EUROPEAN FOREST INSTITUTE
ATLANTIC EUROPEAN REGIONAL OFFICE – EFIATLANTIC

Destructive Storms in European Forests:

Past and Forthcoming Impacts

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Executive Summary

Storm Damage and Classification

- More than 130 separate wind storms have been identified as causing noticeable damage to European forests in the last 60 years (~2/year).
- Storms are responsible for more than 50% of all primary abiotic and biotic damage by volume to European forests from catastrophic events.
- Storm damage is categorized in this report into 3 components:
  - Primary damage: Initial mechanical damage to the trees caused by the storm
  - Secondary damage: Subsequent damage following the initial wind storm. This is mostly from bark beetles, but can be from other biotic factors, fire, sun, snow/ice and even additional wind damage.
  - Tertiary damage: Loss of production in shortened forest rotations and other long-term constraints on forest operations
- A proposed storm classification has been developed based on the percentage of growing stock (%GS) initially damaged (primary damage) by the storm.
- 11 Storms (January 1953, September 1967, September 1969, November 1972, October 1987, January-March 1990, December 1999, November 2004, January 2005, January 2007, January 2009) were selected for study in greater detail.
- An extensive database of storms; and a more detailed database for the 11 specific storms have been created. These are available online at: http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue

Contributing Factors

- The amount and location of storm damage and the vulnerability of forest stands is a complex interaction between the meteorological conditions and stand location, soil type, stand composition, and past forest management.
- The evidence for the impacts of certain forest operations, species choices or site conditions is often weak, missing or contradictory. Therefore, we have only made statements when there is clear scientific evidence to support these statements.
- Gust peak wind speed is strongly correlated to the maximum potential levels of damage:
  - No appreciable damage for gust peak wind speeds below 30 ms^{-1}
  - Moderate levels of damage (maximum damage up to 2% of national growing stock) for gust peak wind speeds between 30 ms^{-1} and 40 ms^{-1}
  - High levels of damage (maximum potential damage between 2 - 4% of national growing stock) for gust peak wind speeds between 40 ms^{-1} and 45 ms^{-1}
  - Severe levels of damage (maximum potential damage > 4% of national growing stock) for gust wind speeds above 45 ms^{-1}.
- Tree height has an important impact on vulnerability.
- Statistical analysis of storm damage suggests that spruces and poplar are among the most vulnerable and silver fir and oak among the least vulnerable respectively of the conifers and broadleaves. However, such differences, and

the generally higher susceptibility of conifers to damage, are confounded by differences in species management and the choice of sites on which they are planted.

- Soil condition is very important. Root anchorage strength is increased by soil freezing, and reduced by water-logging and heavy rain and by poor drainage that allows soil saturation during storms.
- Recent thinning, particularly in older stands, is often associated with increased damage.
- The vertical structure of stands (e.g. irregular versus regular) appears to have little influence on stability.
- Taking any site or stand factor in isolation as a way of assessing vulnerability and/or risk of a forest can be completely misleading.

Current and Future Trends

- The increase of growing stock and average forest age across Europe in the last 60 years has contributed to the increase of observed damage.
- If the total growing stock and average age of European forests continues to increase there will be a proportional increase in the volume of storm damaged trees.
- There is some evidence that storm intensity is increasing and that storm tracks are penetrating further into mainland Europe and along a wider swathe, increasing the risk to forests in Eastern Europe.
- With climate change, higher temperatures will lead to longer periods of unfrozen soils during European winters, potentially leading to an increase in damage particularly in Fennoscandia.
- Storms will tend to be accompanied by heavier rainfall leading to more saturated soils and increased risk of wind damage.
- If the current build-up of growing stock continues together with predicted changes to the climate, damage levels are expected to at least double, and possibly quadruple, by the end of the century.
- Best current estimates suggest that storm damage to European forests results in an annual reduction of 2% in the carbon sequestration by forests. This figure could exceed 5% by the end of the century if the current build-up of growing stock continues.

Existing Responses to Storms

- There is no consistent recording and reporting system for wind damage across Europe or for reporting damage from different hazards (abiotic and biotic). This leads to uncertainties in relative levels of wind damage within different parts of Europe and in assessing the importance of specific hazards.
- There is a large amount of information and knowledge within Europe on the causes of forest storm damage and the best methods for dealing with their aftermath. However, this information is widely dispersed, is often out-of-date and may only be available in certain languages.
- Most countries in Europe affected by storm damage to forests respond in a similar manner. This includes providing subsidies for harvesting, transport and

forest restoration, the short-term derogation of controls, and the production of guidelines on the best methods to re-establish or regenerate the storm affected forests. The similarity in approaches makes the production of a European wide set of generic advice, best practice guidelines and policy instruments a possibility.

Résumé de point clefs

Dégâts de tempête et classification

- Plus de 130 tempêtes différentes ont été identifiées comme ayant causé des dégâts significatifs aux forêts européennes lors des 60 dernières années (soit en moyenne près de 2 par an).
- Les tempêtes sont à l'origine de plus de 50% des dégâts d'origine catastrophique affectant les forêts européennes tous agents confondus. C'est plus que tous les autres agents biotiques et abiotiques réunis.
- Les dégâts de tempêtes sont classés dans ce rapport selon trois catégories:
  - Les dégâts primaires : dégâts initiaux mécaniques affectant les arbres juste après la tempête,
  - Les dégâts secondaires : dégâts affectant les arbres dans un deuxième temps. Il s'agit essentiellement d'attaques d'insectes sous corticaux, mais ce peut être d'autres agents biotiques, le feu, la neige ou la glace, voire d'autres coups de vent.
  - Les dégâts tertiaires : Pertes de production due au raccourcissement des durées de révolution et autres contraintes impactant la gestion forestière sur le long terme.
- Un classement des tempêtes basé sur le pourcentage du volume de bois sur pied (%GS) constituant les dégâts primaires a été proposé.
- 11 tempêtes ont été sélectionnées pour faire l'objet d'une étude plus détaillée : Janvier 1953, Septembre 1967, Septembre 1969, Novembre 1972, Octobre 1987, Janvier-Mars 1990, Décembre 1999, Novembre 2004, Janvier 2007, Janvier 2009.
- Le projet a permis la documentation d'une vaste base de données listant les tempêtes disponibles sur http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue complétée de descriptions plus détaillées pour les 11 tempêtes étudiées en détail.

Facteurs explicatifs

- L'importance et la localisation des dégâts, ainsi que la vulnérabilité des forêts au vent est le résultat d'interactions complexes entre les conditions météorologiques, le type de sol, la composition des massifs forestiers et la gestion passée du peuplement forestier.
- Les démonstrations de l'impact de certaines opérations sylvicoles, du choix des espèces ou des caractéristiques situationnelles sont souvent peu robustes, partiales ou contradictoires. En conséquence, ce document ne liste que les affirmations reposant sur des bases scientifiques fiables.
- La vitesse des rafales de vent est fortement corrélée au maximum de dégâts potentiels :
  - Pas de dégâts notables pour des rafales de moins de 30 ms^{-1}
  - Des dégâts potentiels modérés (maximum de dégâts inférieur à 2% du volume sur pied national) pour des rafales de vent entre 30 et 40 ms^{-1}

  - Des dégâts potentiellement importants (maximum de dégâts entre 2 et 4% du volume sur pied national) pour des rafales entre 40 et 45 ms^{-1}
  - Des dégâts potentiellement très sévères (maximum de dégâts supérieurs à 4% du volume sur pied national) pour des rafales au-dessus de 45 ms^{-1}
- La hauteur des arbres est un facteur important de leur vulnérabilité.
- L'analyse statistique de dégâts de tempête suggère que les épicéas et le peuplier sont les espèces les plus vulnérables et le sapin pectiné et le chêne les moins vulnérables des résineux et feuillus respectivement. Cependant, ces différences, de même que la plus forte sensibilité des conifères, sont partiellement masquées par les choix de gestion et d'essences assignées à chaque station.
- L'état du sol est très important. La force de l'ancrage racinaire est accrue par la congélation du sol mais réduite par des sols chargés en eau par exemple lors de fortes pluies associées à un drainage déficient qui entraine une saturation en eau du sol.
- Une éclaircie récente, en particulier chez des peuplements âgés, induit souvent des dégâts dus au vent plus importants.
- La structure verticale des peuplements (réguliers ou irréguliers) ne semble avoir que peu d'influence sur la stabilité des peuplements.
- Ne considérer qu'un seul descripteur de site ou de peuplement de manière isolée pour évaluer la vulnérabilité ou le risque tempête en forêt peut conduire à des erreurs grossières.

Tendance actuelle et future

- L'augmentation continue du volume sur pied et de l'âge moyen des peuplements forestiers en Europe au cours de 60 dernières années explique en partie l'augmentation des volumes affectés par les tempêtes.
- Les niveaux de dommages sont susceptibles d'au moins doubler d'ici la fin du siècle si l’accumulation du bois sur pied continue au même rythme.
- Il y a des preuves comme quoi l'intensité des tempêtes augmente et que les trajectoires des tempêtes pénètrent de plus en plus profondément à l'intérieur de l'Europe étendant la surface susceptible d'avoir des dégâts jusqu'aux pays d'Europe de l'Est.
- Le changement climatique induira des températures plus élevées qui génèreront des périodes sans gel du sol plus longues qui pourront s'accompagner d'une hausse des dégâts de tempête en particulier dans les pays scandinaves.
- Les tempêtes auront tendance à être accompagnées de pluies plus fortes qui satureront les sols plus vite et augmenteront le risque de dégâts.
- Si l'accroissement du volume de bois sur pied dans le futur suit l'évolution actuelle, les changements climatiques annoncés doubleront, voire quadrupleront le niveau de dégâts dus aux tempêtes d'ici la fin du siècle.
- Les meilleures estimations du moment évaluent à 2% les pertes de séquestration de carbone par les forêts au niveau européen dues aux dégâts de tempête. Ce chiffre pourrait atteindre 5% d'ici la fin du siècle si l’accumulation du bois sur pied continue au même rythme.

Les réponses actuelles aux tempêtes

- Il n'y a pas de système harmonisé pour enregistrer et analyser les dégâts dus au vent en Europe ni pour restituer de manière homogène l'ensemble des dégâts générés par différents agents biotiques ou abiotiques. Ceci occasionne des incertitudes quand à l'importance relative des dégâts causés par le vent selon les régions d'Europe, et à la hiérarchisation des différents aléas.
- Les informations et les connaissances sur les dégâts causés par les tempêtes en Europe et comment en gérer les conséquences sont importantes. Cependant, cette information est dispersée, souvent obsolète et disponible seulement dans quelques langues.
- La plupart des pays touchés affectés par une tempête mettent en place des mesures similaires. Ces mesures incluent des aides pour l'exploitation, le transport et la régénération de forêts, des dérogations temporaires, et la création de guides pour la reconstitution des forêts endommagées. La similitude des réponses rend possible à l'échelle de l'Europe de définir des recommandations générales à appliquer après une tempête, la création d'un guide de bonnes pratiques et le développement d'outils politiques adaptés.

Zusammenfassung

Sturmschaden und Klassifizierung

- Mehr als 130 verschiedene Stürme wurden identifiziert, die schwerwiegende Schäden in den letzten 60 Jahren (~2/Jahr) in den Wäldern Europas verursacht haben.
- Stürme sind für mehr als 50% aller primären abiotischen und biotischen Schäden in Bezug auf das Holzvolumen aufgrund von katastrophalen Ereignissen in europäischen Wäldern verantwortlich. Sturmschaden ist in diesem Bericht nach 3 Komponenten klassifiziert:
  - Primärschaden: direkter Schaden durch Sturm (Windwurf)
  - Sekündärschaden: Folgeschäden nach Windwurf. Meistens verursacht durch Borkenkäfer oder andere biotische Faktoren wie Feuer, Sonne, Schnee/Eis oder durch zusätzliche Windschäden.
  - Tertiärschaden: Produktionsverlust aufgrund verkürzter Umtriebszeiten und anderer langfristiger Einschränkungen in der Forstnutzung
- Eine Klassifizierung von Stürmen wurde auf der Grundlage des prozentualen Anteils des vom Sturm beschädigten Vorrats (%Vorrat) entwickelt (Primärschaden).
- 11 Stürme (Januar 1953, September 1967, September 1969, November 1972, Oktober 1987, Januar-März 1990, Dezember 1999, November 2004, Januar 2005, Januar 2007, Januar 2009) wurden für eine genauere Untersuchung ausgewählt
- Eine umfassende Sturm-Datenbank sowie eine detailliertere Datenbank für die 11 ausgewählten Stürme wurde aufgebaut. Diese sind online verfügbar unter: http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue

Einflussfaktoren

- Das Ausmaß von Sturmschäden und die Schadensanfälligkeit von Beständen ist eine komplexe Interaktion zwischen meteorologischen Bedingungen, Standort, Bodentyp, Bestandeszusammensetzung und vorangegangener Waldbewirtschaftung.
- Der Nachweis für die Auswirkungen bestimmter Waldbewirtschaftungsmaßnahmen, Wahl der Baumarten oder Standortsbedingungen ist oft schwach, nicht vorhanden oder widersprüchlich. Deshalb haben wir nur Aussagen gemacht, wenn es einen klaren wissenschaftlichen Beleg gibt, der diese Aussagen stützt.
- Die Windgeschwindigkeit in Spitzenböen korreliert stark mit dem potentiellen Schadensausmaß:
  - Kein nennenswerter Schaden für Windgeschwindigkeiten in Spitzenböen unter 30 ms^{-1}
  - Moderate Schäden (0 – 2% des Vorrats) für Windgeschwindigkeiten in Spitzenböen zwischen 30 ms^{-1} and 40 ms^{-1}

- Hohe Schäden (2 – 4% des Vorrats) für Windgeschwindigkeiten in Spitzenböen zwischen 40 ms^{-1} and 45 ms^{-1}
    - Schwere Schäden (> 4% des Vorrats) für Windgeschwindigkeiten in Spitzenböen über 45 ms^{-1}
- Die Baumhöhe hat einen wesentlichen Einfluss auf die Schadensanfälligkeit.
- Fichte und Pappel zeigen in statistischen Auswertungen die höchste Sensitivität gegenüber Sturmschäden innerhalb der Nadel- und Laubbäume, während Tanne und Eiche am wenigsten betroffen sind. Allerdings werden diese Unterschiede, wie auch die generell höhere Schadensanfälligkeit der Nadelhölzer, von Bewirtschaftungsmethoden und Standortswahl der Baumarten überdeckt.
- Der Bodenzustand ist sehr wichtig. Die Wurzeln sind bei gefrorenen Böden besser und bei Staunässe, starkem Regen und schlechter Drainage, die zu einer Sättigung der Böden während der Stürme führt, schlechter im Boden verankert.
- Kurz vor Stürmen durchgeführte Durchforstungen, besonders in älteren Beständen, sind oft mit einem erhöhten Schaden verbunden.
- Die vertikale Struktur von Beständen (z.B. vielschichtig oder einschichtig) scheint wenig Einfluss auf die Stabilität zu haben.
- Standort- oder Bestandesfaktoren isoliert zu betrachten, um die Schadensanfälligkeit und/oder das Risiko eines Waldes zu beurteilen, kann (völlig) irreführend sein.

