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REVIEW

FraxForFuture—research on European ash dieback in Germany

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Abstract
European ash dieback caused by the alien, invasive ascomycete species *Hymenoscyphus fraxineus* currently represents, along with its side effects, the greatest threat to common ash (*Fraxinus excelsior*) trees in Europe. The disease is widely distributed in Germany and present in all regions where common ash is growing. In order to study European ash dieback in Germany and to develop management strategies to conserve common ash as a forest tree species, the concerted, interdisciplinary research project FraxForFuture was initiated. FraxForFuture consist of an association of five sub-networks: FraxConnect, FraxMon, FraxGen, FraxPath, and FraxSilva. In total, 27 individual projects conduct research on the epidemiology of the disease, the pathogen and the preservation of ash, including various control, breeding, and silvicultural strategies. The main goals of the FraxForFuture network and the sub-networks as well as essential information about the network of common research plots are provided.

Keywords Demonstration project · European ash dieback · *Fraxinus excelsior* · *Hymenoscyphus fraxineus* · Research plots

Introduction

For 20 years European ash dieback (Fig. 1a) has been observed in Germany, which is caused by the invasive fungal species *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz & Hosoya (syn. *H. pseudoalbidus* Queloz, Grünig, Berndt, T. Kowalski, T.N. Sieber & Holdenr., anamorph: *Chalara fraxinea* T. Kowalski). *H. fraxineus* (Fig. 1b, c) is a member of the order Helotiales (class Leotiomycetes, Ascomycota) and a cryptic sister species of the native, non-pathogenic ash rachis-inhabiting *Hymenoscyphus albidus* (Gillet) W. Phillips. *H. fraxineus* originates from East Asia, where it is native to Japan, Korea, east Russia, and China (Gross et al. 2015). In Europe, it was first observed in Poland at the beginning of the 1990s (Przybył 2002; Kowalski 2006). It is assumed that only a very small number of individuals of the fungus were introduced (Gross et al. 2014; Drenkhan et al. 2014) and these then spread very quickly across Europe (Timmermann et al. 2011; Enderle et al. 2019).

The ash dieback pathogen causes little damage to its host, Manchurian ash (*Fraxinus mandshurica* Rupr.) in its native range (Grosdidier et al. 2018). Due to infections by

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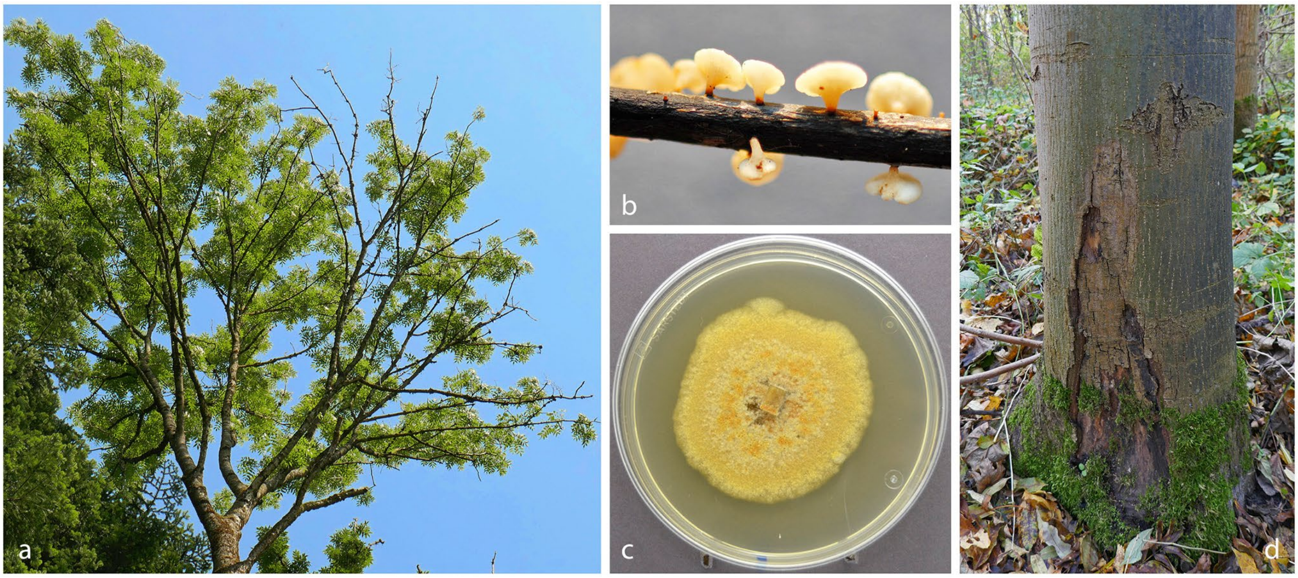

