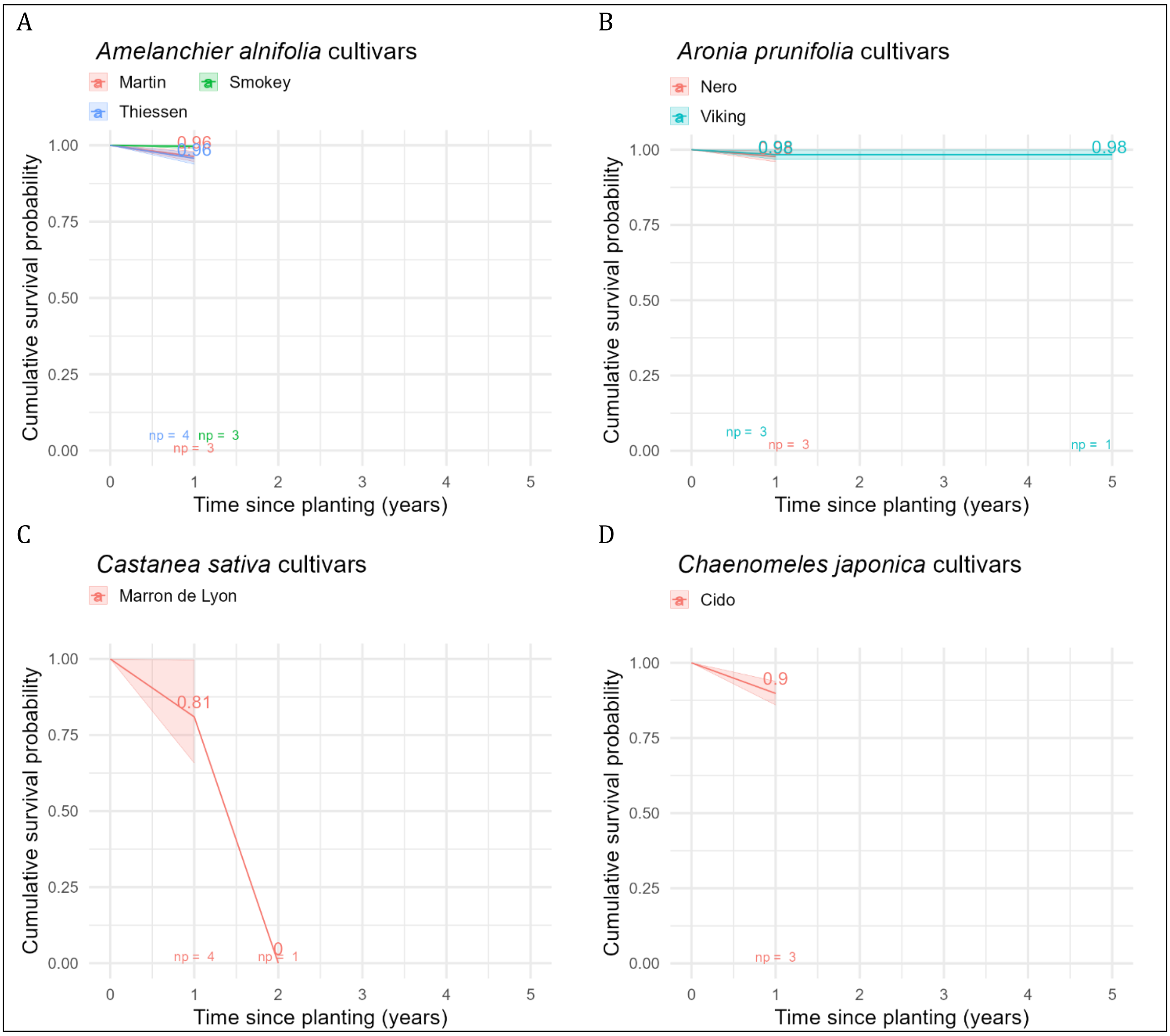
Figure 19 Survival probability of the first year for the selected CAS projects, based on the Kaplan-Meier survival curves that were generated per location. Error bars indicate the 95%-confidence intervals derived from the survival curves. 'ni' indicates the number of individuals used in the calculations for year 1. Locations not overlapping in letters above the upper confidence interval are significantly different by the Bonferroni test based on Model A ($p_{adj} < 0.05$). The letters were assigned using the multcomp package (Hothorn et al., 2008).