Gegenwärtige und zukünftige Trends

- Die Zunahme des Vorrats und des Durchschnittsalters europäischer Wälder während der letzten 60 Jahre hat zu einer Zunahme der beobachteten Schäden beigetragen.
- Wenn der Vorrat und das Durchschnittsalter der europäischen Wälder weiter ansteigt, wird das Volumen der sturmgeschädigten Bäume proportional ansteigen.
- Aufgrund höherer Temperaturen werden Böden in den Wintermonaten für längere Zeit nicht gefroren sein. Dies kann eine größere Sturmanfälligkeit, v.a. in Fennoskandinavien nach sich ziehen.
- Tendenziell werden Stürme von schwereren Regenfällen begleitet werden, die zu erhöhter Wassersättigung der Böden und einem höheren Windschadensrisiko führen.
- Die Schadholzmenge wird sich, falls der momentane Trend ansteigender Holzvorräte weiter anhalten sollte, bis Ende des Jahrhunderts mindestens verdoppeln, möglicherweise sogar vervierfachen.
- Falls der momentane Trend ansteigender Holzvorräte weiter anhält und sich die vorhergesagten klimatischen Veränderungen bewahrheiten, könnte sich die Schadholzmenge bis Ende des Jahrhunderts mindestens verdoppeln, möglicherweise sogar vervierfachen.
- Die besten gegenwärtigen Schätzungen gehen davon aus, dass Sturmschäden zu einer Reduzierung der Kohlenstoffbindung um 2% im Jahr in europäischen Wäldern führen. Diese Zahl könnte 5% am Ende des Jahrhunderts übersteigen, wenn der Vorrat weiterhin wie bisher ansteigt.

Bereits bestehende Sturmbewältigungsmaßnahmen

- Es existiert kein konsistentes Erfassungs- und Berichtssystem für Windschäden oder andere Schäden (abiotisch und biotisch) in Europa. Dies führt zu Unsicherheiten in der Abschätzung von Windschäden und anderer Schadereignisse sowie in der Beurteilung in deren Wichtigkeit in verschiedenen Teilen Europas.
- Es gibt eine große Fülle an Informationen und Wissen in Europa zu den Ursachen von Sturmschäden in Wäldern und effektiven Verfahren, um diese zu bewältigen. Diese Informationen sind jedoch oft nicht zugänglich, veraltet und häufig nur in der jeweiligen Landessprache verfügbar.
- Die meisten europäischen Länder, die von Sturmschäden betroffen sind, ergreifen ähnliche Maßnahmen. Diese beinhalten Subventionen für Holzernte, Transport und den Wiederaufbau des Waldes, das kurzfristige Einsetzen von Ausnahmevorschriften, und die Entwicklung von Leitfäden zu effektiven Verfahren. Die Ähnlichkeit der Ansätze würde es erlauben, europaweite Richtlinien zu allgemeinen Arbeitshilfen und bewährten Verfahren zu erstellen und Politikinstrumente zu erarbeiten.

Sammanfattning

Stormskador och klassificering

- Fler än 130 separata stormar som orsakat märkbara skador på europeiska skogar under de senaste 60 åren har identifierats (~2/år).
- Stormar står för mer än 50% av alla abiotiska och biotiska skador per volym i europeiska skogar till följd av katastrofartade händelser.Stormskador kategoriseras i denna rapport i tre klasser:
  - Primära skador: Initiala mekaniska skador på träden orsakade av stormen
  - Sekundära skador: Skador efterföljande den initiala stormen. Dessa orsakas vanligen av barkborrar men kan orsakas av andra biotiska faktorer, brand, sol, snö/is och till och med ytterligare vindskada.
  - Tertiära skador: Produktionsförluster genom förkortade omloppsperioder och annan långvarig begränsning av skogliga åtgärder
- En föreslagen klassificering av stormar har utvecklats baserat på andelen stående volym (%) initialt skadad (primär skada) av stormen.
- 11 stormar (januari 1953, september 1967, september 1969, november 1972, oktober 1987, januari-mars 1990, december 1999, november 2004, januari 2005, januari 2007, januari 2009) valdes ut för mera ingående studium.
- En omfattande databas över stormar och en mera detaljerad databas för de 11 utvalda stormarna har upprättats. Dessa är också tillgängliga på: http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue

Bidragande faktorer

- Stormskadornas omfattning och skogsbeståndens sårbarhet beror på ett komplext samspel mellan de meteorlogiska förhållandena och beståndens lokalisering, markförhållandena, beståndssammansättningen och tidigare skötsel.
- Bevisen för inverkan av vissa skogliga åtgärder, trädslagsval eller ståndortsfaktorer är ofta svaga, saknas eller är motsägelsefulla. På grund av detta har vi endast uttryckt påståenden när det finns tydligt veteskapligt stöd för dessa påståenden.
- Maximal byvindhastighet är starkt korrelerad till maximal potentiell skadenivå:
  - Inga märkbara skador för byvindhastigheter under 30 ms^{-1}
  - Moderat skadeomfattning (maximal skadeomfattning upp till 2% av den stående volymen) för maximal byvindhastighet mellan 30 ms^{-1} och 40 ms^{-1}
  - Omfattande skador (maximal skadeomfattning 2-4% av den stående volymen) för maximal byvindhastighet mellan 40 ms^{-1} och 45 ms^{-1}.
  - Allvarliga skador (maximal skadeomfattning >4% av den stående volymen) för byvindhastigheter över 45 ms^{-1}.
- Trädens höjd har en betydande inverkan på deras sårbarhet.
- Statistisk analys av vindskador indikerar att gran- och poppelträdslag är bland de mest sårbara och silvergran och ek bland de minst sårbara av barr- och

lövträd. Dessa skillnader, och den vanligen högre skadekänsligheten hos barrträd, kompliceras av skillnader i skötsel och val av ståndort för plantering.

- Markförhållandena är mycket viktiga. Styrkan hos rötternas förankring ökar med förekomst av tjäle och minskar vid hög markvattenhalt. Stora regnmängder under stormar och med dålig dränering som leder till att marken mättas på vatten.
- Nyligen utförd gallring, speciellt i äldre bestånd, är ofta förknippad med ökade skador.
- Beståndens vertikala struktur (t.ex. oregelbunden jämfört med regelbunden) verkar ha liten inverkan på stabiliteten.
- Att använda en enskild ståndorts- eller beståndsfaktor som ett sätt att bedöma sårbarheten och/eller risken för stomskada i en skog kan vara fullständigt missvisande.

Pågående och framtida trender

- Ökningen av den stående volymen och medelåldern hos skog i Europa under de senaste 60 åren har bidragit till ökningen av observerade skador.
- Om den stående volymen och trädens medelålde i de europeiska skogarna fortsätter att öka kommer detta att leda till en fortsatt ökning av stormskadorna.
- Det finns vissa tecken på att stormars intensitet ökar och att lågtrycksbanorna tränger djupare in över det europeiska fastlandet och längs ett bredare stråk vilket ökar risken för skogar i östra Europa.
- Högre temperaturer kommer att leda till längre perioder utan tjäle vintertid i Europa vilket potentiellt leder till ökade skador, särskilt i Fennoskandia.
- Stormar förväntas tendera att åtföljas av mera omfattande regnmängder vilket leder till mer vattenmättade marker och ökad risk för vindskada.
- Om den pågående uppbyggnaden av den stående volymen fortsätter liksom förutsagda klimatförändringar, förväntas skadenivåerna åtminstone fördubblas, och möjligen fyrdubblas, vid slutet av århundradet.
- Bästa uppskattning till dags dato innebär att stormskador i Europeiska skogar resulterar i en årlig minskning av kolinbindningen i skogar med 2%. Denna siffra kan överskrida 5% vid slutet av århundradet om den pågående uppbyggnade av den stående volymen fortsätter.

Befintlig respons på stormar

- Det finns inget samordnat noterings- och rapporteringssystem för vindskador i Europa inte heller för rapportering av skador för olika risker (abitiska såväl som biotiska). Detta leder till osäkerhet i bedömningen av relativa skadenivåer inom olika delar av Europa och i bedömningen av betydelsen av specifika riskfaktorer.
- Det finns omfattande information och kunskap inom Europa vad gäller orsakerna till stormskador i skog och de bästa metoderna för att hantera konsekvenserna av stormskador. Denna information är emellertid vitt utspridd, är ofta föråldrad och finns ibland tillgänglig endast på vissa språk.

- De flesta länder i Europa som påverkas av stormskador i skog reagerar på liknande sätt. Responsen innefattar att tillhandahålla stöd för avverkning, transporter och återplantering, kortvarigt hävande av restriktioner och tillhandahållande av instruktioner för hur man bäst återplanterar eller föryngrar den stormskadade skogen. Likheten i tillvägagångssätt inom Europa gör det möjligt att ta fram ett set av gemensamma råd, riktlinjer och policyinstrument.

Summary of Recommendations

- European Union Member States should develop forest storm risk management plans and procedures for dealing with the aftermath of storms. This could be facilitated by the provision of best practice information, guidelines and risk modelling tools at a single location in the languages of affected Member States, and in the setting up of pre-storm training for harvesting machine operators and crews
- The European Commission has a potential role in enhancing post-storm coordination between affected countries and in facilitating the rapid response to storm damage by putting in place procedures to minimise storm impact. This could be, for example, aiding the implementation of multilateral or bi-lateral cooperation plans following storms, triggering plans and emergency measures to allow quick access to funds, and the rapid implementation of short-term derogation of regulations to allow immediate storm clear-up and forest restoration.
- There is a clear requirement for the provision of a central source of up-to-date, appropriate and easily available information prior to and following storm events. Such information could consist of early warning systems for damaging storms, immediate maps of areas affected by storm damage using remote sensing, and the provision of information on global timber prices to assist in post-storm timber marketing.
- European Union Member States should work in partnership with insurance companies, to promote a harmonised and equitable insurance system across storm affected countries that properly compensates forest owners for their private losses.
- There is an urgent need to harmonize the monitoring and reporting of storm damage and all other hazards (abiotic and biotic) across Europe. Only with such a harmonised approach will it be possible for policy makers to make informed decisions on the mechanisms and appropriate levels of response to different threats to European forests.
- Active integrated management of all risks to forests (abiotic and biotic) should become part of standard forest practice in Europe.

Résumé des recommandations

- Les États de l'Union européenne devraient développer des plans de gestion du risque tempête et des procédures préétablies pour gérer les conséquences des tempêtes. Ceci pourrait être facilité par la mise en place de bonnes pratiques, de guides et de modèles pour la gestion des risques disponibles dans la langue de chaque pays ainsi que la mise en place de formation avant tempêtes pour les équipes chargées de l'exploitation et du dégagement.
- La Commission Européenne a un rôle à jouer en améliorant la coordination post-tempête entre les pays affectés, et en facilitant la mise en place de procédures pour limiter les impacts de la tempête. Ceci pourrait ce faire par exemple par le soutien de plans bilatéraux ou multilatéraux, déclenchant des mesures d'urgence pour un accès plus rapide aux fonds, et une mise en place rapide des dérogations de court-terme permettant un nettoyage des zones sinistrées et une reconstitution de la forêt immédiate.
- Il y a un besoin évident d'un point d'information central à jour, avec des informations pertinentes et facilement accessibles avant et après une tempête. Le type d'information que l'on pourrait trouver serait un système d'alerte précoce annonçant les tempêtes potentiellement dangereuses, une cartographie immédiate des zones affectées par télédétection et des informations sur les marchés du bois pour aider à la définition des mesures en faveur de la valorisation des bois de tempête.
- Les État de l'Union Européenne devraient travailler en partenariat avec les compagnies d'assurance pour promouvoir un système d'assurance équitable et harmonisé dans les pays concernés par les tempêtes de manière à compenser correctement les propriétaires forestiers de leurs pertes financières.
- Il y a urgence à harmoniser l'évaluation et la description des dégâts de tempête et des autres aléas (biotique et abiotique) en Europe. Ce n'est qu'après cette harmonisation qu'il sera possible aux décideurs politiques de prendre des décisions fondées sur des données fiables pour définir les mécanismes et les mesures appropriées aux différentes menaces qui pèsent sur les forêts
- La gestion active intégrant tous les risques des forêts (abiotiques et biotiques) doit maintenant faire partie des pratiques forestières standard en Europe

Zusammenfassung der Empfehlungen

- Die Mitgliedsstaaten der Europäischen Union sollten Risikomanagementpläne und Verfahren für Waldstürme entwickeln, um mit den Folgen von Stürmen besser umzugehen. Dies könnte erleichtert werden durch die Bereitstellung von bewährten Informationen, Handbüchern und Risikomodellen für einen bestimmten Ort in den jeweiligen Sprachen der betroffenen Mitgliedsstaaten sowie durch die Einrichtung von Schulungen für Lastwagenfahrer und Arbeiter in der Sturmholzaufarbeitung vor Sturmereignissen.
- Die Europäische Kommission könnte potentiell die Aufgabe übernehmen, die Koordination zwischen den betroffenen Ländern nach einem Sturm zu erhöhen und eine schnelle Reaktion auf Sturmschäden zu erleichtern, indem sie Verfahrensabläufe etabliert, die das Ausmaß von Stürmen minimieren. Dies könnte beispielsweise durch die Untersützung der Implementierung von multilateralen oder bilateralen Kooperationsplänen nach Stürmen oder durch die Veranlassung, Pläne und Katastrophenschutzmaßnahmen zu erstellen, die einen schnellen Zugang zu finanzieller Unterstützung erlauben, erreicht werden. Außerdem ist eine schnelle Durchsetzung von kurzfristigen Ausnahmeregelungen, die sofortige Aufräumarbeiten und den Wiederaufbau der Wälder erlauben, von Bedeutung.
- Es gibt einen eindeutigen Bedarf für die koordinierte Bereitstellung aktueller, adäquater und schnell verfügbarer Informationen vor und nach einem Sturmereignis. Solche Informationen könnten ein Frühwarnsystem für schädliche Stürme, die unmittelbaren Erstellung von Karten der sturmgeschädigten Flächen mit Hilfe der Fernerkundung, und die Bereitstellung von Informationen über die globalen Holzpreise für die Vermarktung des Holzes nach dem Sturm, sein.
- Die Mitgliedsstaaten der Europäischen Union sollten mit Versicherungsgesellschaften zusammenarbeiten, um ein harmonisiertes und gleichwertiges Versicherungssystem für alle sturmbetroffenen Länder zu fördern, das Waldbesitzer für ihre privaten Verluste entsprechend kompensiert.
- Es besteht dringender Bedarf, das Monitoring und die Berichterstattung von Sturmschäden und anderen Gefahren (abiotisch und biotisch) in Europa zu harmonisieren. Nur mit einem harmonisierten Ansatz wird es für die Politik möglich sein, fundierte Entscheidungen zu geeigneten Maßnahmen und deren raschen Umsetzung für die verschiedenen Gefahren in den Wäldern Europas zu treffen.
- Aktives, integriertes Management aller Risiken für Wälder (abiotisch und biotisch) sollte Teil der Waldbewirtschaftung in Europa werden.

Sammanfattning av rekommendationer

- Medlemsstater i den europeiska unionen bör utveckla skötselplaner för att hantera risken för stormskador på skog och för att hantera situationer som följer efter stormskada. Detta skulle kunna underlättas genom att tillhandahålla information om hur man bäst går tillväga, rekommendationer och riskmodelleringsverktyg för en given plats på de berörda medlemsländernas språk, och genom att organisera utbildning av skördaroperatörer och personal innan stormskada inträffar
- Den europeiska kommissionen har potentiellt en roll i att förstärka koordinationen mellan drabbade länder i händelse av stormskada och genom att underlätta snabb respons på stormskada genom att ta fram procedurer för att minimera konsekvenserna av stormen. Detta skulle exempelvis kunna ske genom att underlätta aktivering av multilaterala eller bilaterala samarbetsplaner i händelse av stormskada, utlösa planer och nödåtgärder för att snabbt göra medel tillgängliga, och för att snabbt införa tillfälliga undantag från regler för att därigenom göra omedelbar uppröjning och återbeskogning möjlig.
- Det finns en tydlig efterfrågan på en central källa tillhandahållande av uppdaterad, lämplig och lättillgänglig information före och efter stormskadehändelser. Sådan information skulle kunna bestå av tidiga varningssystem för skadande stormar, fjärranalysbaserade omedelbart genereradekartor över skadedrabbade områden och tillhandahållandet av information över globala virkespriser för att underlätta virkesförsäljning efter stormskada.
- Medlemsstater i den europeiska unionen bör arbeta tillsammans med försäkringsbolag för att ta fram ett harmoniserat och rättvist försäkringssystem mellan stormskadeutsatta länder som på ett tillbörligt sätt kompenserar skogsägare för deras privata förluster.
- Det finns ett brådskande behov av att harmonisera övervakning och rapportering av stormskador och alla andra risker (abiotiska och biotiska) över Europa. Bara med ett sådant harmoniserat tillvägagångssätt kommer det att bli möjligt för beslutsfattare att fatta välunderrättade beslut angående mekanismer och lämplig respons på olika hot mot europeiska skogar.
- Aktiv integrerad hantering av alla risker på skog (abiotiska och biotiska) borde ingå i standard europeiskt skogsbruk.