Fig. 1 Ash dieback—Crown Symptoms (**a**), ascocarps of the causal agent *Hymenoscyphus fraxineus* on a rachis of *Fraxinus excelsior* (**b**) *Hymenoscyphus fraxineus* pure culture on malt yeast pepton agar (**c**), and stem collar necrosis / rot (**d**)

the non-native *H. fraxineus,* the occurrence of the common ash (*Fraxinus excelsior* L., Oleaceae.) in Central Europe is declining dramatically. European ash dieback represents the greatest threat to the common ash tree species in Europe to date (Skovsgaard et al. 2017; Peters et al. 2021b). Ash dieback and its impacts, such as stem collar necrosis or rot and secondary infestation with bark or wood rot fungi as well as insects, often have fatal consequences for the survival, growth, and wood quality of *F. excelsior*. Deterioration of wood quality, tree mortality, and rising expenses for disease controls and measures to address safety issues concerning infected trees have led to financial losses for landowners and forest enterprises. The future use of the common ash in forestry is highly uncertain, because the Europe-wide probability of survival 30 years after the fungus was first observed is as low as 0.51 (George et al. 2022). Survey data from the ICP Forests Level I network showed that the frequency of tree mortality due to ash dieback was moderate in the affected European countries between 1987 and 2000. Like in other parts of Europe, mortality accelerated in Germany between the years 2000 and 2010 and increased significantly in the decade 2010–2020 (George et al. 2022). In addition, investments into regenerating stands with a susceptible population of ash trees are no longer recommended.

Fraxinus excelsior, also known as European ash or common ash, is the only native ash species in Germany. This deciduous tree species has a tall, narrow crown, rarely exceeds 250 years of age and adult trees range between 12 and 18 (43) m in height. Young trees are characterised by a pale grey and smooth bark, which becomes thick and vertically fissured with age (Thomas 2016). The shoots, which are considered a main point of entry for *H. fraxineus* after leaves and stem collars, are greenish-grey, stout, with jet-black buds. It is known that in temperate, mixed forests ash roots are colonised by arbuscular mycorrhizal fungi (Seven and Polle 2014).

Common ash has a noteworthy relevance in forestry and is a popular ornamental urban tree species. In floodplain and ravine forests as well as on calcareous soils, *F. excelsior* can be the dominant tree species in Germany. So far, other ash species such as *F. angustifolia* Vahl, *F. pennsylvanica* Marshall, and *F. ornus* L. only play a minor role as ornamental or forest trees. According to the third German National Forest Inventory in 2012, ash covered an area of about 250,000 ha, which corresponded to 2.4% of the total forest area of Germany (Enderle et al. 2017). At that time, the ash stock was estimated at 74.7 million solid cubic meters. Common ash is abundant all over Germany, but unevenly distributed. For example, a quarter of the total German ash area (25.3%) and ash stock (23.8%) was located in south-western Germany in the federal state of Baden-Württemberg (Enderle et al. 2017). Before the occurrence of European ash dieback in Germany, the ability of natural ash regeneration to dominate and outcompete admixed tree species on certain sites (“Fraxinisation”, in German: “Vereschung”) had been discussed as a problem by foresters. One reason for this was that the growth of undesired dense layers of herbaceous plants and grasses in mature stands dominated by ash increases due to the high light transmission (Miegroet 1956; Boerth 1990; Wagner 1990; Rysavy and Roloff 1994). However, in those decades the planting of common ash and its regeneration had been promoted, because German forest policies aimed to increase the area of ecologically stable mixed forests (Mantel 1990; Schriewer 2001; Baumgarten and Teuffel 2005). Moreover, this robust, ecologically, and economically valuable tree species is considered as advantageous to face the climate change due to its high drought tolerance (Schmidt 2007).