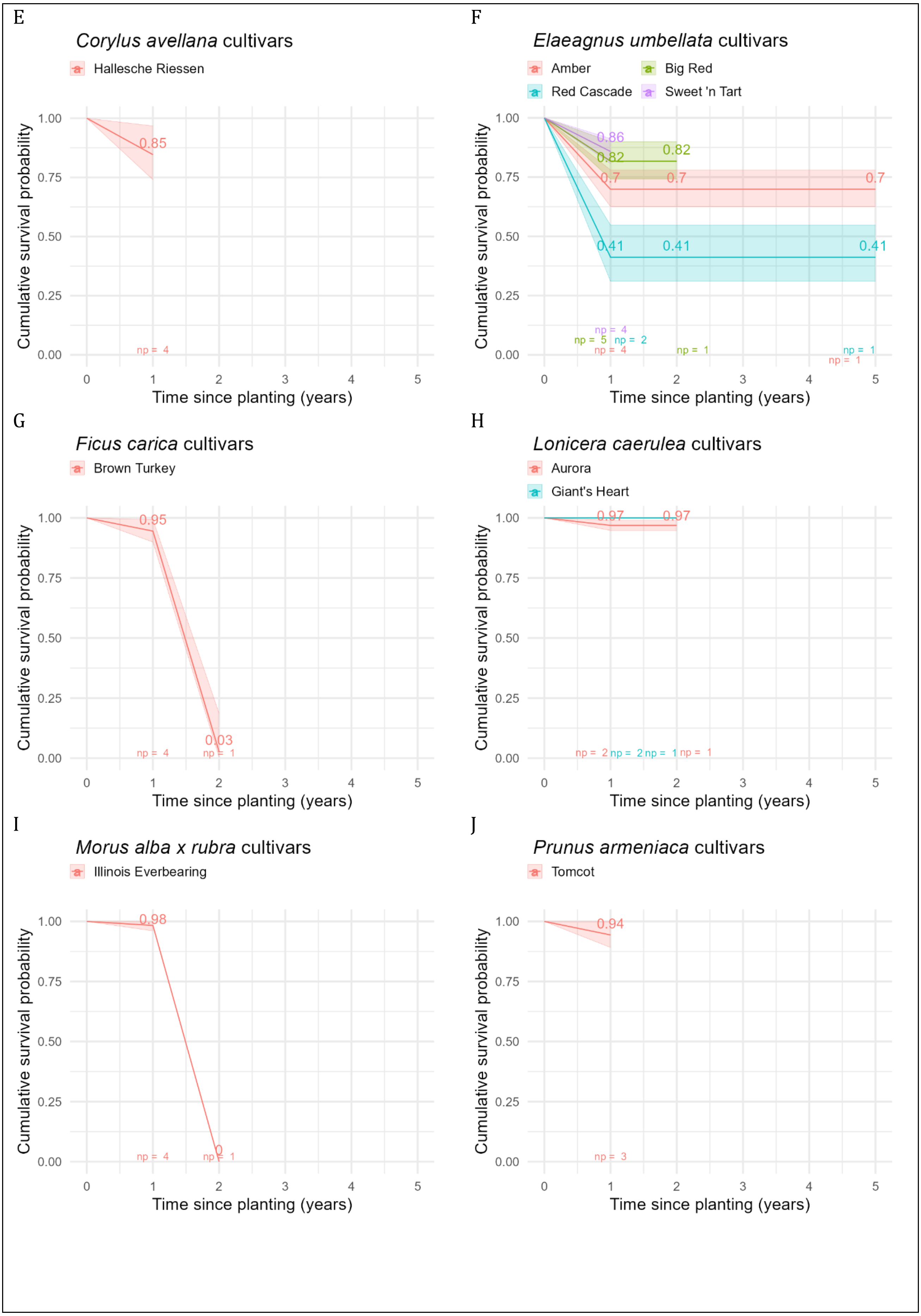
7.5.4 Survival per cultivar

Table 12 Overview of the survival probability of the selected species per year. Only the years for which data was collected are included. The standard error, number of plants and number of projects are also shown.

Species	Cultivar	Years since planting	Cumulative survival probability	Standard Error	Number of individuals	Number of projects
Amelanchier alnifolia	Martin	1	0,96	0,0087	466	3
	Smokey	1	1,0	0,0037	269	3
	Thiessen	1	0,96	0,0098	422	4
Aronia prunifolia	Nero	1	0,98	0,0091	265	3
	Viking	1	0,98	0,0080	247	3
		5	0,98	0,0080	1	1
Castanea sativa	Marron de Lyon	1	0,81	0,0857	21	4
		2	0,0	*NA*	1	1
Chaenomeles japonica	Cido	1	0,90	0,0201	226	3
Corylus avellana	Hallesche Riessen	1	0,85	0,0578	39	4
Elaeagnus umbellata	Amber	1	0,70	0,0394	136	4
		5	0,70	0,0394	2	1
	Big Red	1	0,82	0,0401	93	5
		2	0,82	0,0401	2	1
	Red Cascade	1	0,41	0,0597	68	2
		5	0,41	0,0597	1	1
	Sweet 'n Tart	1	0,86	0,0269	169	4
Ficus carica	Brown Turkey	1	0,95	0,0239	91	4