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We may have unintentionally missed names. If this is so we apologise and reiterate how grateful we are for all the help we have received.

1. Introduction

- **Forest and other wooded land within Europe cover 42 % of the land area and have a wide range of ecological, social and economic functions that continue to grow in importance.**
- **Wind storms have caused catastrophic damage to forests throughout history, but during the last century damage has increased markedly. Storms are now responsible for more than 50% of primary damage to European forests.**
- **Much of the damage increase can be related to forest expansion and change.**
- **Responses of foresters, researchers and policy makers to European storms have provided a large and valuable body of knowledge and expertise, but this is scattered.**
- **With an expanding forest and climate change, wind damage in Europe will continue to increase, and it is increasingly important that mitigation and management of forest storms is coordinated at a European scale**

European forests and woodland cover 177 million ha, equivalent to 42 % of the land area (Eurostat, 2008). Forests fulfil a range of vital functions for society in Europe, providing economic, social and environmental benefits, and serve as a key reservoir of biodiversity. More than 2 million people are directly employed in forest management, and primary forest-based industries. The sector currently has an estimated €300 billion turnover, representing 1.5 % of EU GDP.

Storms and other disturbances are an essential element of the dynamics of natural forest ecosystems driving regeneration and adaptation processes. They can occur as catastrophic events but also allow for small scale gap dynamics which modify stand structure and micro-climate. Small scale disturbances that affect individual trees or groups of trees within a stand can result in an increased amount of dead wood and a diversification of stand structure with positive benefits for the diversity of fauna and flora. Such small scale disturbances in managed forests can thus have positive effects on biological diversity, while damage for forest owners stay within acceptable limits. In cases where storm events are of larger magnitude they can cause considerable problems for managed forests. Extensive storm events can affect landscapes, the quality of wildlife habitats and the structure of forest stands, which can lead to major disruptions in management goals. They can also destroy the economic base for private forest owners and seriously affect timber markets and the wood processing industries. In the years following a storm the likelihood of insect infestations also increases the impact of the initial storm damage.

Wind is responsible for more than 50% of reported primary damage by volume to European forests from catastrophic events, including all biotic and abiotic damage (Schelhaas, 2008a). Storms have always affected forests and left evidence of damage behind them. For example, historical studies show that eighteen major wind storms affected France from 1500 to 1950 with two during the 16^{th} century, one in the 17^{th}

century, eight during the 18th century, five in the 19th century and two in the first part of the 20th century (Corvol, 2009).

Storms have long been a major concern for foresters, but since 1950, storms have caused increasing damage to forests (Schelhaas, 2003). This is probably due to two phenomena: the first part of the 20th century was quiet in terms of storms, compared with the two previous centuries, and forest sensitivity to wind has progressively increased with time due to new wooded areas (afforestation), new silvicultural regimes (high forests, plantation forestry, etc.) and to new economic and environmental conditions (less wood shortage, and rising productivity (EFI, 1999; Loustau, 2010).

Foresters have responded to the increasing damage by developing better methods to deal with the consequences, for example, improved salvage and storage, and new uses for timber (Jubertie, 2008). The experience gained from some storms has been used in order to develop more effective management for future events (for example 1953 and 1968 in UK, 1972 in Germany and Netherlands, and 1982 in France) and to develop research programmes to more comprehensively understand the causes and effects of wind damage to forests (for example 1987 in UK, 1990 in Germany, 1999 in France (Birot *et al*, 2009)). Uncertainties still remain but there is now a substantial body of knowledge of the mechanisms and incidence of wind damage to trees and forests (Gardiner *et al*, 2008). This knowledge has generally been developed at the country level and better integration of knowledge and expertise at the European level is desirable. This report is an attempt to synthesise and review much of the existing knowledge on storm damage to European forests and the mechanisms and factors controlling damage.
.
The European Commission DG Environment provided the following terms of reference that were followed in compiling the report:

- A1) To compile from scientific literature the elements needed for a classification of storms according to the intensity of their effects on forests, with a view to lay the basis for a widely acceptable standard (if such standard does not exist yet).
- A2) To assess, on the basis of historical meteorological and geographical data the occurrence of storms in EU27 Member States for the past 50 years and apply the A1 classification to create a consistent time series of the 30 most forest damaging storms during that period, paying due attention to differences in data quality across countries (forest statistics/records, time series consistency, density of meteorological stations, etc.), so to avoid countries with better data sets being over-represented.
- B1) To assess in both qualitative and quantitative manners the ecological, social and economical effects of a representative selection of 10 major storm events identified and classified under task A2. Each of these storms should be documented in a consistent and structured manner that would allow comparison in a tabular format.
- C1) For the 10 major storms identified and analysed in task B1, indicate possible links between their consequences and the most relevant pre-storm local conditions that may explain the extent of damages (type of forests, type of management, human population density, predominant forest use, etc.).
- C2) To assess and document the potential benefits and drawbacks of documented post storm interventions in and around the affected forests (B1 list).

- C3) Based on the findings of tasks C1 and C2, to carry out an analysis and a synthesis of "successful" policy mix to prevent and respond effectively and efficiently to the most severe storm damages.
- D1) Based on the findings of task B1, to review relevant scientific literature and synthesize the most accurate bio-climatic projections regarding storm occurrence, forest cover and forest damage up to 2100. A critical assessment of the trends identified in existing data shall be performed in order to allow for an evaluation of the predictive value of such a review.
- D2) Based on the findings of task D1 and a review of relevant scientific literature, to evaluate Green House Gas emissions/non-removals related to storm damages in forest for the period 2010-2100.
- E1) Based on the findings of tasks C and D1, to evaluate how the 2010-2100 period could compare to the 1960-2010 period and how it would come up (in terms of forest damages and consequences) if no coordinated early action was taken at EU level.
- E2) With reference to the policy mix identified in task C3, to assess if effective "storm proofing" or post storm policy measures are in force in the bodies of laws related to forests or civil protection, in EU countries that are or could become exposed to storm damages according to task D1.
- E3) To determine if other provisions for storm damages prevention/reduction exist in EU countries that are or could become exposed to major storm damages according to task D1.
- E4) Based on tasks E1 to E3, to develop an argument on whether or not EU action could improve the situation of European forests with regard to prevention of storm damage and restoration measures, such as provided for by the rural development Regulation or other existing EU instruments and to sketch out the shape of such possible measures.

In order to make progress towards these objectives, past wind storms in Europe from 1950 to 2010 have been compiled in a catalogue, described in **Chapter 2**. The latest storm that is included occurred on 28th February 2010 in western France. Vulnerability of trees and forest stands to wind damage is a result of the complex interaction between location, soil, stand composition, management and conditions at the time of the storm. From a database of more than 130 storm events, the 30 most damaging storms were extracted and we explored the range of factors influencing whether and how a storm will cause damage forests. Note that this report deals only with damage initiated by wind. Storm damage associated with ice and snow is on a much smaller scale in Europe, although it can be locally important (Nykänen *et al.*, 1997).

In **Chapter 3** a general discussion of the ecological, social and economic impact of storm damage to forests is presented. This is based on a review of studies carried out following storm damage in different parts of Europe and illustrates similarities and differences between the impacts in different countries and regions due to variations in forests and site types and socio-economic structures. To further illustrate these points eleven storms have been selected in **Chapter 4**, for a more in depth analysis. The logic behind their selection is explained in the chapter, followed by an analysis of each catastrophic storm in terms of the meteorological conditions, forest conditions, impact on the forest, and responses.

Recent analysis of storm damage shows an increase in storm damage to European forests over the last 50 years (Schelhaas, 2008a), and substantial research effort has been dedicated to understanding the complex mechanisms influencing storm damage. Available methods to alleviate the impacts of storms to forests are explored in **Chapter 5**, with an examination of the links between storm damage and forest conditions. This is followed in **Chapter 6** by an evaluation of relevant operational planning and response to storm events and provides guidelines for developing effective response systems and structures.

There is evidence that storm intensity is increasing (Leckebusch *et al.*, 2008a) and that storms are penetrating further into Europe and along wider tracks. In addition, climate forecasts predict increasing precipitation accompanying these storms and higher winter temperatures leading to longer periods of unfrozen ground. **Chapter 7** provides estimates of future damage up to 2100 and implications for GHG exchange. These estimates are based on increasing volume of growing stock of European forests, and climate change projections.

Current policies and legislation that is currently relevant to forest storm mitigation, crisis management, and post-storm response are identified at country and European levels in **Chapter 8**. In addition, this chapter presents results of a recent workshop held in Brussels on 'Policies for Forest Storm Damages, Mitigation and Restoration', which explored the effectiveness of current policies and identified where more effective systems are needed.

The implications of increasing forest storm damage in Europe is summarised in **Chapter 9**. This chapter also includes a series of policy recommendations that could reduce the ecological, social and economic effects across Europe, and assist countries, forest related industries, and communities to deal more effectively with the aftermath of storm damage to forests. It also attempts to identify policy gaps and the possibilities for a wider scale European response to storm damage.

A Glossary of key terms used in this report is provided at the end.

2. European Storm Classification

- **Storms are a common phenomenon in Europe, especially in winter and along the Atlantic coasts.**
- **A useful measure of storm severity is the maximum gust wind speed, but how this translates to forest damage depends on the characteristics of forests in the affected area.**
- **Trees can acclimate to windy conditions so that in more exposed parts of Europe trees may be better adapted to resist storm winds.**
- **Storm impacts to forests can be separated into Primary, Secondary and Tertiary damage.**
- **We propose a classification of forest storm damage that is simply the percentage of growing stock that is damaged in a defined area. For practical purposes we use the national level throughout the report.**
- **Forest storm damage interpretation and comparison across Europe is limited by the lack of a standardised system of damage reporting.**
- **A database of forest disturbance has been provided online that includes all recorded European forest storm damage between 1950 and 2010.**

2.1 Classification System

Storms are a common phenomenon in Europe. Most storms occur in winter, especially along the Atlantic coast (see Table 1 and Figure 3; Munich Re, 1990; Troen and Peterson, 1989; Riser, 2010: http://www.quae.com/fr/livre/?GCOI=27380100845170). A common measure of the severity of a storm in meteorological terms is the highest wind speed measured either gust wind speed (normally the highest wind speed measured over a 3 second period[1]) or average speed over a certain period. However, not all severe storms cause damage to the forest, and not all damage events to the forest are caused by the most severe events. Many storms have high wind speeds over the ocean and along the coastline, but do not cause high wind speeds further inland (Troen and Peterson, 1989). Also, the average wind climate of the region is of importance. Trees acclimate to windy conditions (Nicoll *et al.* 2008) by strengthening their anchorage, so a storm will cause less damage in an area where higher wind speeds are a regular occurrence than in an area where higher wind speeds are unusual. For example, for the UK, wind gust speeds of >45 ms^{-1} at inland locations are expected to cause catastrophic forest damage (Quine *et al.* 1995), while in Sweden, the maximum wind gust speed of the Gudrun (January 2005) storm, one of the most damaging storms in the last half century, was around 35 ms^{-1} at inland locations.

There are a number of possible severity indices that may be used to compare the impact of storms. The most simple are based on the maximum wind speed (e.g. Leckebusch *et*

[1] http://www.weather.gov/forecasts/graphical/definitions/defineWindGust.html

al., 2008) but others indices (*SSI*) are calculated from maximum wind speed (*Umax*), storm duration (*D*) and area damaged (*A*), e.g. Lamb and Frydendahl (1991).

However, in addition to wind speed, a number of other meteorological conditions have an impact on the amount of forest damage. Frozen soil will increase the resistance of trees to uprooting, while frozen stems are much stiffer than unfrozen stems (Silins *et al.* 2000). Heavy rain in the preceding days may weaken the soil and decrease the anchorage of the trees (Usbeck *et al.*, 2010a). Heavy rain or snow during the storm event may add considerable weight to the crowns and will be a particular problem if drainage is poor or poorly maintained and the water is unable to drain away. Individual broadleaves are believed to be more vulnerable when still in leaf (Peltola *et al.*, 1999), leading to more damage from summer or early autumn storms compared to a winter storm, however within a closed canopy there is no evidence of a difference.

The result is that the vulnerability of trees or forest stands to wind damage is a complex interaction between the location, the soil, the stand composition, the past management of the stand and the conditions at the time of the storm (Quine and Gardiner, 2007). Taking any factor in isolation as a way of assessing vulnerability and/or risk can be completely misleading.

Given the wide range of factors that play a role in wind damage occurrence in forests, it is most straightforward to classify storms based on their impact on the forest rather than on meteorological variables. Also in the insurance sector an impact-based classification system for storms is used. Storm impacts in the forest sector can be separated into:

1. Primary damage: Initial mechanical damage caused by the storm.
2. Secondary damage: Subsequent damage by, for example, bark beetles, fire, snow/ice or further wind.
3. Tertiary damage: Loss of production in shortened forest rotations and other long-term constraints on forest operation

Secondary and tertiary damage is not often reported and therefore not suitable as basis for a classification system. Primary forest storm damage is normally reported either volumetrically (volume wood damaged) or spatially (area of windthrown or snapped forest). Volumetric reporting for large European storms is usually millions m^3 of wind damaged timber. Spatial reporting is commonly in hectares of damaged forest. The area of windthrown or snapped forest can be distributed among damage classes (by volume), for example: from 0 to 20%, from 20 to 40%, from 40 to 60%, from 60 to 80% and more than 80%. The economic significance of the storm damage for the forest sector is often expressed as a percentage of average national removals. Both may be converted to average yearly damage figures for regional or national reporting. Data may also be presented proportionally, i.e. the percentage of the growing stock that is damaged, or the percentage of forest area that is damaged. The absolute total amount of wind damage is strongly dependent on the forest resources available in the affected area (Schelhaas *et al.* 2003). A good indicator for that is the total growing stock. We therefore propose classifying storms based on the percentage of growing stock that is affected. In this report we refer to growing stock and harvesting volumes at a national level because it is very difficult to separate damage to smaller administrative levels. When possible this has been done in the descriptions of the 11 storms selected for more detailed analysis and that are described in Chapter 4 and Appendix 3.

One disadvantage of an impact-based system is that it depends on the voluntary reporting of damage, since there is no (common) monitoring system for storm damage at the EU level. Smaller events are less likely to be reported, and reports can be difficult to obtain. For example in the UK, minor damage is often not reported, but damaged timber is just salvaged during the next harvesting operation. Holmsgaard (1986) estimated that only half of the damage in Denmark was officially reported. Moreover, the accuracy of reported damage is uncertain and estimates vary or change over time, as illustrated by the example in Box 1.