In Germany, European ash dieback was first observed in 2002 and the causal agent was first proven in 2006 (Schumacher et al. 2007). Since then, the progression of the disease has been monitored independently with different disease severity indices and monitoring keys in the German federal states. European ash dieback is now present in all regions of Germany were common ash is growing (Langer 2017).

In order to ensure the preservation of ash trees as a native forest tree species, and thus the preservation of adapted species and respective biological communities, the research network FraxForFuture (https://www.fraxforfuture.de) funded by the German Waldklimafonds (https://www.waldklimafonds.de/foerderung/ausgewaehlte-projekte/projekte/fraxforfuture-hoffnung-fuer-die-esche-1) was initiated. The Waldklimafonds (WKF) itself is funded by the German Federal Ministry of Food and Agriculture (BMEL) and Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) administrated by the Agency for Renewable Resources (FNR). FraxForFuture was designed as an interdisciplinary demonstration project with 27 sub-projects within five sub-networks have been conducting research since 2020. Each of the five sub-networks, namely FraxConnect (1), FaxMon (2), FraxGen (3), FraxPath (4), and FraxSilva (5) (Fig. 2), address different research topics while working closely to take advantage of synergies in research on European ash dieback and the conservation of the forest tree species *F. excelsior*.

Goals of FraxForFuture

FraxForFuture is developing a national strategy for forestry, policy, and research for effective collaboration to preserve ash trees, which are threatened by an invasive alien pathogen. A crucial factor for the management of invasive pathogens is solid knowledge about the dispersal patterns and distribution of the pathogen as well as the epidemiology of the disease (compare Grosdidier et al. 2018). Therefore, one of the first actions of the research consortium was to develop a key to assess the damage due to ash dieback nationwide (Peters et al. 2021a, b) and to map the disease using different methods.

Important goals of the project include the long-term preservation of common ash as a commercial tree species, developing a deeper understanding of the disease, and determining the management of infected stands. Using European ash dieback as a case study, the FraxForFuture research network is the first of its kind in Germany to develop a coordinated approach to recording, describing and handling an emerging forest disease by an alien causal agent. FraxForFuture thus works both directly on ash dieback and in preparation for other anticipated far-reaching damages in forests, by establishing structures for effective nationwide management of such events.

Research goals of FraxConnect

FraxConnect fulfils a dual function: (i) it ensures the communication and coordination of the entire FraxForFuture research network and (ii) conducts economic analyses and is responsible for its transfer to practitioners. Therefore, the creation of a communication concept for the general public,