		2	0,03	0,0266	35	1
Lonicera caerulea	Aurora	1	0,97	0,0108	257	2
		2	0,97	0,0108	2	1
	Giant's Heart	1	1,0	0,0	24	2
		2	1,0	0,0	2	1
Morus alba x rubra	Illinois Everbearing	1	0,98	0,0117	120	4
		2	0,0	*NA*	1	1
Prunus armeniaca	Tomcat	1	0,9	0,0274	71	3
Prunus domestica	Opal	1	1,0	0,0	27	2
		2	0,77	0,1169	13	1
Prunus salicina x cerasifera	Rose of July	1	0,90	0,0566	29	3
	Skoroplodnaja	1	1,0	0,0	32	3
Pyrus pyrifolia	Hosui	1	0,84	0,0733	25	2
		4	0,84	0,0733	1	1
	Kil Tsu	1	1,0	0,0	23	4
	Niitaka	1	1,0	0,0	33	3
	Nijisseiki	1	0,91	0,061	22	2
		2	0,45	0,323	2	1
Ribes nigrum	Ben Sarek	1	0,97	0,019	91	3
	Titania	1	1,0	0,0	408	2
		2	0,57	0,132	14	1

Ribes rubrum	Gloire des Sablons	1	1,0	0,0	128	3
		2	0,0	*NA*	1	1
	Jonkheer van Tets	1	1,0	0,0	395	4
	Rolan	1	1,0	0,0	156	3
		2	0,96	0,043	23	1
	Rovada	1	1,0	0,0	100	2
		2	1,0	0,0	51	1
	Witte Hollander	1	1,0	0,0	272	2
		2	1,0	0,0	10	1
Ribes uva-crispa	Hinnonmäki Grön	1	0,76	0,085	25	1
		2	0,76	0,085	11	1
		5	0,76	0,085	1	1
	Hinnonmaki Röd	1	0,88	0,030	121	3
		2	0,88	0,030	12	1