2.2 European Storms Catalogue

The Database on Forest Disturbances in Europe (DFDE; Schelhaas *et al.* 2002) contains an overview of reported forest disturbance events in Europe up to about the year 2000. These reports were collected in an extensive literature survey, but it is unlikely that all possible literature was collected and reviewed. Based on this overview, Schelhaas *et al.* (2003) reported an increasing trend in damage in the period 1950-2000. An updated version of this overview from Schelhaas (2008a) is shown in Figure 1a with the levels of damage at a European level by calendar month shown in Figure 1b. This clearly illustrates the increasing levels of damage from storms to European forests from 1950 to the present and that the damage is mainly due to winter storms (November-January). The number of disturbance events reported and the accuracy of reporting will undoubtedly have increased over time. However, we are confident that particularly the large disturbance events are well reported in a densely populated continent like Europe. It is these events in particular that influence the trend of increasing damage, and thus we think the observed trend is real and not a data-related effect. Other important damaging agents such as pollution, tree disease, insect attack and herbivore browsing often cause chronic low level damage, the impact of which is difficult to fully evaluate, and may be underrepresented.

Uncertainty in reported forest damage following the Lothar and Martin storms in France

At the end of December 1999, the two successive storms Lothar and Martin caused the most damage ever experienced by European forests. In France, the most damaged country, the assessment of physical damage was not easy and figures varied greatly over time. Initially (January 2000), damage was estimated at 110 million cubic metres (Mm3) following field and some aerial reconnaissance by local managers. The possible error was estimated to be 30%. In February this figure was updated to 139.6 Mm3 and then fixed at 138.3 Mm3 (official data published on February 27th 2000). In the frame of a research study, Peyron carried out a new survey and slightly increased this figure in April 2000 up to 145 Mm3. Later, the French National Forest Inventory began a field survey (statistical plots) and, extrapolating partial results, assessed the felled volume to be within the range 150-170 Mm3 (Wencelius F., 2002). The same French National Forest Inventory published a leaflet in 2003 on the assessment of the total damage but did not publish any final total figure and just mentioned in relative terms an average estimation of the gap between its assessment and the official one (21%) (IFN, 2003). This gap led to a derived figure of about 170 Mm3. However, the document on the indicators for the sustainable management of the French forests (MAP, IFN, 2006) gave the estimate of 176 Mm3 of roundwood felled in 1999 by the storms, secondary damage not included. Pignard et al. (2010) retained this figure in their chapter of a textbook on storms and forests.

This example shows not only the large evolution of primary damage assessments over time but also the difficulty in updating official data once they are published, and emphasises the need for standardised damage reporting methods to allow objective assessment and comparison of damage.

Box 1: Uncertainty in Wind Damage Reporting. An example based on the Lothar and Martin (December 1999) storms.

For the purpose of this study, all records related to storm damage events from 1950 were extracted from the database. The resulting list of damage events was then reviewed and updated to include more recent storms by the partners involved in the preparation of this report. National level growing stock data were obtained from Kuusela (1994) and MCPFE (2007) and interpolated to an annual basis. Each storm event was then converted to a percentage of the national growing stock damaged.

The resulting European Storms Catalogue is available on the web (http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue) and will continue to be updated in future. Appendix 1 contains the full list of storms that was compiled, while Table 1 shows the most damaging events.

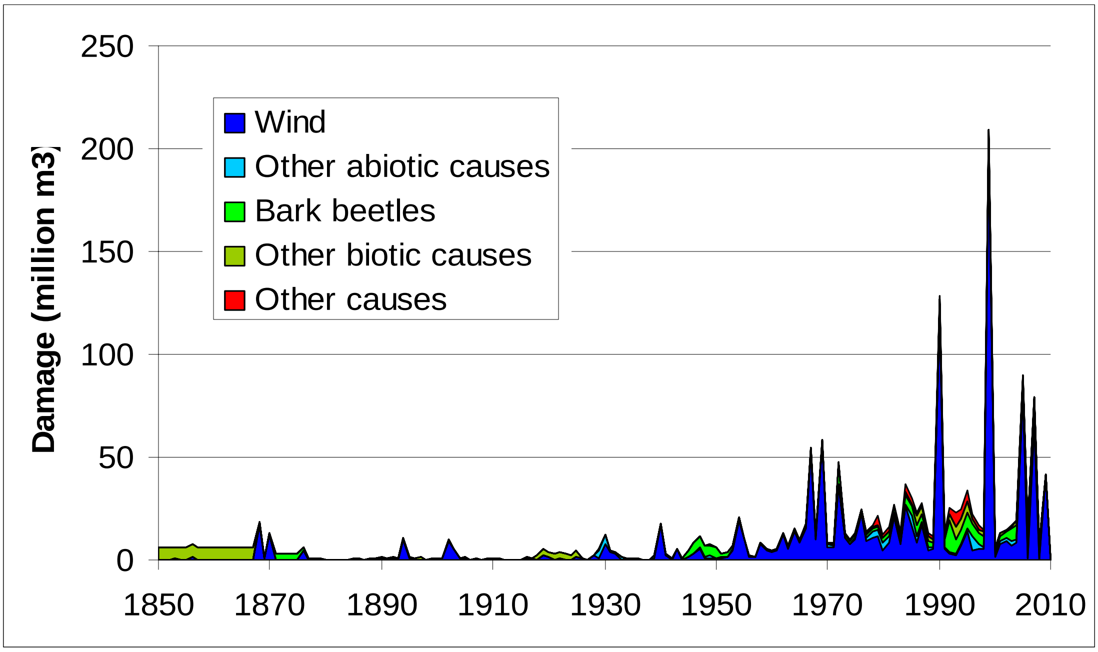

Figure 1a: Total damage due to disturbances in Europe (Schelhaas 2008a). The category "Other causes" includes anthropogenic damage, unidentified causes and mixed causes.

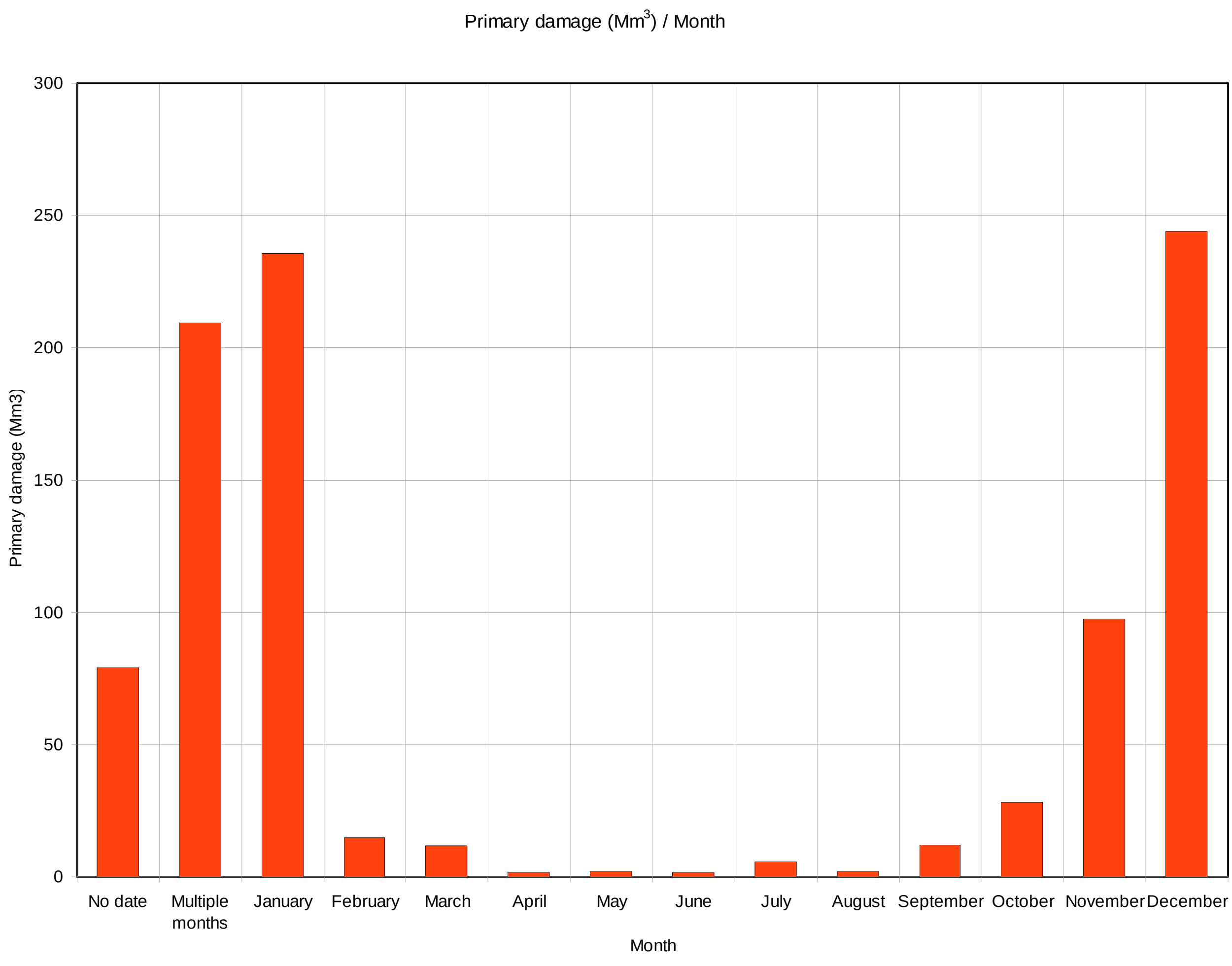

Figure 1b: European storm damage by month of the year.

Table 1: Data on key damaging events from 1950 - 2010

Year-Number	Month-Day	Storm Name	Country	Primary Damage Mm^3	% Growing Stock	Max Wind Speed (ms^{-1})	Duration of Storm (Hrs)	Value (M€)
1953-01	January 31		UK	1.8	1.44	50	7	5
1954-01, 1954-02, 1954-03, 1954-04	January 3-4, (Oct 29, Nov 25, Dec 13)		Sweden	18.45	0.89	36		
1956-01	January 21-22 and February 2		Denmark	3.5	8.32			
1956-01	January 21		Sweden	0.2	0.01			
1957-01	January 8		Sweden	0.2				
1957-05	December		Ukraine	1.2				
1962-01	February 11-16		Denmark	2	4.59			
1962-03	November 7-8		Ukraine	1.2				
1962-03	November 8		Switzerland	2.1	0.74			
1964-02	November 2-3, December		Sweden	0.2				
1964-02			Slovakia	5	1.79			
1965-03	July		Slovenia					
1967-01	February 23		Denmark	0.83	1.89			
1967-01, 1967-02, 1967-03	February 21-24, 28, March 13, June		Germany	11.3	0.84			
1967-04	August		Estonia					
1967-05	October 17		Denmark	2.34	5.34			
1967-05	October 17-18		Sweden	4.47	0.19	41		181
1967-05	October		Russia					
1969-03, 1969-04	September 22, (Sept 29 and November 1-2)		Sweden	42.2	1.73	35		175
1972-06	November 12-13		Netherlands	1	4.45			
1972-06	November 13		Germany	18	1.27			
1972-06	November 12-13			25	0.15			
1973-01	April 2		Netherlands	0.67	2.97			
1973-02	November 19		Romania	3.1	13.69			
1973-02	November 23		Sweden	1.6	0.07			52

1975-?	?		Russia	22.4				
1981-03	November 24-25		Denmark	3.23	7.13			
1982-04	November 6-7		France	12	0.72			
1984-07	November 22-24			25				
1984-07	November 23-24		Belgium	1.22	1.31			
1985-01, 1985-02	August, October		Sweden	1.5	0.06			300
1985-?			Czech Republic	7	1.21			
1987-01	October 15-16		UK	3.91	1.71	41	3	0
1987-01	October 15-16		France	7.5	0.40	40	6	
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	France	8	0.40			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Luxembourg	1.6	6.56			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Denmark	1.1	2.24			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Belgium	5.5	4.34			

1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Czech Republic	11.3	1.90			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Germany	72.5	2.70			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1 (February 26-27)	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Switzerland	4.9	1.26	45		
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	UK	6	2.70	44		2330
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke		120	0.53			
1990-01, 1990-02, 1990-03, 1990-04, 1990-05, 1990-06, 1990-07, 1990-08	January 25 - March 1	Daria, Herta, Judith, Nana, Ottile, Polly, Vivian, Wiebke	Sweden	0.6				
1999-02	(Nov 29-30 Dec 1) Dec 3	Anatol	Sweden	5	0.17	37		1498

1999-02, 1999-03	December 3-4	Anatol/Carola	Denmark	3.5	6.38	48		
1999-04	December	Lothar	Germany	34	1.03	48	2	650
1999-04	December	Lothar	Lithuania	0.4	0.11			
1999-04	December	Lothar	Baltics	2				
1999-04	December 26	Lothar	Switzerland	13.8	3.25	44	2	500
1999-04, 1999-05	December 26 (7h) / 27-28 (pm-night)	Lothar/Martin	France	176	8.36	55	4	6098
2000-01	January 29-30		Denmark	3.6	6.49			
2001-01	November 15		Sweden	2.1				
2004-02	November 19		Slovakia	5.4	1.20		64	
2005-01	January 8	Gudrun (Erwin)	UK	0.5	0.17	46	18	
2005-01	January 9	Gudrun (Erwin)	Denmark	2	3.44	46		
2005-01	January 8-9	Gudrun (Erwin)	Sweden	75	2.32	42	42	1890
2005-01	January 8-9	Gudrun (Erwin)	Latvia	7.8	1.36	40	48	
2005-01	January 9	Gudrun (Erwin)	Estonia	1		37		
2005-01	January 9	Gudrun (Erwin)	Lithuania	1				
2007-01	January 14	Per	Norway					
2007-01	January 14	Per	Sweden	12	0.37	38		
2007-02	January 18	Kyrill	UK	0.1	0.03	44	44	520
2007-02	January 18	Kyrill	Netherlands	0.25	0.48			
2007-02	January 18	Kyrill	Germany	37	1.10			
2007-02	January 18	Kyrill	Czech Republic	12	1.70			
2007-02	January 18	Kyrill	Poland	3	0.17			
2009-02	January 24	Klaus	France	43.1	1.79	53	8	900
2009-02	January 24	Klaus	Spain	1.1	0.16	55		

3. Ecological, Social and Economic Impacts

- **Catastrophic storm damage to forests has important ecological, social, and economic impacts.**
- **In managed forests windthrow can increase the risks of fire, insect and fungal damage, and there is an increased risk of damage to lakes and watercourses.**
- **Catastrophic storms in Europe can result in damage to the forest and forest industry that may cost billions of Euros to restore.**
- **Forest damage can cause severe disruption to the infrastructure, including electricity supply, phone networks, and roads that can take days or weeks to restore.**
- **Consideration should be given to maintaining civil security following catastrophic storms.**
- **State support and insurance cover for storm damage varies considerably between European countries.**
- **We have identified the 11 most damaging storms to have affected European forests, and described them in relation to ecological, social and economic impacts.**

The effects of wind damage to forests is traditionally considered primarily in economic terms, but the ecological and social effects can, depending on the storm, be more important or long lasting.

3.1 Ecological Effects

Wind is an important dynamic factor for forest ecosystems with the areas affected by wind ranging from small-scale gaps to large-scale tracts (Ulanova, 2000). While gaps generated in the stands favour regeneration of light demanding species (Castelli *et al.*, 1999; Jonásová, 2010), it has been suggested that some forests are shaped by large-scale disturbances more than such gap-phase regeneration (Holeksa *et al.*, 2007)

3.1.1 Biodiversity and Resilience

The effects of forest storm damage on biodiversity depend to a large extent on the post-storm management (Andersson *et al.*, 2006). If not cleared, the increase in deadwood favours saproxylic beetle fauna (Andersson *et al.*, 2006; Rossi *et al.*, 2009). According to *intermediate disturbance theory*, biodiversity is in general largest in an intermediate succession phase after a disturbance (Connell, 1978). Following windthrow this corresponds to the mid-term of the decomposition of the dead wood. With respect to birds, large-scale windthrow may positively affect the abundance of birds and diversity of the bird community several years following windthrow whereas the composition of the bird community may be affected more by the post-storm management than by the windthrow itself (Zmihorski, 2010). However, the deadwood present in a forest after a storm damage event may increase the risk of damage by fire (SFA, 2006).