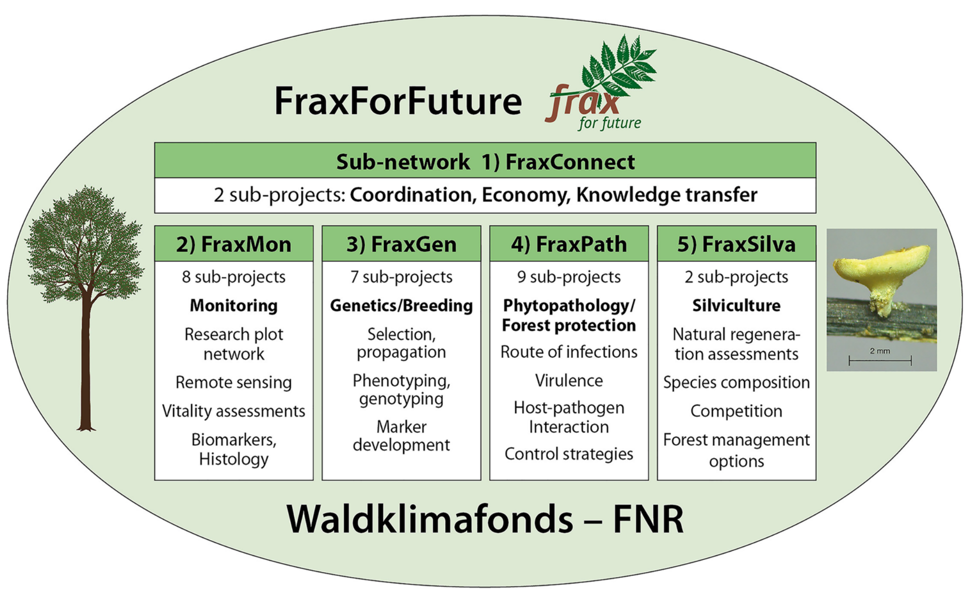

Fig. 2 FraxForFuture—organisation chart (FNR: Fachagentur für nachwachsende Rohstoffe)

forestry practitioners, political decision makers and the scientific community as well as the organisation of internal scientific exchange and an international scientific conference, will be designed and evaluated. Knowledge transfer for the development of a web-based project portal, practical trainings or policy advice will be encouraged and supported by this sub-network. This contributes a decision-making manual for silvicultural recommendations, strategy development, and economic analyses.

Research goals of FraxMon

Alongside the research on ash dieback, the sub-project FraxMon develops a monitoring programme for the continuous observation of the vitality states of ash tree populations. At first, it was examined if it is possible to infer the historical distribution of the ash dieback in Germany from already existing raster data from earlier National Forest Inventories and from the Forest Condition Reports. To enable the observation of the spatio-temporal expression of different symptoms consistently on the same trees and stands within a broad spectrum of locations, 14 intensive monitoring plots (German: Intensivbeobachtungflächen, IBF plots) have been established in Germany (Table 1; Fig. 3). These constitute the working platform and data basis for several groups of the research association.

Different phenotypical characteristics of the crown and stem are recorded twice per year (in summer and winter), and these constitute important reference values. To this end, a special programme for estimating the level of crown dieback and collar rot was developed jointly within the research consortium. In addition, histological structures and biochemical contents of the primary and secondary metabolism in the wood and leaves are analysed for the phenotyping of selected individual trees with diverse vitality states. Thereby, the extent physiological condition impacts the dynamics of infection and which physiological alterations occur after an infection in ashes is investigated. In order to enable the extrapolation from those detailed, but isolated, examinations to a broader geographical scale, the monitoring programme will be complemented by diverse methods of remote sensing. Amongst other things, which technical approaches of remote sensing might be most suitable to determine the tree species and its vitality will be investigated.

Research goals of FraxGen

FraxGen has two foci. The first one is on the selection of ash genotypes with tolerance to *H. fraxineus*. This is pursued by selecting plus trees in the field throughout Germany and propagating them vegetatively by grafting, including tests of tolerance in nursery and greenhouse settings. Seeds of plus trees serve as the basis for progeny trials. Final aims are clonal and seedlings seed orchards. Selection will be supported by population genetics to ensure genetic diversity of plus trees and progenies, and by in vitro culture techniques to preserve and propagate selected genotypes. The second focus is on the genetic basis for tolerance with different methods. Differential transcriptomics of ash trees in the monitoring plots of FraxMon should lead to expression related markers for tolerance. A quantitative trait loci analysis of up to ten full-sib progenies will unravel the genetic architecture of ash dieback on the basis of genomic data. Analysis of phenolics will be correlated with expression levels of several transcripts and the tolerance status of plus trees and heavily damaged trees.