E
Corylus avellana cultivars
Hallesche Riessen
Cumulative survival probability
1.00
0.75
0.50
0.25
0.00
0.85
np = 4
0
1
2
3
4
5
Time since planting (years)
F
Elaeagnus umbellata cultivars
Amber
Big Red
Red Cascade
Sweet 'n Tart
0.86
0.82
0.82
0.7
0.7
0.7
0.41
0.41
0.41
np = 4
np = 5
np = 2
np = 4
np = 1
np = 1
np = 1
G
Ficus carica cultivars
Brown Turkey
0.95
0.03
np = 4
np = 1
H
Lonicera caerulea cultivars
Aurora
Giant's Heart
0.97
0.97
np = 2
np = 2
np = 1
np = 1
I
Morus alba x rubra cultivars
Illinois Everbearing
0.98
0
np = 4
np = 1
J
Prunus armeniaca cultivars
Tomcot
0.94
np = 3

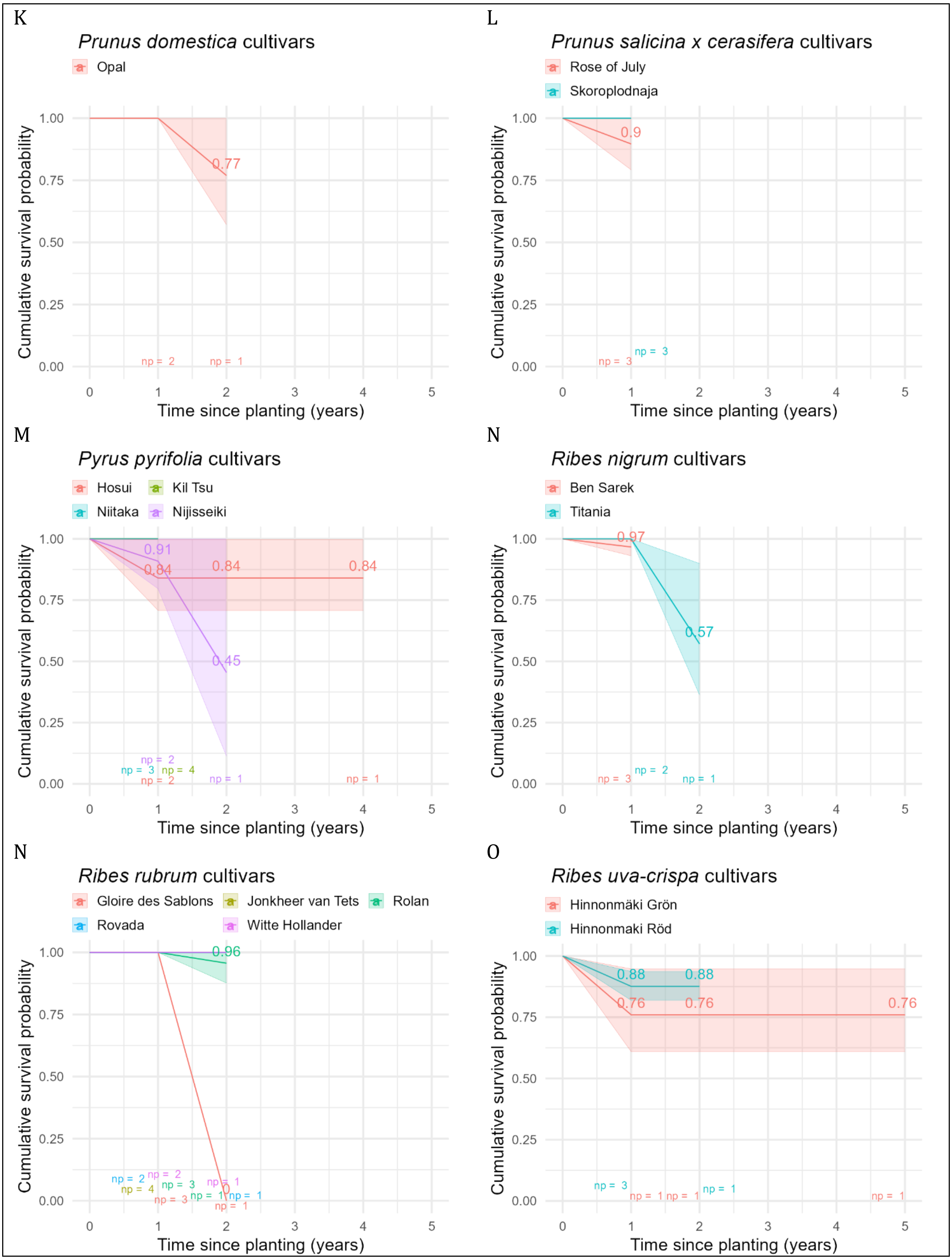


Figure 20 Kaplan-Meier survival curves with their 95% confidence intervals of all selected cultivars per species. np = number of projects in which the plants can be found.

7.6 Model results

7.6.1 Model A

```
Call:
glm(formula = Survival ~ Genus + FF_code, family = binomial(link = "logit"),
    data = selected_genus_data)

Coefficients:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)       3.05054    0.19705  15.481  < 2e-16 ***
GenusAronia       1.31219    0.28458   4.611 4.01e-06 ***
GenusAsimina     -1.55893    0.31232  -4.991 5.99e-07 ***
GenusCastanea    -1.65098    0.26013  -6.347 2.20e-10 ***
GenusChaenomeles -1.08201    0.24903  -4.345 1.39e-05 ***
GenusCornus      -0.09655    0.35176  -0.274 0.783725
GenusCorylus     -0.40913    0.34950  -1.171 0.241762
GenusCydonia     -1.32363    0.51182  -2.586 0.009706 **