Where foresters attempt to regenerate large areas as fast as possible, there is a risk of erosion of genetic diversity from extensive use of a small pool of genetic material (Berges, 2004). As regeneration will often be grant-aided and take place in synchrony over the damaged area, there may be reduced flexibility in management options, target species and products, and hence less diversity in forest stands. On the other hand, if biodiversity and associated resilience is included as part of the reconstitution plan, it can be an opportunity to adapt species to sites and to maintain biodiversity in stands and in marginal areas such as very old stands, riversides, wetlands, hedges, drains, fire-breaks. Reduction of exposure by converting high forest to coppice, or reducing rotation length of fast growing species, may result in the reduction of habitats of interest for biodiversity (Brockerhoff, 2008). Such habitats may remain fragmented, diminished, and with a lower value than before, especially if they are lost within large areas of homogeneous forest that are reconstituted after a storm (http://landes.gip-ecofor.org/index.php?sujet=docfinaux). The spatial pattern and connectivity between habitats should be taken into account in the reconstruction process. Game, as a component of biodiversity, can take advantage of storm damage if harvesting is not too rapid, using the quieter parts of the forest and more easily available food from the downed trees.

3.1.2 Soil and Water Chemistry

There can also be measureable impacts of windthrow on soil chemistry. Following storm damage in Sweden, the additional forestry operations required to clear timber resulted in a substantial local increase in the mobilization and leaching of total mercury and methyl mercury from forest soil (Munthe *et al.*, 2007). Increased leaching can lead to increased bioaccumulation in aquatic ecosystems. Substantially increased leaching of nitrate from wind damaged areas has also been observed after wind damage (Hellsten *et al.*, 2009) although it would have to take place over a large part of a water-catchment to pose a serious problem. After extensive wind damage, lakes may be seen as providing an opportunity for storing excess harvested timber for future use. However, water leakage from stored timber may contain high levels of phosphorus and organic material during the beginning of the storage period. Phosphate stimulates increased algal growth, and presents a potential threat of oxygen deficiency in streams and lakes (SFA, 2006). Storage close to large water bodies is expected to have very small impact, while storage of large amounts of timber close to small streams or lakes may lead to substantial impact (SFA, 2006). Another major problem is likely to be increased sediment delivery to watercourses due to the soil disturbance from the wind damage itself or from subsequent harvesting and clearup operations (Croke and Hairsine, 2006).

3.1.3 Protective Function

Approximately 13% of forests in Europe have a protective function, in particular to protect water resources, to control soil erosion and landslides, or to provide protection from avalanches or rockfall (Eurostat, 2009). Such forests are often in more vulnerable mountain or upland locations, and their importance in protecting environments and society make them a high priority for protection, where possible, from wind disturbance. The risks of windthrow of trees on steep slopes may need particularly careful management, as for example the soil disturbance and potential loss following windthrow from a steep forested slope may be up to 1800 m^3 per ha (Nicoll *et al.*, 2005).

3.1.4 Carbon Balance

For a forest in a clear-felling system, wind damage affects the carbon balance in two main ways (Lindroth *et al.*, 2009). First, soil respiration is increased following disturbance by uprooting of root systems (Knohl *et al.*, 2002) and there is more intense use of machinery in clearing up the wind damaged forest leading to loss of CO2 to the atmosphere until the forest is regenerated. Second, the rotation period of affected forest stands is reduced leading to less carbon sequestration over a shortened rotation period compared to normal. The Lothar wind damage event in 1999 is estimated to have reduced the carbon balance by approximately 16 million tons C, which is equivalent to roughly 30% of the net annual carbon increase of forests in Europe (Lindroth *et al*., 2009). The 30% loss is measured losses at storm-damaged and salvaged sites from soil disturbance and reduced productivity due to shorter rotations but does not include any salvaged timber. Salvaged timber will compensate for carbon losses to a certain extent, but even so not all damaged timber can be salvaged after storms. Therefore, overall storm damage to forests reduces the carbon balance of forest ecosystems

3.2 Social Effects

In regions with extensive wind damage, lengthy disruptions may be caused to the infrastructure, such as telecommunications, electricity supply and transport (Haanpää *et al.*, 2007; http://www.assemblee-nationale.fr/13/rap-info/i1836.asp). Following the Gudrun storm in 2005, 300,000 Swedish subscribers' non-mobile telecommunications systems were not functioning and two months later a large number of subscribers were still without telecommunications (FMV, 2006). With respect to power-failure, some areas were particularly difficult to reconnect after Gudrun, and customers suffered failure for up to 45 days after the storm (FMV, 2006). The implications were particularly important for the maintenance of civil security. At this time, the Swedish security system was stretched to its limits and there could have been more severe consequences had not favourable circumstances, such as mild weather, mitigated the situation (KBM, 2005).

After extensive wind damage, the landscape may be dramatically changed in many ways. After the Gudrun storm, there were reports that some people were unable to find their way home in areas where they had spent most of their lives and people had to cope with the forest being destroyed that they had spent a life-time tending (Guldåker, 2009). Approximately one third of the respondents to a questionnaire to private individual forest owners in Sweden, one year after Gudrun, claimed that their wellbeing was reduced (Ingemarsson *et al.*, 2006). Casualties from wind damage to forest result both directly from falling trees and from salvage work (Rannhoff *et al.*, 1992). However, it may be difficult to separate these casualties from the total casualties from storms. For example, in total 140 individuals were killed by the 24-28 December 1999 storms (Martin and Lothar) in France but this figure includes all causes of death including collapse of buildings, and a forest related figure is not available.

Game hunting is also affected by storms. Although game populations may increase after a storm, benefitting from the newly available quieter areas with no forest activity and abundant food, hunters often cannot easily penetrate the storm-damaged forest, and may in fact not be aware of new habitats or game. However, to permit good forest regeneration, it is important to control the game population (Roucher, 2010). Other uses of the forest such as mushroom picking, trekking or recreation and sport in the forest can be totally disrupted, generating losses in the local tourism sector.

3.3 Economic Effects

The series of wind damage events in December 1999 affected several countries and were the most extensive on record in Europe. The total losses have been estimated to be €10 billion (Willis, 2007). In France storms Lothar and Martin (1999) felled about 8% of the total growing stock in a forest area covering 15 million ha (http://www.ifn.fr/spip/spip.php?article618). Storm Klaus 10 years later (2009), felled 32% of the maritime pine growing stock in Aquitaine, which followed the 15% of the growing stock that had previously been damaged (in a forest area covering about 1 million ha). In Sweden, wind damage following the Gudrun storm on 8-9 January 2005 was the most extensive on record, yet it caused damage to only approximately 2% of the growing stock on a national basis (Table 1 and Table 4). At the same time individual forest owners in the affected region saw large proportions of their forest devastated. In the most severely damaged Södra forestry districts, more than 20 years of annual harvest was felled during 2004-2008 (Södra, 2010).

The type of damage that occurs has different economic implications. Trees that are completely overturned but with part of their root system still in the ground may survive for a considerable period (months to years) and there may be little loss of wood quality if they are harvested in a reasonable time (Moreau, *et al.*, 2006; http://www.fcba.fr/tempete/docs/FIF683.pdf). Trees that are partly overturned and are left leaning will continue to grow but may produce significant quantities of reaction wood in subsequent years, but this will be in the outer rings of the tree (Mochan, 2002). If there is stem breakage, particularly in the most valuable part of the stem (<10m), then the economic consequences are more serious. In trees where breakage is in the crown, the economic consequences are reduced or may be negligible, but the breakage point is a potential entrance site for insects and pathogens. Overturning will usually be predominant on wetter sites or those with limited rooting depths, for example on gleyed, indurated, or skeletal soils, while stem breakage is more common on frozen soils or sites with deeper soil, and therefore better anchorage, especially forest brown earths or deep littoral soils. Crown snap is often associated with a combination of wet snow and wind. Breakage may predominate in trees with large height to diameter ratios (sub-dominants) but the evidence for specific trees within a stand being more or less resistant is weak (Dunham and Cameron, 2000). Often damage occurs to groups of trees following initial damage to some vulnerable trees or because they are within the swathe of an especially strong gust. The level of damage varies from sporadic damaged trees to loss of the whole stand, with a corresponding variation in economic consequences. For damage levels less than around 10% there may be little need to take any immediate management action, between 10-30% there will be a need to start removing damaged timber before it is degraded, but once the damage reaches 30-40% foresters usually clear the whole site[2] (see Appendix 2).

Secondary damage is common, especially insect holes in wood, damage by blue stain fungus, and increased incidence of root rot in the affected forest area (Schelhaas *et al.*, 2001; SFA, 2006). Increasing populations of saproxylic insects provide an economic threat to the forest industry through deterioration of the quality of the remaining forest and fallen trees and potential attacks on living trees, e.g. by bark beetles such as *Ips sp.*, *Tomicus sp.*, etc. A number of different insect species such as *Trypodendron sp.* cause damage in timber of both conifers and broadleaves (Schelhaas *et al.*, 2001). In pines there can be serious problems with deterioration due to blue stain (*Ophiostoma* sp., *Leptographium* sp., *Ceratocystis coerulescens and Sphaeropsis sapinea*), which although not significantly affecting the performance of sawn timber can markedly reduce the market value. These fungi are spread by bark beetles, which invade the wind blown trees along their entire length. Particular beetles tend to be associated with a particular pathogen, for example a relationship between *Tomicus* and *Leptographium* sp. has been found in damaged trees in Britain, Sweden and France (e.g. Gibbs and Inman, 1991).

Storm damage gives rise to a sudden, unplanned increase in the supply of timber which commonly affects timber prices and therefore the financial return of both the seller and the buyer. For example, after the storm Gudrun in 2005 the average prices of sawlogs of

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[2] The primary damage reported here does not, as far as possible, include the additional volumes from subsequent harvesting but only the volumes actually damaged by the storm.

spruce and pine in southern and central Sweden was only 63% and 86%, respectively, of those in the year before the storm (SFA, 2010). An example of the impact of storms on prices in Germany is provided in Figure 2. Such substantial drops in prices have strong implications for forest owners and local people. The impact on prices was less in other parts of Sweden further away from the storm damaged area. The demand for machinery and man-power also increases in the storm damaged area. In 2008 there were 258 harvesting machines operating in Aquitaine but after the January 2009 storm it doubled and after the storm Gudrun the forest owner association in southern Sweden reported a more than doubling of the total work force, mainly by logging or transportation businesses (Södra, 2010).

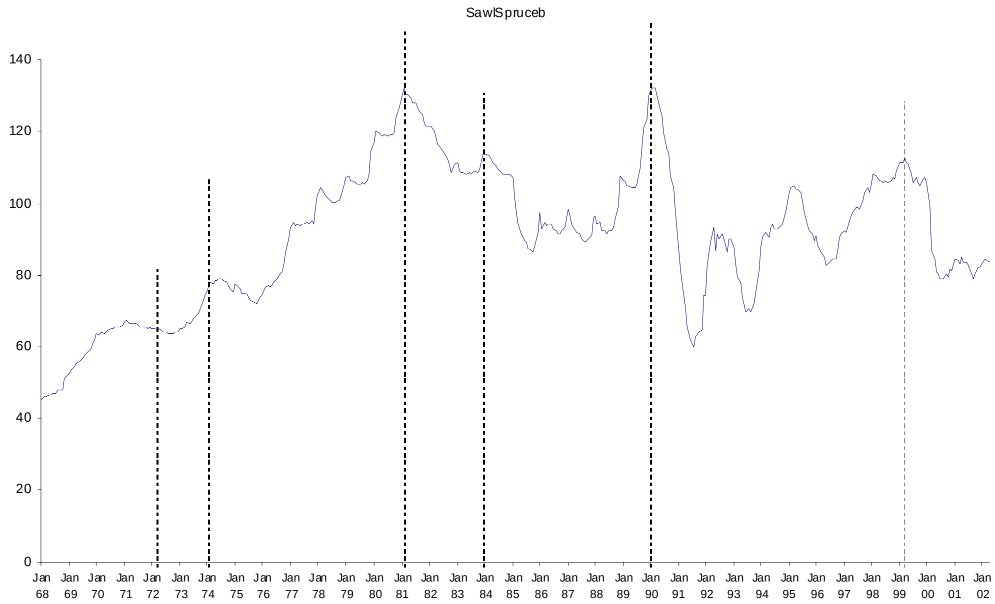

Figure 2: Prices for Norway spruce from 1968 until 2002 in Germany illustrating the drop in price following storms in 1972, 1974, 1981, 1984 and 1990.

As mentioned above, after damaging storms, roundwood prices are generally much lower than in normal conditions. The reasons are many; higher costs, lower roundwood quality and the consequences of an excess supply. Higher costs are due to logging in complex and dangerous situations, transportation over longer than usual distances (FAO, 2000), storage costs for roundwood (or sawnwood) that cannot be processed or sold immediately, and financial risks that are taken by buyers who invest in much bigger quantities than normal. The roundwood quality is lower than usual because trees are likely to have experienced extreme loading and timber will often have reduced mechanical or aesthetic properties, and the mixture of tree sizes and quality classes is abnormal. Importantly the difference between normal prices and post-storm prices is larger for stumpage prices than for roadside or mill gate prices, and so has a particular impact on growers.

The increased costs of operations after storm damage correspond to increased activity and increased added value within the sector. However, this will be at least partially compensated for later on when activity will be lower. The harvesting of storm damaged trees has consequences in unaffected regions and forests. These forests often have to postpone their normal cuts in order to give priority to the salvage of damaged trees and to avoid potential loss of revenue while roundwood prices are low. This can have an economic impact on communities normally reliant on this income stream, and after the 1999 storms several communes in France needed financial loans in order to deal with the lack of revenue. Furthermore, although this loss can be small at the per hectare level it involves large areas and is not globally negligible. For example, in the 1999 storms in France, this loss was estimated to represent about 10% of the total economic loss. Together with the more difficult operating conditions and scattered logging sites, overall forestry operations may become more expensive (Peyron, 2000; Peyron, 2002; Costa *et al.*, 2009). In summary:

- Roundwood abandoned in the forest because it cannot be harvested in a profitable way correspond to a definitive loss that represents often 40% of the felled volume.
- The depreciation in quality of harvested roundwoods also leads to a loss in value.
- The increased costs of operations after storm damage provide increased income for some people. However, some of this benefit will be compensated by decreased activity in the future.
- Other gains are scattered among many activities such as increases energy usage, increased transportation, short-term increase in trade, temporary increase in the requirements for forest and wood-based services, etc.

In an attempt to show the contrasting impact of storms we provide a brief outline of potential costs and benefits from storm damage in Table 2.