Research goals of FraxPath

The main focus of FraxPath is the investigation of the host–pathogen interaction between common ash and *H. fraxineus,* as well as other associated organisms, such as fungal endophytes and secondary pathogens, bacteria or viruses and secondary metabolites. The various symptoms of ash dieback (e.g. collar rots, shoot infections, leaf necroses) are being explored and innovative approaches to pathogen management and options for disease control are being developed, e.g. the use of antagonistic or hypervirulent microbial strains or RNAi-mediated control. Therefore, the influence of site factors on the development of collar rots and on ash microbiota, the aetiology and infection pathway for collar rots, and the role of the rhizosphere are studied. In addition, the transcriptomes of infected specimens of susceptible common ash and Manchurian ash, which has co-existed with the pathogen for a long time, are compared and differentially expressed gene markers of *H. fraxineus* as an indication of possible resistance should be identified.

Research goals of FraxSilva

The main goal is to test and develop silvicultural treatment options for the conservation and management of ash stands in the future. Therefore, FraxSilva conducts different research approaches both in forest environments and under controlled conditions. This includes the following research approaches: (i) identification of factors related to forest structure and stand treatment that influence the vitality of ash trees and stands; (ii) description and investigation of the ash dieback epidemiology under varying tree species compositions and mixing forms; (iii) determination of growth and competitiveness of natural ash regeneration in mixed stands affected by European ash dieback; (iv) assessment of collapsing ash stands and silvicultural management options with a focus on natural adaptation processes of ash populations and alternative tree species; and (v) review and

Table 1 Site characteristics of the intensive monitoring plots (Intensivbeobachtungsflächen, IBF plots); Lat/Long: latitude and longitude in WGS84, MAP: mean annual precipitation (1991–2020), MAT: mean annual temperature (1991–2020), SE: south-east, SW: south-west, NNE: north-north-east, SSW: south-south-west, N: north, NE: north-east, NNW: north-north-west, N: north

ID	Forest site, federal state	Lat/ Long	Elevation above sea level (m)	Exposition/ Inclination	Climate/ MAP (mm)/ MAT (°C)	Soil water supply	Nutrient supply	Soil type (German nomenclature)	Bedrock	Specific characteristics
BB_1	Stegelitz, Brandenburg	53.186/ 13.954	85	SE / 1°	Sub-continental, planar / 549 / 9.1	Wet, gleysol, groundwater 20–100 cm below surface	Mesotrophic-eutrophic	Gley-Parabraunerde	Sandy loess over marly till	20% of the site is a partly flooded bog with histic gleysols
BW_1	Plattenwald, Baden-Wuerttemberg	49.018/ 8.874	291	SW / 2°	Sub-atlantic, colline / 752 / 10.2	Slightly moist, periodically stagnic, high soil water storage	Eutrophic	Pelosol-Braunerde	Solifluctic claystone over calcareous claystone	
BW_2	Weisweil, Baden-Wuerttemberg	48.23/ 7.682	180	Flat	Sub-atlantic, planar / 749 / 11.2	Periodically wet-dry, groundwater mostly at 150–250 cm	Highly eutrophic, calcareous, deeply humic	Auenvega	Flood plain deposits and sediments	High flooding amplitudes due to the close-by Rhine river
BY_1	Monheim, Bavaria	48.807/ 10.795	530	NNE / 9°	Sub-atlantic-sub-continental, colline / 759 / 8.5	Slightly moist, periodically stagnic, slope interflow	Highly eutrophic, calcareous	Pseudogley-Parabraunerde	Loamy loess over colourful breccia	
BY_2	Bruckberg, Bavaria	48.483/ 11.952	412	Flat	Sub-continental, colline / 758 / 9.3	Periodically wet-dry, groundwater mostly at 150–250 cm	Highly eutrophic, calcareous, deeply humic	Auenvega	Flood plain deposits and sediments	
BY_3	Isen, Bavaria	48.196/ 12.082	551	SSW / 7°	Sub-continental, sub-montane / 994 / 8.8	Rather moist, periodically stagnic, slope interflow	Eutrophic, deeply humic	Pseudogley-Kolluvisol	Colluvial deposits over marly till	
HE_1	Schotten, Hesse	50.48/ 9.127	338	N / 5°	Sub-atlantic, colline / 934 / 9	Rather moist, predominantly stagnic, slope interflow	Eutrophic	Braunerde-Pseudogley	Solifluctic basalt	
MV_1	Karlsburg, Mecklenburg-Western Pomerania	54.067/ 13.451	31	NE / 1°	Sub-atlantic-sub-continental, planar / 633 / 9	Slightly moist, periodically stagnic	Eutrophic	Pseudogley-Pararendzina	Marly till	
NI_1	Mollenfelde, Lower Saxony	51.532/ 9.777	343	SSW / 8°	Sub-atlantic, colline / 781 / 8.6	Slightly moist, slightly stagnic in deep layers	Eutrophic, calcareous	Pelosol	Solifluctic basalt over limestone	