GenusDiospyros   -1.42984    0.52762  -2.710 0.006729 **
GenusElaeagnus   -1.96369    0.18596 -10.560  < 2e-16 ***
GenusFicus       -2.12231    0.25434  -8.344  < 2e-16 ***
GenusHippophae   -2.00244    0.25246  -7.932 2.16e-15 ***
GenusJuglans     -0.49380    0.32108  -1.538 0.124064
GenusLonicera     0.76987    0.27013   2.850 0.004371 **
GenusMalus        1.01103    0.44802   2.257 0.024028 *
GenusMespilus     0.24927    0.62385   0.400 0.689479
GenusMorus       -0.51909    0.31897  -1.627 0.103654
GenusPrunus      -1.10848    0.20395  -5.435 5.48e-08 ***
GenusPyrus       -0.79036    0.26538  -2.978 0.002900 **
GenusRibes        0.71584    0.18766   3.815 0.000136 ***
GenusRubus       -2.99562    0.16246 -18.440  < 2e-16 ***
GenusSambucus    -0.91323    0.28928  -3.157 0.001594 **
GenusToona       -2.52596    0.23309 -10.837  < 2e-16 ***
GenusZanthoxylum -1.54555    0.37333  -4.140 3.47e-05 ***
FF_codeB          0.32047    0.13499   2.374 0.017596 *
FF_codeC         -0.43496    0.14839  -2.931 0.003376 **
FF_codeD          0.63090    0.22674   2.782 0.005394 **
FF_codeE         -0.93293    0.19915  -4.684 2.81e-06 ***
FF_codeF         -1.03000    0.14299  -7.203 5.88e-13 ***
FF_codeG         -0.34947    0.20341  -1.718 0.085787 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 8202.4  on 11869  degrees of freedom
Residual deviance: 5878.0  on 11840  degrees of freedom
AIC: 5938

Number of Fisher Scoring iterations: 6
```