Table 2: Potential Costs and Benefits from Storm Damage to Forests

	Costs	**Benefits**
Private Individuals and Companies	• Low prices = Loss of income • Early harvesting = Loss of return • Poor quality of harvested wood = Loss of products	• Low prices = Cheap raw material for private companies processing wood • More opportunities to buy land for other uses than forest = Land uses switch to urban, industrial or agricultural use.
Society	• Immediate extra cost for road (and drains) • Forest closure for fire prevention and harvesting • Immediate extra cost for harvesting, which is often supported by state • Low motivation of forest owner for forest reconstitution = Grants for planting • Dead wood increase = Preventive measures to avoid pest proliferation such as bark beetles • Loss of carbon and growing stock = Lower activity based on local resource • Fallen trees = Less possibilities for hunting, mushroom picking, and increased fire risk • More leaning tree = Less public access as areas closed • Extra cost to re-establish stands with erosion control role or other protective functions • Carbon stock is reduced = Less stock to negotiate in international treaties • Less tall and/or old trees = Less high value products, and less trees of high value for biodiversity • Disruption in age classes = Less continuity in industry resource and necessary to import material and/or stop local harvesting	• Dead wood volume increase = More saprozoic related fauna • Temporary increase of activity with international companies = More business, more staff, more logistics during the harvesting period

3.3.1 Insurance

In some countries it is possible to buy insurance policies to cover the risk of wind damage to forest. This kind of insurance has been available since the 1950s in Sweden (Anon., 1969) and is also readily available in the UK and the Netherlands. At the time of the Gudrun storm in Sweden in 2005 approximately 40% of the forest owners in the affected area had bought a forest insurance policy. The proportion of insured forest owners increased with increasing property size, and among the forest owners with more than 400 ha of forest, as many as 80% were insured (Ingemarsson *et al.*, 2006). In other countries such as Germany and Austria where there are national schemes for compensating owners after storm damage private insurance is much less common. Central Europe is characterized by low coverage with only 2% in Germany, 0% in Austria and Switzerland and 7% in France of the total forest area insured (Table 3). Although there is a cost associated with private schemes they have the security of clearly defining what is covered and payments after damage are more guaranteed. Public schemes may be less well known to owners and more difficult to access for compensation.

Damage from storms results in extra labour costs for the forest owner and fundamental changes in the planning of the forest, both short term and long term. Much time is spent on inventories of damage and meetings with insurance brokers. On the basis of their evaluations, the insured forest owner receives compensation, which will cover part of his/her losses. In Germany and Sweden the amount of compensation is related to site quality, age of the stand, mean diameter, composition of species, and the degree and type of damage (AXA, 2010; Ekman, 2009). In Germany insurance is paid above certain wind speeds, as an agreed lump sum per hectare of storm damaged area or solid cubic meter of storm-damaged timber (AXA, 2010). The smallest area qualifying for compensation is in general 0.5 hectares and at least half of the growing stock must be damaged. The following are covered by insurance (Ekman,2009):

- Wood losses and raised prices of cutting
- Damage to timber, pulp wood and logging residues
- Regeneration costs
- Loss of production capacity on forest soils
- Re-establishment following secondary damage

However, other impacts are not covered by insurance, for example, reduced timber prices, and notices to quit the contract with a timber buyer.

Table 3: Insurance penetration in different countries (Welten, 2010).

Country	Insurance penetration (% of forest area)	Comment
Austria	0%	Catastrophic fund is in place; no forestry insurance is active
France	7%	
Germany	2%	
Sweden	70%	
Switzerland	0%	Catastrophic fund is in place; no forestry insurance is active
The Netherlands	12%	The main insurance company is OBV (Onderlinge Bossen Verzekering) covering about 55,000 ha.
United Kingdom	10%	There is a UK woodland scheme in place which consists of 200,000 ha insured for fire, and fire & wind. The woodland scheme represents about 66% of insured woodlands in England, Wales and Scotland.

Studies investigating insurance for storm damage in forests in Switzerland and Germany have shown low enthusiasm among forest owners for insurance under current economic and legal policies (Holthausen *et al.* 2004, Hänsli *et al.* 2002). The main reasons identified are the low economic importance of the forest to many forest owners and low risk awareness or rather underestimation of risks, in light of the long productivity times in forestry (Schwierz *et al.*, 2010; Holthausen *et al*. 2004). The disaster relief practice of many states to compensate widely for storm damage decreases the incentive for forest owners to take their own precautions (Holthausen *et al*. 2004). If public risk management strategies were changed, an insurance or fund could offer advantages, such as spreading the risk and reducing unexpected private and public costs. Active risk management is also uncommon in the Swedish forestry culture. Blennow (2008) explained this by widespread perceptions of wind damage as a natural hazard that cannot be modulated, and to consider forestry as an enterprise free of valuation in which value aspects of risk are neglected.

An estimation of forest insurance in 2005, suggested that 0.5% of French forest owners were covered, representing 7% of the forest (Picard *et al.*, 2009). At that time insurance was relatively cheap, however, many insurance companies closed their contracts after the 1999 storms, arguing that they could no longer cover payments of up to 65 times the premiums that had been collected. Currently, only two insurance companies remain for forest owners in France: MISSO and XLB. The cost of insurance per hectare has multiplied by three, and the area covered has reduced. As an example, after the 2009 storm, the number of owners covered by MISSO reduced from 4260 to 2565 and the area under insurance protection reduced from 367000 to 221000 ha.

In the Netherlands the area insured against storm damage is currently 22,500 ha, about 6% of the total forest area (OBV, 2009).

3.3.2 Government Support

France

Under French law, storms are not considered to be natural disasters, thus damage cannot be directly covered by the state. Only flooding, landslides and sea damage induced by the storm were covered by support measures introduced in state legislation of 28 January 2009. In 1999 the total cost for the French government was 3 billion € in grants for cleaning and planting (not for reimbursement of losses: Costa *et al.*, 2009). The new regulation passed in summer 2010 (code forestier, Article L261-4, 27/07/2010) makes a condition of support from the state for cleaning and regenerate stands after a storm on subscription to private insurance (partially from 2011, totally from 2017). In the short term this measure will reduce the cost of storm damage to the state. It may also increase the number of forest owners covered by insurance, but discourage them from investment to restore forests after storms.

Sweden

After the Gudrun storm, the Swedish government decided to support the industry with a range of support measures. These measures favoured particular parts of the working population, for example along the reprocessing and transport chains. The following support measures were introduced after the Gudrun storm:

- The Swedish government made a request for support from the EU solidarity fund for removal of timber, restoration of infrastructure and rescue services.
- Tax reduction by 5 € per cubic metre timber.
- Exemption from tax on diesel.
- Support for replanting.
- Support for maintenance of forest roads and forest soils.
- Temporary support for storage of timber.

United Kingdom

A range of economic measures have been initiated following catastrophic storm damage. For example, following the 1953 storm, the government placed large orders for windthrown pine, which were to be used for railway sleepers and for coal mine pit props, and land and sea transport was subsidised to assist transportation of large quantities of timber (Steven, 1953b). After the 1987 storm, the government provided subsidies for clearing and restoration of affected forests and woodlands, and suspended income and corporation tax for forestry. Financial measures are generally decided upon after the storm event.

Germany

Based on experiences from previous storms events (1967, 1968) the German government initiated the Forest Damage Compensation law. It allowed the application of a set of financial assistance measures (e.g. after the 1972 storm). Measures included subsidies for transport, changes to taxation and direct financial support for affected forest owners (German Federal Parliament, 1969). Länder are responsible for financing activities related to storm damage but were overwhelmed by the scale of the damage following the 1990 storm. The German government set up a Federation-State auxiliary fund and additional funds were made available for removal of wood and for processing and storage of damaged timber (Kühnel, 1994).

Summary

Public financial measures are not an alternative to private insurance systems. The two solutions are complementary in circumstances when the consequences of the storm damage are high at the regional level. Indeed, when the total volume damaged by the storm exceeds the annual cut in a region by more than 0.5 million hectares, then the whole forest economy is affected and requires decisions by the public authorities in order to collectively organise the salvage of damaged trees, to maintain prices, and to organize for the future. Private insurance is generally more adequate for local damage, which does not have repercussions on the roundwood market and forest economy. In the case of catastrophic events, the two systems, public and private, need to work together.

4. Selection of 11 Storms/Storm Series

To analyse and illustrate the ecological, social and economic effects of wind damage eleven of the most damaging storms in Europe since 1950 have been selected (Table 4). The following indicators of impact have been used: volume damaged, % growing stock damaged, casualties (primary and secondary), environmental value, financial value, market disruption and effect on policy. The basis of the selection is provided in the last column of Table 4. The selected storms represent storms of local importance (1953, 1969, 1987, 2004), regional significance (1967, 1972, 1990, 2005, 2009) and European importance (1999, 2007). Some of the storms had important policy impacts (1953, 1969, 1990, 1999) whereas others had profound effects on timber markets (1990, 1999). In other instances the storms were chosen because of important ecological (e.g. 2004, 2005) or social impacts (e.g. 1953, 2005) impacts.

The selected storms are summarised in the section below. However, for a comprehensive range of supporting background information, source material and references please refer to Appendix 3.

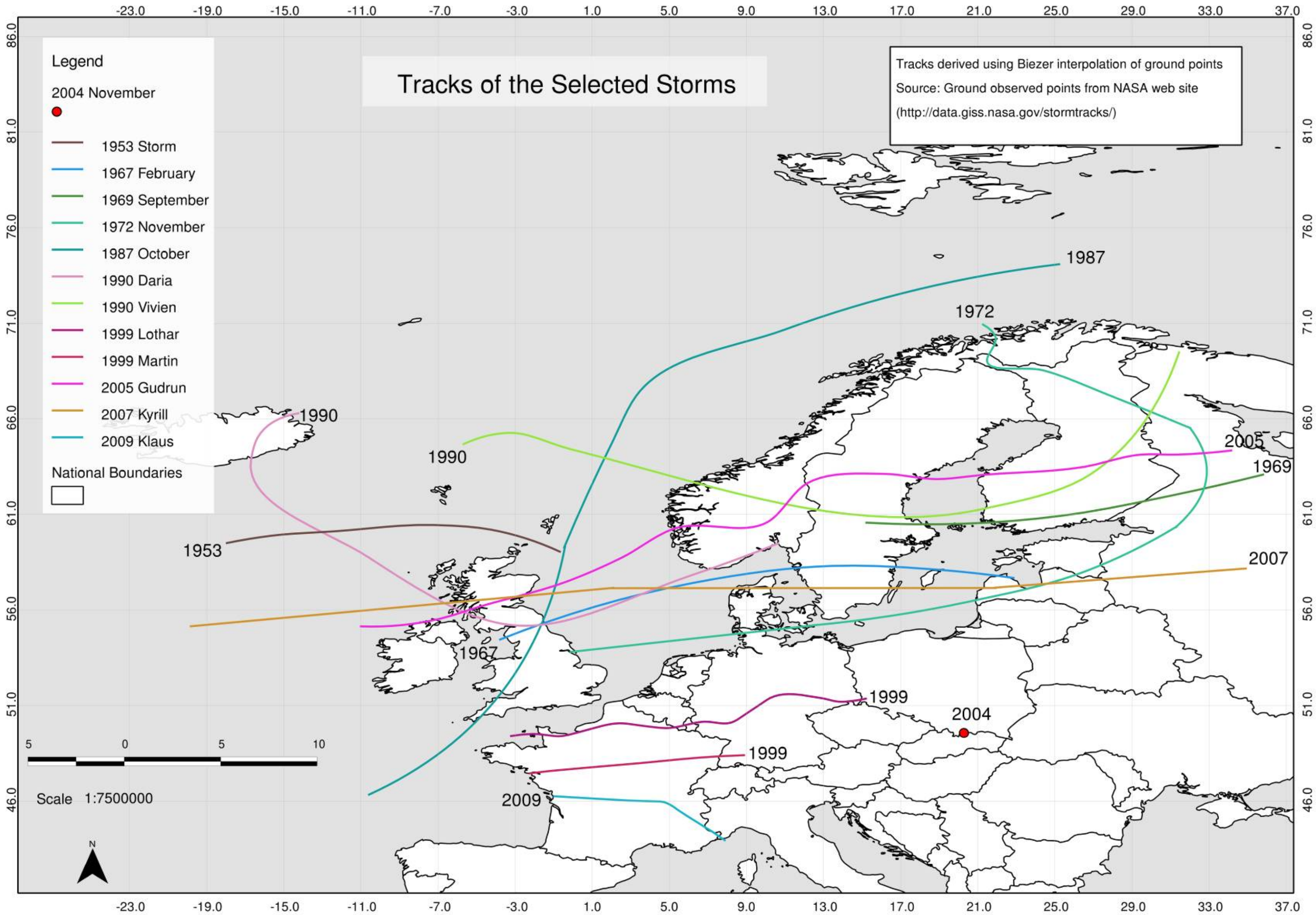

Figure 3a: Paths of low pressure centres for selected storms. (Most of the storm tracks are derived from the NASA re-analysis of extratropical storms: see http://data.giss.nasa.gov/stormtracks/)

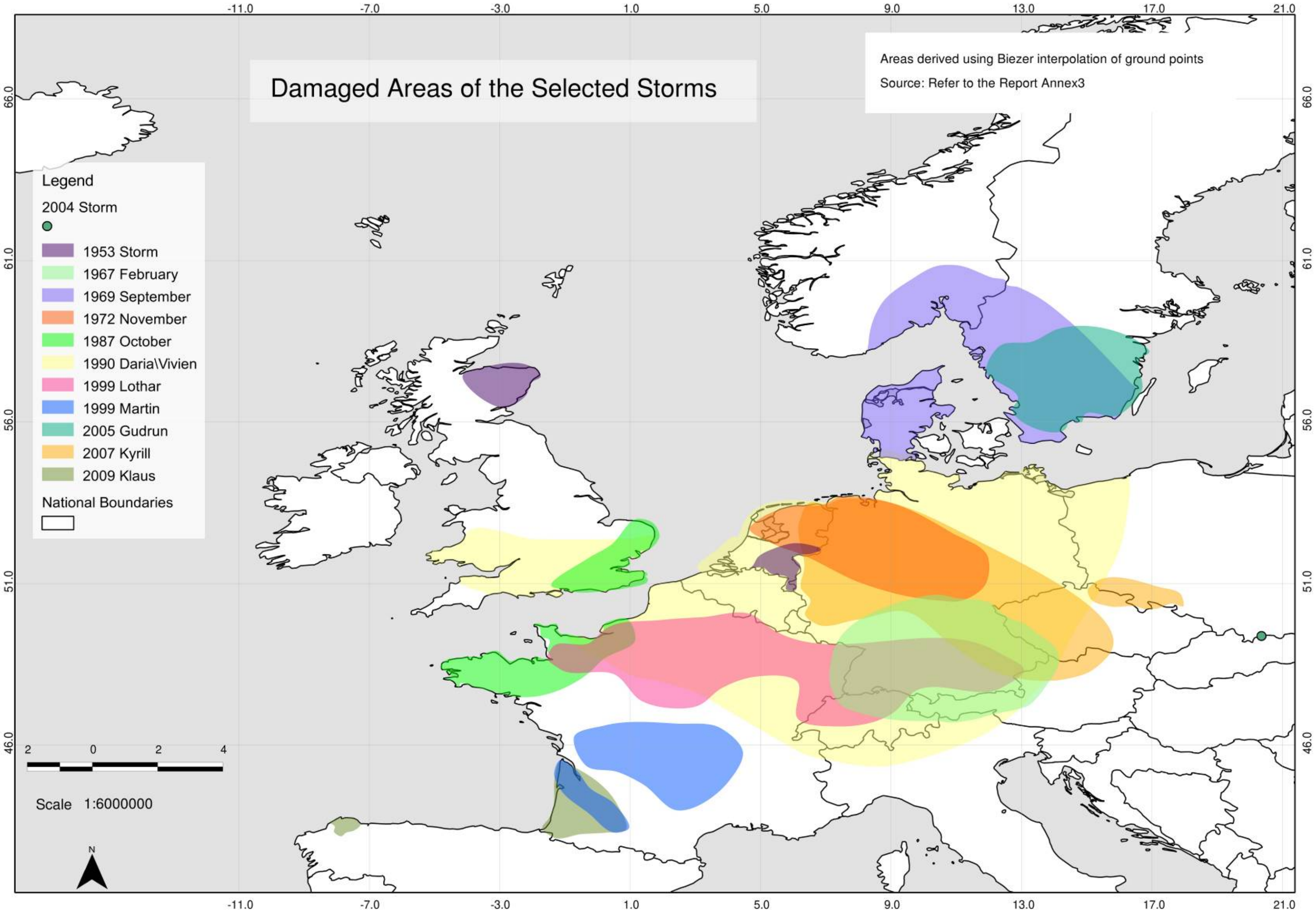

Figure 3b: Estimated areas affected by selected storms. (The areas are derived from reports and publications described in Appendix 3 and are only provided to allow an impression of the impact area and should not be taken as absolutely correct).