Table 1 (continued)

ID	Forest site, federal state	Lat/ Long	Elevation above sea level (m)	Exposition/ Inclination	Climate/ MAP (mm)/ MAT (°C)	Soil water supply	Nutrient supply	Soil type (German nomenclature)	Bedrock	Specific characteristics
SN_1	Leutzsch, Saxony	51.361/ 12.324	103	Flat	Sub-continental, planar / 568 / 10.2	Slightly moist, high soil water storage, rare flooding, groundwater mostly at 150–250 cm	Eutrophic, deeply humic	Auenvega	Flood plain deposits and sediments	
SN_2	Bienhof, Saxony	50.815/ 13.954	478	NNW / 5°	Sub-continental, sub-montane / 766 / 8.1	Rather moist, periodically stagnic, slope interflow	Mesotrophic-eutrophic	Pseudogley-Braunerde	Basalt over gneiss	
ST_1	Huy, Saxony-Anhalt	51.96/ 10.996	266	NNW / 20°	Sub-continental, colline / 652 / 8.9	Slightly moist, slight slope interflow	Eutrophic, calcareous	Terra Fusca	Solifluctic limestone over soliflutic claystone	
TH_1	Ettersberg, Thuringia	51.021/ 11.291	394	N / 10°	Sub-continental, colline / 630 / 8.5	Hardly moist, summer-dry	Eutrophic, calcareous	Terra Fusca-Parabraunerde	Loamy loess over limestone	Slightly moister hollow in the northern part
TH_2	Schwansee, Thuringia	51.077/ 11.097	166	Flat	Sub-continental, planar / 505 / 9.8	Wet, gleysol, groundwater at 30–80 cm	Highly eutrophic, calcareous, deeply humic	Auengley	Lake sediments	Former lake flood plain

Fig. 3 FraxForFuture—map of the intensive monitoring plots (IBF plots): The common field investigation platform of all project partners

revision of silvicultural recommendations on affected ash stands for forestry practice.

Research plots

Fourteen intensive monitoring plots (IBF plots, Fig. 3, Tables 1 and 2) distributed across Germany serve as a common working platform for investigations of all participating project partners. The purpose of this platform is to enable concerted monitoring, sample collection and collaboration of a wide range of scientific disciplines on shared plots and trees. The plots cover a wide range of ecoregions as well as the most common site and habitat types of common ash in Germany (Table 1). This includes a high differentiation in soil water supply (semi-dry, periodically flooded and stagnic- to hydromorphic-wet), substrates (calcareous, basaltic and claystone-dominated bedrocks) and covering deposits (eolian, fluviatile and colluvial deposits). Geology, soil and site properties were mapped in each plot using a 30×30 m grid with a soil auger at a depth of 150 cm. Soil chemical and physical properties were determined at 200 cm following the methods of the German soil inventory (BZE II, Höhle et al. 2018).