Explained deviance: **99,72%**

7.6.2 Model B

```
Call:
glm(formula = Survival ~ Plant_code + FF_code, family = binomial(link = "logit")
,
    data = selected_species_data)

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)    
(Intercept)         3.15404    0.20446  15.426  < 2e-16 ***
Plant_codeAro_p     1.07333    0.31998   3.354 0.000796 ***
Plant_codeAsi_t    -1.57374    0.31538  -4.990 6.04e-07 ***
Plant_codeCas_s    -1.74986    0.29834  -5.865 4.48e-09 ***
Plant_codeCas_sxc  -1.04652    0.49594  -2.110 0.034843 *  
Plant_codeCha_c     0.15892    1.04245   0.152 0.878830    
Plant_codeCha_j    -1.16759    0.26606  -4.388 1.14e-05 ***
Plant_codeCorn_m    0.09074    0.41814   0.217 0.828196    
Plant_codeCory_a   -0.38252    0.39105  -0.978 0.327979    
Plant_codeCyd_o    -1.40198    0.51747  -2.709 0.006742 ** 
Plant_codeEla_u    -1.88452    0.18942  -9.949  < 2e-16 ***
Plant_codeFic_c    -2.19760    0.25983  -8.458  < 2e-16 ***
Plant_codeHip_r    -2.08751    0.25976  -8.036 9.26e-16 ***
Plant_codeJug_a    -0.77295    0.41203  -1.876 0.060660 .  
Plant_codeJug_r    13.20503  307.40731   0.043 0.965737    
Plant_codeLon_c     0.76152    0.26316   2.894 0.003807 ** 
Plant_codeMal_d     0.92360    0.45023   2.051 0.040226 *  
Plant_codeMes_g     0.15325    0.62763   0.244 0.807093    
Plant_codeMor_a    -0.66366    0.56271  -1.179 0.238233    
Plant_codeMor_axr   0.46872    0.60478   0.775 0.438329    
Plant_codePru_ar   -0.14686    0.37949  -0.387 0.698753    
Plant_codePru_do   -1.12063    0.29561  -3.791 0.000150 ***
Plant_codePru_p    -2.85719    0.44526  -6.417 1.39e-10 ***
Plant_codePru_sxc   0.07842    0.61305   0.128 0.898210    
Plant_codePyr_c     0.56590    0.73069   0.774 0.438651    
Plant_codePyr_p    -1.28782    0.28488  -4.521 6.17e-06 ***
Plant_codeRib_d    13.22263  209.70445   0.063 0.949724    
Plant_codeRib_j    -0.12773    0.24968  -0.512 0.608932    
Plant_codeRib_n     0.71035    0.32182   2.207 0.027294 *  
Plant_codeRib_r     3.49400    0.72449   4.823 1.42e-06 ***
Plant_codeRib_u     0.17720    0.22595   0.784 0.432899    
Plant_codeRub_b    -3.32759    0.31674 -10.506  < 2e-16 ***
Plant_codeRub_f    -1.83743    0.22947  -8.007 1.17e-15 ***
Plant_codeRub_fxi   1.92898    1.01781   1.895 0.058062 .  
Plant_codeRub_i    -4.03670    0.17766 -22.722  < 2e-16 ***
Plant_codeRub_p    -1.45633    0.42849  -3.399 0.000677 ***
Plant_codeSam_n    -1.12072    0.28825  -3.888 0.000101 ***
Plant_codeToo_s    -2.66313    0.23859 -11.162  < 2e-16 ***
FF_codeB            0.21254    0.14531   1.463 0.143564    
FF_codeC           -0.38130    0.17382  -2.194 0.028263 *  
FF_codeD            0.57418    0.25303   2.269 0.023257 *  
FF_codeE           -0.57929    0.19309  -3.000 0.002699 ** 
FF_codeF           -1.11633    0.14684  -7.602 2.91e-14 ***
FF_codeG           -0.26652    0.21463  -1.242 0.214326    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 7663.3  on 11117  degrees of freedom
Residual deviance: 4975.3  on 11074  degrees of freedom
AIC: 5063.3

Number of Fisher Scoring iterations: 14
```