Table 4: 11 Storm / Storm series selected for detailed analysis (Financial figures can include all damage or forest damage as indicated)

Storm Dates	Name	Countries	Vol. (Mm^3)	% Growing Stock (most affected country)	Casualties	Effect on biodiversity (H/M/L)	Financial Value M€	Major Ownership	Information Availability (H/M/L)	Market Disruption (H/M/L)	Effect on Policy (H/M/L)	Area Impacted (L/R/N/E)	Rationale for choice of storm
31 Jan 1953		UK Netherlands Denmark	1.8	1.4 (UK)	2100 (mainly from drowning)	L	5.82	Public	L	L	H	Local	Important impact on forest policy in UK
21 Feb – 25 May 1967		Czech Rep Germany Switzerland Denmark France Austria	46.5	1.0 (Germany)	60 (Germany)	M	600 (all damage)	Public + Private	M	H	M	National	Storm affected a large area of Europe
22 Sept 1969		Sweden	42.2	1.7	16	M	17.52	Private	M/H	M	H	Regional	Major impact in Sweden with high impact forest policy in Sweden and on small-scale owners
13 Nov 1972		France Germany Netherlands	25 19 (Germany)	1.3 (Germany)	54	M	1billion DM (Germany)	Public + Private	M	M	M	Regional	Regionally important
16 Oct 1987		UK Ireland France Norway	11.4	0.6 (UK)	18 (UK) 4 (France)	M	30 (UK)	Public + Private	M	M	L	Regional	Large damage in urban area with high financial impact
25 Jan – 1 Mar 1990	Daria, Herta, Judith, Nana, Ottilie, Polly, Vivien, Wiebke	UK France, Belgium Netherlands Luxembourg Germany Switzerland Denmark Czech Republic Austria Poland Slovakia Sweden Italy	120.0	2.7 (Germany) 1.3 (Average all countries)	272	M	12,800	Public + Private	H	H	H	National	Huge impact in Central Europe with important policy impacts
24 – 28 Dec 1999	Lothar, Martin	France Germany Switzerland Denmark Poland Czech Republic Austria Lithuania	196.7	8.4 (France) 1.3 (Average all countries)	>140 (Europe) 88 (France)	H	10,000 (all damage) 3,000 (forest damage)	Private + Public	H	H	H	European	Largest storm damage to European forests ever recorded

		Belgium Estonia Spain Latvia UK Italy Portugal											
19 Nov 2004		Tatra Mts Slovakia	5.40	1.2 (Slovakia)	Non reported	H	5–6000 €/ha 66M€ for Tatra Mts	Public	H	L	H	Local	Devastating local damage with up to 90% of forest destroyed and important biodiversity impact
7 – 9 Jan 2005	Gudrun	Sweden Latvia, Denmark, UK Estonia Lithuania	77.5	2.3 (Sweden)	19	H	1,500 (all damage)	Public + Private	H	M	M	National	Large regional impact and particular impact on small-scale owners
14 – 18 Jan 2007	Kyrill	Germany Sweden Czech republic Poland Austria Latvia Slovakia Lithuania Belgium France Netherlands Romania	64.5	1.1 (Germany)	55 (Europe) 13 (Germany) 13 (UK)	M	5,000 (all damage)	Public + Private	H	M	M	National European	Large coverage across many countries.
24 Jan 2009	Klaus	France , Spain	44.6	1.8 (France). Regional = 30%!	31	M	1,045 (forest damage)	Private	H	M	M	Regional	Large regional impact, timber market already depressed

4.1 Description of 11 Storms/Storm Series

In this section a brief description of the 11 storms or storm series is provided within four sub-headings (Meteorological Conditions, Forest Condition, Impact of the Storm and Response to the Storm). The sub-headings for each storm give the relevant dates and the countries affected. An analysis of the overall impacts of the 11 storms or storm series is provided in the final section of this chapter, and an in-depth analysis of the responses and relevant policy recommendations is provided in Chapters 6, 8 and 9. Further detailed information on each of these storms is provided in Appendix 3 and a catalogue of responses to the storms in Appendix 4.

The tracks of the low pressure system responsible for the storms causing the most damage in the 11 time periods selected is illustrated in Figure 3a. In the years when a series of storms contributed to the forest damage only the tracks of the most damaging storms are illustrated. Figure 3b illustrates the damage area from the storm or storm series and reflects the cumulative damage from all the storms for the period described.

4.1.1 31st January 1953 (UK, Netherlands and Denmark)

Meteorological Conditions

A depression formed on 29th January 1953 as a wave on a warm front just north of the Azores (Douglas, 1953). The centre of the depression tracked north-east and then east-north-east on the 30th January between the Faroe Islands and the north of Scotland before heading between Shetland and Orkney and then down the North Sea towards Denmark on the 31st. The depression reached a minimum of approximately 968 mbar at around 6:00 GMT on 31st January just east of the north-eastern point of mainland Scotland.

The geostrophic winds at 12:00 GMT on 31st January were approximately 78 ms^{-1} and these were the highest values recorded in the UK during the 20th century. Surface wind speeds were very high with gusts reaching 56 ms^{-1} in Orkney, 50.5 ms^{-1} in Kinloss (Morayshire) and 45 ms^{-1} at Dyce (Aberdeenshire). The wind direction in the affected areas started in a north-westerly direction and slowly moved to a northerly direction. The storm occurred at the same time as a spring tide leading to the North Sea rising by almost 2 m above predicted levels in many parts of the eastern coast of England and the coasts of the Netherlands and Belgium. This caused extensive flooding with a large loss of life and damage to property.

Forest Condition

The affected forest in the north-east of Scotland consisted mainly of mature Scots pine and larch with some younger spruce and Douglas fir. The majority of the pine and larch was in private ownership whereas the recently planted spruce and Douglas fir was mainly in the public sector. In the valley bottoms there was some beech and oak on private estates (Andersen, 1954).

The soils in the affected area are mainly of glacial origin and derived from the underlying bedrock. They primarily consist of podzols but with gleys, peats and littoral soils in places. Indurations are known to impede rooting in much of the area. Prior to the storm the weather had been dry and so soil wetness was not considered to be an issue.

Impact of Storm

A large number of conifers were damaged in the storm, primarily mature Scots pine and larch with the younger spruce and Douglas fir less badly affected. In addition much damage occurred in mature beech and oak stands. Substantial damage occurred at lower elevations possibly due to a combination of the location of the mature stands and the funnelling of the wind along river valleys (Steven, 1953a). The damage occurred in mature stands because they were taller and most of the damage (~90%) occurred in private woodlands.

Approximately 1.8 Mm^3 of woodland were blown down and the damaged conifer volume was equivalent to approximately 5% of the conifer standing volume in the UK (Steven, 1953b). Most of the damage was from overturning but some broken stems occurred on the better soils. Following the initial wind damage there were concerns about the secondary damage from insects and in particular *Hylobius abietes*, *Myelophilus sp.*.

This storm is regarded as the worst natural disaster of the 20th Century in the UK and the Netherlands. A large amount of damage and most fatalities were caused by the associated flooding from the high tides. More than 2000 people died with 1,835 people killed in the Netherlands, 307 killed in the United Kingdom, and 28 in Belgium. Further loss of life (> 230) occurred at sea along the northern European coasts and the North Sea and a ferry was lost between Belfast and Stranraer in the north Irish Sea.

Response to Storm

In the UK there was a major response to the storm with the primary focus on the salvage of pine to reduce the risk of insect outbreaks. Large orders were placed by British Railways for sleepers and by the National Coal Board for pit props with sawn timber representing 2/3 and pit props 1/3 respectively of the conversion. The total material only represented 10% of annual UK consumption so was relatively easily absorbed. Markets for damaged beech were more difficult to find because of the quality of the material.

Land and sea transport was subsidised by the UK Government in order to ensure that the material could be transported for processing because the whole sawmill capacity of Scotland was required to deal with the aftermath of the storm (Steven, 1953b). In addition, special fire-protection and fire-fighting plans were introduced by the Forestry Commission in the affected areas to minimise the chance of fire starting in the drying material in damaged stands.

The policy response to the widespread flooding was even more extensive, particularly in the Netherlands. These included erections of sea defences and the introduction of warning systems to alert residents in low-lying areas of the possibilities of flooding. The massive sea defence projects initiated in the Netherlands at this time have only been completed in the last 10 years and now provide that country with comprehensive flood defences.

There was a major response in forest management and research into forest wind damage in the UK. Many of the research initiatives started at that time are still evident to this day. The management of upland UK plantation forests was adapted to deal with the threat of wind damage and this threat has dominated UK forest practice until the last 10-15 years. In particular, restrictions on thinning in exposed locations and early (compared to the economic optimum) clear-felling practices were initiated. Recently there has been a movement back to more central European silvicultural practices with an increasing emphasis on biodiversity and amenity, and the requirements to comply with forest certification have led to increased use of thinning.

4.1.2 21st February – 25th May 1967 (Germany, Austria, France, Switzerland, Denmark, Czech Republic)

Meteorological Conditions

The precipitation prior to the damaging series of storms that occurred between February and May 1967 was above average throughout the period and was accompanied by very high temperatures (Wangler, 1974). A serious of deep depressions occurred on 21st February, 23rd February, 28th February, 13th March and the 25th May 1967. The centres of the depressions causing the damaging storms tracked at different latitudes from the North Atlantic across to the Norwegian Sea or the North Sea. However, the strongest winds from these storms were primarily concentrated over eastern France, western Germany, Switzerland, Austria and the Czech Republic with wind direction primarily starting from the south-west and gradually moving to the north-west. The highest wind-speeds at lower elevations approached approximately 40 ms^{-1} on 23rd February. At the Feldberg high elevation meteorological station in the Black Forest (Germany) wind speeds exceeded 55 ms^{-1} on a number of occasions (Wangler, 1974) and in Switzerland also occasionally exceeded 40 ms^{-1} (Bosshard, 1967).

Forest Condition

The forest soils were saturated and unfrozen during the period of the storms leading to the poorest possible soil and rooting resistance. In addition, the occurrence of a sequence of damaging storms led to additional wind damage due to increased fatiguing of the root soil system with each storm before the roots were able to recover in the spring and summer (O'Sullivan and Richie, 1993).

The damaged forest consisted mainly of Norway spruce, and Silver fir with additional damage to Douglas fir, Scots pine, beech and oak in descending order of occurrence (Wangler, 1974, Majunke, 2008).

Impact of Storm

The sequence of storms caused huge damage to forests in eastern France, western Germany, Switzerland, Austria and the Czech Republic (Kohler, 1973). Over 26.5 Mm^3 of timber were damaged amounting to around 110% of the average annual harvest in the affected countries. Damage was distributed between state forests, municipal forests and private forests

Expected secondary damage from insect outbreaks was not as bad as predicted because weather conditions were cool and moist during the following spring and summer (Wegmann, 2009).

Prices were badly affected by the storm and values were typically 50% below average but the export of timber from the affected countries increased with exports mainly to France and Italy. The storms also caused a large number of ships to sink in the North Sea with at least 80 sailors drowned. Germany recorded 40 fatalities. The economic impact of the storms of 21st – 23rd February is estimated at 600M€ (Müchner Rück, 2001).

Response to Storm

Austria, Switzerland and Germany responded in a number of ways to the storm damage. All 3 countries actively encouraged the export of timber. In Germany this included the temporary lifting of export restrictions and the approval of short-haul trains to move material over longer distances. Germany also reduced train transport taxes (Kohler, 1973).

In Austria new methods for processing roundwood were developed (Flachberger, 1968), and in Germany financial support was provided to help forest owners to store spruce and fir roundwood. Interest price reduction on credit facilitated the processing of storm-damaged timber. In Switzerland and Germany financial assistance was available at both federal and regional (Länder and cantons) levels to aid the restoration and replanting of the damaged forest (Kohler, 1973). In addition guidance was provided for the selection of tree species (Wegmann, 2009). In the Zürich Kanton no recommendation was made on the tree species choice but in a neighbouring Kanton, it was explicitly demanded that there should be more broadleaves in the young stands than in the older damaged stands with an emphasis on mixed stands. In practice, 100% of the restocking was done by planting, with spruce as the main species since not enough broadleaves were available.

4.1.3 22nd September – 1st November 1969 (Sweden)

Meteorological Conditions

An extra-tropical cyclone that passed from southern Norway across Sweden and then across southern Sweden was responsible for high winds in Southern Sweden with a maximum wind speed of 35 ms-1 being recorded at Ölands södra grund (SMHI, 2010).

Forest Condition

Much of the damaged forest consisted of Norway spruce (Persson, 1975). There was a proportional level of damage in Scots pine based on its share of the growing stock but there was little damage to deciduous forests despite being in leaf at that time of year. Most damage was done to tall stands and those that had been recently thinned (especially older or heavily thinned stands) (Jantz, 1971).

Impact of Storm

The storm caused 42.2 Mm^3 of damage in Sweden (Jantz, 1971) and resulted in 16 deaths either during the storm or in the clear up after the storm (SMHI, 2010). In the most heavily damaged districts 70% of the damage was in spruce, which made up 50% of the total growing stock (Persson, 1975). Most of the forests affected were in southern Sweden and were privately owned.

Following the storm damage large parts of the Nordic countries experienced the most extensive spruce bark beetle (*Ips typographicus*) outbreak recorded to date. This led to destruction of approximately 3 Mm^3 of trees (Eidmann, 1983). The insect damage continued through to the early 1980s.

The storm also severely damaged property and caused massive disruption to communications in the region (SMHI, 2010).

Response to Storm

The Swedish government provided subsidies for transport, felling and storage. Felling restrictions were put in place for the unaffected forest to allow the marketing of timber from the storm affected areas. Later in 1978 stricter regulations were put in place to force forest owners to actively manage forests in order to reduce bark beetle outbreaks due to the continued impact of beetle attacks precipitated initially by the 1969 storm (Ekelund and Hamilton, 2001).

4.1.4 13th November 1972 (Germany, France, Netherlands)

Meteorological Conditions

An extremely active depression passed across central England and tracked eastward over the North Sea before crossing the Baltic and making landfall in Estonia. The lowest pressure recorded was below 970 mbar. Wind speeds were typically 25 ms^{-1} but wind speeds up to 50 ms^{-1} were recorded in Germany (Kate and Zwart, 1973; Otto, 1994).

Forest Condition

The affected forest was mainly older conifer stands, with pine particularly badly affected in the Netherlands and Germany (Heij, 1972; Wiebecke, 1973). Other species affected were spruce, Douglas fir, beech and oak (Heij, 1972).

Impact of Storm

Damage was mainly reported in the Netherlands, Germany and France with a total of over 25 Mm^3 of damaged trees (Guillery, 1987). There was probably also damage in Belgium but no reports have been found. Austria, Switzerland, Czech Republic and Ireland all recorded less than normal damage for the year and so were probably not affected by the storm. No damage is reported for the UK and there are no reports of damage for Poland and the Baltic States. There were outbreaks of a number of insects for a few years following the storm including *Tomicus piniperda* and *Ips typographus* (Luitjes, 1977; Niemeyer, 1982).

Altogether 54 people died in the storm, mainly in Germany (Kate and Zwart, 1973). In the clear-up after the storm there were around 40 accidents in the state forest sector and 106 accidents (not all due to clear-up of storm damage) in the private sector in the Netherlands (State Forest Service, 1973). In Germany there were 700 accidents including 6 deaths in the state forest service and 602 accidents and 12 deaths in the private sector (Arnold et al., 1977). Most of these accidents were due to a lack of training and lack of safety equipment and could have been prevented. In Germany workers were recruited from Austria, Switzerland and Yugoslavia. In the Netherlands, use was made of Norwegian and Swedish harvesting machines and there was further investment in mechanisation. In addition, information was published in forestry magazines on how to deal with the clearance.