All plots are located in deciduous, broad-leaved mixed forests with a substantial share of *F. excelsior.* The plots contain a core area of one hectare, where all tree individuals with more than 70 mm dbh (diameter at breast height) have been marked, their positions georeferenced, and their attributes (species, height, dbh, dominance-class) recorded. Each plot contains a minimum of 30 adult ash trees with a broad spectrum of tree vitality and ash tree regeneration. In order to monitor the regeneration, parts of the core areas are fenced against deer browsing. During the project no felling is planned for within the IBF plots. However, some research disciplines need to undertake destructive sampling, therefore ash trees are available in the close surrounding area of the IBFs for extraction. The structure of three IBF plots (BY_2, BY_3, and TH_2) differs to some extent, because they were not set up with the rest of the plots when the project FraxForFuture started, but were integrated into the IBF platform afterwards from previous investigations or projects.

The health of all ash trees within all IBF plots is visually assessed from the ground twice a year (starting in 2021) using the aforementioned ash dieback assessment key (Peters et al. 2021a, b) to track spatial and temporal changes of damage patterns. Additionally, most of the IBF plots are monitored with remote sensing techniques (aerial stereo photography, hyperspectral imaging). The ground-based assessments are used as training data for the development of an airborne system to identify ash trees and estimate crown damage classes. Furthermore, the abundance of ash saplings and the degree of infection in the natural regeneration are assessed systematically over 1% of the area.

Conclusion and outlook

Two of the main research milestones for the FraxForFuture project have already been reached. First was the establishment of a nationally applicable disease severity index and monitoring keys based on summer and winter monitoring of ash trees affected by European ash dieback (Peters et al. 2021a, b). Second was the selection and mapping of suitable joint investigation and intensive monitoring plots (ibid).

The complex of symptoms associated with European ash dieback has prompted Peters et al. (2021b) to recommend individually recording the different disease characteristics using separate "modules" in the monitoring keys, where they were previously jointly assessed. So far, there is no consensus on which symptoms or markers are suitable to indicate the overall health status of ash trees affected by European ash dieback and which symptoms are potentially lethal or only accompanying. A set of appropriate indicators to predict disease progression can be used in models for single

Table 2 Forest stand information for the intensive monitoring plots (Intensivbeobachtungsflächen, IBF plots), dbh = diameter at breast height, 1.3 m above ground, na: not available at the moment

ID	Forest site, federal state	Tree age [y]	Fence	dbh range of ash trees [mm]	dbh of mean basal area ash tree [mm]	dbh of the upper 10th quantile [mm]	Number of ash trees	Species composition [% of basal area, min 10%]
BB_1	Stegelitz, Brandenburg	Unknown	Small area fenced	200–1010	426	668	112	*Fraxinus excelsior* 41% *Alnus glutinosa* 37% *Fagus sylvatica* 10%
BW_1	Plattenwald, Baden-Wuerttemberg	Unknown	Fully fenced	70–520	275	421	235	*Fraxinus excelsior* 50% *Quercus* 37%
BW_2	Weisweil, Baden-Wuerttemberg	60–79	Fully fenced	73–770	415	640	94	*Fraxinus excelsior* 45% *Acer pseudoplatanus* 30% *Acer platanoides* 12%
BY_1	Monheim, Bavaria	Unknown	Fully fenced	70–780	386	599	224	*Fraxinus excelsior* 55% *Carpinus betulus* 26%
BY_2	Bruckberg, Bavaria	Unknown	No fence	118–713	458	670	53	na
BY_3	Isen, Bavaria	Unknown	No fence	136–674	424	612	50	na
HE_1	Schotten, Hesse	124	Half fenced	75–1115	535	843	45	*Fraxinus excelsior 37% Carpinus betulus 26% Acer pseudoplatanus 19% Fagus sylvatica* 14%
MV_1	Karlsburg, Mecklenburg-Western Pomerania	126–137	Half fenced	155–913	637	837	123	*Fraxinus excelsior* 69% *Fagus sylvatica* 13% *Acer platanoides* 11%
NI_1	Mollenfelde, Lower Saxony	100	Half Fenced	71–680	384	579	111	*Fraxinus excelsior* 46% *Fagus sylvatica* 16% *Larix decidia* 19%
SN_1	Leutzsch, Saxony	Up to 157	Fully fenced	190–1130	684	1017	38	*Fraxinus excelsior* 36% *Acer pseudoplatanus* 31% *Fagus sylvatica* 14%
SN_2	Bienhof, Saxony	49–66	Fully fenced	75–700	241	410	175	*Fraxinus excelsior* 34% *Acer pseudoplatanus* 34% *Betula pendula* 26%