Explained deviance: **99,72%**

7.6.3 Model C

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation)
['glmerMod']
 Family: binomial  ( logit )
Formula: Survival ~ Soil_type_group + Mulching + Irrigation + Planting_season +
(1 | Genus)
   Data: df
Control: control(Optimizer = Nelder_Mead)


     AIC      BIC   logLik deviance df.resid
  5029.0   5094.4  -2505.5   5011.0    10635

Scaled residuals:
    Min      1Q  Median      3Q     Max
-9.0804  0.1101  0.1464  0.2361  1.3046

Random effects:
 Groups Name        Variance Std.Dev.
 Genus  (Intercept) 1.247    1.117
Number of obs: 10644, groups:  Genus, 24

Fixed effects:
                        Estimate Std. Error z value Pr(>|z|)
(Intercept)              1.01109    0.40791   2.479 0.013186 *
Soil_type_groupLoam      0.16701    0.22479   0.743 0.457519
Soil_type_groupSand     -0.56943    0.19536  -2.915 0.003559 **
Mulching                 0.27597    0.07349   3.755 0.000173 ***
Irrigation              -0.12375    0.05429  -2.279 0.022654 *
Planting_seasonvoorjaar  0.38905    0.43182   0.901 0.367620
Planting_seasonwinter    0.49708    0.17237   2.884 0.003929 **
Planting_seasonzomer    -1.98445    0.80801  -2.456 0.014051 *

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Sl_t_L Sl_t_S Mlchng Irrgtn Plntng_ssnv Plntng_ssnw
Sl_typ_grpL  0.064
Sl_typ_grpS  0.111 -0.042
Mulching    -0.700  0.049 -0.506
Irrigation  -0.352 -0.476  0.123  0.148
Plntng_ssnv  0.634  0.194  0.115 -0.749 -0.655
Plntng_ssnw -0.250  0.052  0.237  0.097 -0.349  0.258
Plntng_ssnz  0.138  0.027  0.000 -0.190 -0.121  0.258       0.084
```

7.6.4 Model D

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation)
['glmerMod']
 Family: binomial  ( logit )
Formula: Survival ~ Planting_season + Initial_size_category + (1 | Genus)
   Data: df_clean
Control: control (Optimizer = Nelder_Mead)

     AIC      BIC   logLik deviance df.resid
  2099.1   2158.5  -1040.5   2081.1     5463

Scaled residuals:
     Min       1Q   Median       3Q      Max
-12.3023   0.0902   0.1302   0.1789   1.7315

Random effects:
 Groups Name        Variance Std.Dev.
 Genus  (Intercept) 1.987    1.41
Number of obs: 5472, groups:  Genus, 16

Fixed effects:
                                Estimate Std. Error z value Pr(>|z|)
(Intercept)                       1.6908     0.6621   2.554 0.010662 *
Planting_seasonvoorjaar           1.2384     0.3428   3.612 0.000304 ***
Planting_seasonwinter             0.7981     0.3544   2.252 0.024340 *
Initial_size_category100-125 cm  -0.1087     1.2763  -0.085 0.932130
Initial_size_category125-150 cm   1.5469     0.7749   1.996 0.045911 *
Initial_size_category150-200 cm   1.4930     0.6479   2.304 0.021199 *
Initial_size_category30-60 cm     0.2565     0.3563   0.720 0.471565
Initial_size_category60-100 cm   -0.0585     0.4382  -0.133 0.893802
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Plntng_ssnv Plntng_ssnw I__10c I__12c I__15c I__30c
Plntng_ssnv -0.662
Plntng_ssnw -0.611  0.889
I__100-125c -0.239  0.093       0.102
I__125-150c -0.407  0.186       0.190       0.238
I__150-200c -0.433  0.184       0.204       0.434  0.403
Int__30-60c -0.728  0.624       0.540       0.224  0.390  0.443
In__60-100c -0.674  0.518       0.394       0.218  0.405  0.430  0.824
```