Table 2 (continued)

ID	Forest site, federal state	Tree age [y]	Fence	dbh range of ash trees [mm]	dbh of mean basal area ash tree [mm]	dbh of the upper 10th quantile [mm]	Number of ash trees	Species composition [% of basal area, min 10%]
ST_1	Huy, Saxony-Anhalt	90	Half fenced	70–420	261	386	104	*Fagus sylvatica* 54% *Fraxinus excelsior* 26% *Acer pseudoplatanus 10%*
TH_1	Ettersberg, Thuringia	Approx. 70	Half fenced	110–480	275	392	180	*Fraxinus excelsior* 30% *Betula pendula* 24% *Carpinus betulus* 24% *Fagus sylvatica* 10%
TH_2	Schwansee, Thuringia	Approx. 70–80	No fence	na	na	na	na	na

trees and scaled up with remote sensing techniques for whole stands and regions. At the end of the FraxForFuture project, the goal is to develop an "Integrative Damage Index" based on continuous monitoring of the vitality of many ash trees at various locations in Germany. The results of this monitoring, especially on the intensive monitoring plots, should allow for reliable statements about the probability of survival or resilience, and thus determine the value of breeding individual ash trees. Ultimately, the FraxForFuture "Integrative Damage Index" can represent a fundamental base for the identification of resilient ash trees, which ensures the long-term preservation of this tree species.

The design of FraxForFuture as a demonstration project means that, in addition to the immediate findings on ash dieback and forestry management, other important elements in the research process will be studied and evaluated. This research network is the first of its kind in Germany to develop a coordinated approach to recording, describing and handling a forest disease, utilising ash dieback as a case study. Thus, for example, relevant and competent research partners are to be identified in order to establish a transdisciplinary research network for addressing a complex research question in the case of an emerging new disease. The challenge of establishing such a network will likely be faced by other researchers and research funding agencies in the future. Ash dieback, as a multifaceted forest disease, is hence exemplary for similarly extensive and anticipated research efforts. Therefore, it has to be clarified which technical competences are needed, who covers them in Germany, and into which sub-tasks a complex research question needs be broken down. The process of collaboration between these partners must be organised, structured, and moderated, during the preliminary planning stage as well as while the research is being conducted. Therefore, permanent structures should be established in preparation for other anticipated far-reaching damages in forests and for an effective nationwide management of such events.

The demonstration approach is also reflected in the publication and communication strategy. A fairly unique feature of the project is the addition of the FraxConnect network to organise and improve communication and public relations. This enables the establishment and maintenance of a webpage (https://www.fraxforfuture.de), project conferences and a powerful project database for the long-term availability and exchange of all collected data to facilitate joint analyses and publications. A special issue in the Journal of Plant Diseases and Protection is planned for 2024 to jointly publish important results of FraxForFuture as peer-reviewed articles. Besides the articles already published by various associated research groups (e.g. Halecker et al. 2020; Lutz et al. 2022a, b), the special issue will include joint publications between sub-networks and sub-projects. In addition, other knowledge transfer tools are being used that are very important for informing forestry practice. The results of FraxForFuture are being incorporated into publications in German forest magazines (e.g. Fussi 2021; Peters et al. 2021a; Steinigen 2021), forest protection information, short communications and leaflets from forest research institutes (e.g. Metzler 2010; NW-FVA 2016), workshops, lectures and training excursions. Therefore, the work and structure of FraxForFuture should be viewed as an example of concerted research on an emerging disease, with the goal of developing a management strategy to eradicate or control the pathogen and thereby conserve the affected species, an example that can be applied to other emerging forest diseases in the future.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest. There are only non-financial research interests, related directly or indirectly to this work submitted for publication.

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