Following the storm, wood prices in the Netherlands temporarily dropped from 35-40 Dutch guilders per m^3 to 1 Dutch guilder per m^3 (State Forest Service, 1973). The storm occurred at the beginning of the harvesting season so its impact was reduced. However, a second storm in 1973 occurred just after clearance from the 1972 storm and even though there was only half the damage the impact on prices was even more severe.

Response to Storm

There were major responses in Germany and the Netherlands in an attempt to buffer the market. In Germany there was a reduction in planned harvesting and the government successfully applied to the EU for a temporary restriction on imports of timber to the country (Wiebecke, 1973). In addition 1.4 Mm^3 of pine were stored after the storm using sprinkler systems that had also been utilised in Scandinavia. In the Netherlands, the state forest sector reduced its wood sales on the understanding that the same would happen in the private sector in order to help absorb timber from damaged woodland.

The previous lessons from the damaging storms of 1967 and 1968 led to the Forest Damage Compensation law in Germany, which allowed the government to introduce a series of measures to help deal with the aftermath of the storm. In addition to the restrictions on harvesting there were subsidies for transport, changes to taxation, and direct financial support to affected forest owners. Subsidies were also available in the Netherlands (State Forest Service, 1973).

For the first time questions began to be asked publicly in both countries about the structure of the forest and the need to consider modification of the silvicultural and economic goals of forestry (Neefjes, 2007).

4.1.5 16th October 1987 (France, UK, Ireland, Norway)

Meteorological Conditions

The depression leading to the storm damage of 16th October 1987 originated as one of a number of low pressure areas that developed to the west of Spain along a pronounced polar front. There was a strong thermal gradient across the front with indications that part of the warm air mass to the south of the front originated from the remnants of hurricane Floyd off the coast of Florida.

The depression tracked north-east across the Bay of Biscay and rapidly deepened giving a minimum pressure of 952 mbar as it passed just west of Finistère in Brittany, France (Burt and Mansfield, 1988). The depression continued north-eastward across England and up the North Sea and then along the coast of Norway. The storm was accompanied by heavy rains. Gust wind speeds of more than 40 ms^{-1} affected a large area of south-west England with some areas experiencing more than 45 ms^{-1}. The highest wind speed over the UK was 51ms^{-1} at a coastal station (Shoreham-on-Sea). In the north-west of Brittany and the coastal area of Normandy, France gusts greater than 40ms^{-1} were experienced with the highest wind speed of 60 ms^{-1} near Granville on the Normandy coast.

Forest Condition

The areas affected by the storm had a large broadleaf component with beech and oak the predominant species. The broadleaves were still in leaf at the time of the storm and there had also been exceptional rainfall in the weeks preceding the storm meaning that the soil was waterlogged. Overall in England the total volume of damaged conifers and broadleaves was similar but as a percentage of growing stock there was more damage in the conifers (Quine, 1988; Grayson, 1989).

Much of the forest affected in both England northern France was privately owned and of small area. Also much of the privately owned forest was kept for reasons other than timber production such as for visual appearance and sporting interests. Because of this much of the forest had received little management intervention.

Impact of Storm

The storm was the most costly in UK history with total estimated damage of around €30 billion. In total 3.9 Mm^{-3} and 7.5 Mm^{-3} of timber were damaged in England and France respectively. This represented around 12% and 20% of the growing stock respectively in the affected regions of the two countries. In England this was equivalent to 5 months of UK conifer production and 2 years of UK broadleaf production (Grayson, 1989). In France the damage was equivalent to 8-10 times the annual timber production in Brittany.

The storm also affected a large number of amenity, urban and park trees, many of which were regarded as historically important. Approximately 800,000 non-forest trees were blown or damaged in England with a further 500,000 orchard trees blown over.

In England the first year after the storm (1988) there was little sign of additional problems with the damaged trees or in the surrounding undamaged woodland. However, in the 2nd year damaged trees suffered from discolouration and decay reducing their value. Hardwood values were substantially lowered both in England and France in the regions affected. Pine values in England were maintained after an initial 38% drop because of the large-scale storage of pine (75000 m^3) using water irrigation, which avoided a flood of material onto the market. Scots pine was given priority over Corsican pine for harvesting and storage because it is more prone to blue stain (Grayson, 1989). There was also a good demand at the time for pine roundwood which helped to maintain prices. In France there were difficulties in selling the conifer wood because it is mainly used for pulp outside of the region. The financial impact on the French hardwood was also high with the damaged material dispersed and difficult to extract.

There were 18 people killed in England and 4 in France with many more injured. The loss of life would have been even greater if the storm had occurred a few hours later when people were making their way to work.

Response to Storm

There was a well organised and ultimately successful response in England to the storm damage (Forestry and British Timber, 1989). The Forestry Commission set up a Forest Windblow Action Committee (FWAC) that was made up of members from both the public and private sector. FWAC was responsible for assessing the level of damage, providing advice to forest owners and harvesting operators, providing lists of contractors and timber merchants and advising ministers. Extra money (~€18 M) was made available by the UK government and other bodies to aid in the clean-up and restoration of affected forests and woodlands. In addition, income and corporation tax were suspended for forestry. Subsidies for transport were slow (8 months after the storm) and were therefore not particularly effective. Nevertheless some 30-40,000 tonnes of additional timber were hauled by rail.

Although in the short-term the response to the 1987 storm in the UK was comprehensive there were no specific policy changes in the longer term. However, the UK Meteorological Service was severely criticized in the aftermath of the storm for failing to forecast it better. In response, observational coverage to the south and west of the UK was improved by increasing the observations from ships, aircraft, buoys and satellites. In addition there were continued improvements to the forecast models, purchase of a new supercomputer and changes in training for forecasters.

4.1.6 25th January – 1st March 1990 (Germany, Czech Republic, France, UK, Belgium, Austria, Switzerland, Luxembourg, Poland, Slovakia, Denmark, Sweden, Netherlands, Italy)

Meteorological Conditions

The meteorological conditions during the winter of 1989/90 were unusual with the air temperatures over Canada and the western Atlantic unusually cold and temperatures over Northern and Eastern Europe unusually warm. The winter of 1989/90 was one of the mildest in 100 years in Europe with temperatures above 20^{0}C recorded in several regions of Germany and temperatures above 10^{0}C in northern Russia. This synoptic situation led to cyclones taking abnormal routes with many passing across the UK and then across the North Sea into the Baltic States (Kühnel, 1994).

Between 25th January and 1st March 1990, eight severe storms crossed Europe over a wide area. The most damaging storms were Daria on 25th and 26th January and Vivien and Wiebke from 25th February to 1st March. Daria began on a cold front in the North Atlantic before tracking across Scotland (reaching a lowest pressure of 950 mbar), then across the North Sea and tracking just north of Denmark. Wind speeds of 33 - 36 ms^{-1} were recorded over a large area with the highest gust wind speeds reaching 50 ms^{-1}. Daria was accompanied by heavy rain and this led to flooding in some regions. In contrast, the weather before Vivian was dry with extremely warm conditions and a record temperature for February of 22^{0}C in Freiburg. The storm developed in the northern North Sea and then tracked across central Norway and Sweden before crossing the Gulf of Bosnia and heading up the western side of Finland. Average wind speeds were very similar to storm Daria (33 – 36 ms^{-1}) with gusts again of up to 50 ms^{-1}. At higher elevation such as in the Black Forest wind speeds of over 55 ms^{-1} were recorded (Kronauer, 1990). Storm Wiebke followed immediately afterwards and mainly affected southern Germany, Switzerland and Austria with wind speeds on the Jungfraujoch mountain reaching 80 ms^{-1} and the storm was accompanied by heavy rain and snow (Stringfellow, 2008).

Forest Condition

The warm temperatures across Europe and Russia meant that much of the forest soils were unfrozen. At the time of the first storm, Daria, the soils in most of the affected areas were saturated following a wet winter. Most of the damage was to coniferous species with spruce and silver fir affected in Germany and Switzerland (Schmid-Haas and Bachofen, 1991) and spruce, Douglas fir and larch affected in the UK. There was also substantial damage to beech.

In the UK, stands that had been thinned following the 1987 storm were found to be particularly prone to damage.

Impact of Storm

The series of storms from January and March 1990 was one of the most devastating to hit Europe. The total cost of almost €13 Billion makes it the most expensive series of storms ever recorded (Münchner Rück, 2001). There was around 120 Mm^3 of damaged timber in 9 European countries, which, at that time was more than 4 times the previous worst storm in 1972 (Münchner Rück, 2001).

There was also significant damage to buildings and enormous disruption to infrastructure, transport and electricity supplies (Zou *et al.*, 2008). In the UK more than a million homes were initially without power and over 300,000 were without power for a few days. There was extensive coastal flooding and erosion. In total 272 people were killed during the sequence of storms (Münchner Rück, 2001) with a large percentage of these due to Daria, primarily because it reached peak intensity during daytime.

Despite the lessons of 1972 there were still numerous accidents in clearing up the wind damage. In south-west Germany there were 3544 accidents, 10 of which were fatal, in private and community woodlands and 1032 (3 fatal) in state forests (Kühnel, 1994).

Despite preventative measures to reduce the incidence of beetle attacks there were noticeable beetle outbreaks in southern Germany lasting for several years (Kühnel, 1994). Between 1992 and 2000 an area of 3700 ha of Norway spruce was killed by bark beetles in the Bavarian Forest National Park (Wermelinger, 2004). In Switzerland bark beetle maxima occurred in 1992 and 1993 leading to an additional 500,000 m^3 of harvested timber (BUWAL, 2000). The beetle outbreaks corresponded to the area affected by wind damage in 1990 (Engesser, 1998).

Response to Storm

In Germany the federal states are responsible for dealing with the aftermath of damage from natural events. However, because of the severe impact of the 1990 storms the

German government initiated a Federation-State auxiliary fund. In total the German states received €0.85 billion for processing storm damaged timber (Kronauer, 1990). Additional funds were made available by states for the removal of wood from community woodlands and for the processing and storage of damaged timber as a precaution against bark beetle attack (Kronauer, 1990).

In Switzerland approximately 370 million Swiss francs were made available by the Federal government and cantons for dealing with the storm aftermath. In addition the government provided military personnel and engaged foreign contractors to assist in salvage logging. It also helped by acquiring and maintaining harvesting machinery, constructing timber yards, transporting timber and purchasing storm-damaged timber.

In the UK the Forest Windblow Action Committee (FWAC) was reformed to provide advice and guidance but there appears to have been much less financial aid than in the previous storm in 1987.

4.1.7 24th – 28th December 1999 (France, Germany, Switzerland, Denmark, Poland, Czech Republic, Austria, Lithuania, Belgium, Estonia, Spain, Latvia, UK, Italy, Portugal)

Additional information on the immediate investigations of damage from these storms may be found in the proceedings of the Wind and Trees Conference held in Karlsruhe in 2003 (Ruck *et al*., 2003).

Meteorological Conditions

There were a series of 3 damaging storms during December 1999 starting with Anatol, which affected Sweden (2nd – 4th December), followed by Lothar (24th – 27th December) and then Martin (25th – 28th December). The storm tracks of Lothar and Martin were unusually southerly for Atlantic depressions.

Lothar started off the American East coast at about 35N and then entered the strong baroclinic zone that had formed across the Atlantic with a very strong associated polar jet. The development of Lothar was accelerated by a strong area of upper level divergence between Brittany and Cornwall. On reaching the French coast Lothar's central pressure had dropped to 961 mbar and this only slowly increased as it crossed Europe reaching 980 mb over Poland. Maximum wind speeds reached 48 ms^{-1} on the west coast of France and 50 ms^{-1} in the valleys of Switzerland and over 70 ms^{-1} on the Jungfraujoch Mountain. In the Alps there were particularly strong foehn winds due to the drop in pressure ahead of the associated cold front which brought exceptionally high wind speeds to lower altitudes.

Storm Martin followed only a day later and because Lothar was a "shallow" storm the large-scale synoptic pattern had hardly changed. Martin formed as a surface low on 25th December upstream of a long upper air trough over North America. By the 27th December Martin interacted with the eastward moving upper level depression forming on the northern end of the trough and then it moved rapidly across the Atlantic aided by the extremely intense polar jet. Martin's central pressure fell to 965 mbar just before the storm crossed the coast of France south of Brittany. The depression then crossed France, the Alps and down over the northern Balkans. Wind speeds were very high along the west coast of France reaching 55 ms^{-1} on the Ile d'Oléron, above 50 ms^{-1} at the mouth of the Gironde River and above 40 ms^{-1} in many parts of the coastal forest in the Medoc region. Wind speeds were also high across much of central and southern France and eastern Corsica. See Birot *et al*. (2009), Ulbrich *et al.* (2001) and Bründl and Ricki (2002) for more complete descriptions of the storms.

Forest Condition

The two storms affected areas with very different forest types. Lothar affected northern France, south-west Germany and Switzerland, which has large areas of Norway spruce and beech and lower levels of fir, Douglas fir and oak. With Martin the vast majority of the damage was to Maritime pine and some damage to Douglas fir. Overall in France the volume of damage was evenly divided between broadleaves (mainly beech) and conifers (mainly pine). However, the levels of damage in stands were rather different. Large amounts of the broadleaf damage occurred in stands with 10-20% damage levels whereas the damaged conifers were predominately in heavily damaged stands (>80% damage).

A large number of scientific papers have investigated the distribution of damage following the storms in 1999, for example Schütz *et al*. (2006) and Albrecht *et al*. (2010).

Impact of Storm

The two storms Lothar and Martin were the most destructive to European forests on record. More than 240 Mm^3 of timber were damaged across 15 countries. France was the worst affected country with 176 Mm^3 followed by Germany with 34 Mm^3 and Switzerland with 14 Mm^3. The damage in France represented 3 times the annual harvest (5 times the softwood and 2 times the hardwood harvest).

There was huge damage to buildings, infrastructure and transport systems with the total cost of the storms put at around €10 billion. Severe flooding occurred along the French coast. In total 140 people were killed, 88 of whom were in France and in 2000 there were 100 forest workers killed in France clearing the wind damage.

Insect attack followed the storm with increasing damage until the end of 2001 in both France and Germany. This was followed by a dip in 2002 with a very bad year in 2003 following very dry conditions. Insect damage was highest in broken trees with levels of infection higher in conifers (up to 64%) than in broadleaves (up to 42%). Insect attacks were responsible for a further 4 Mm^3 of damage in France and 3.5 Mm^3 in Switzerland.

Timber prices fell after the storms with an estimate of €6 billion lost in revenue in France alone. In 2000 the Office National des Forests sold 49% more timber than in 1999 but overall revenue was 7% less. The oak market was less affected but the beech market suffered heavily and the amount of stored beech depressed the market for a number of years. Detailed description of the impact of the storm in France can be found in Birot *et al.* (2009)

Response to Storm

The French government provided financial aid to help clear the forest, to construct extraction roads and rides, to repair roads damaged by timber trucks, and to build timber landing areas. There were also subsidies for three years to help forest owners harvest and store wind damage, including loans for purchasing harvesting machinery. In addition there was funding to help pay for remedial work to reduce the risk of insect attacks, to restore blown over young stands and to encourage regeneration of the damaged forest. There were also subsidies for rail and road transport for timber. Training courses were given to woodcutters to reduce casualties.

In France special terms were applied to land tax, income tax, wealth tax and VAT for affected forest owners. The government also provided a number of supporting facilities such as damage assessment using aerial photography, assignment of additional staff to field organisations, special aid for state forests and establishment of a think-tank to explore forest insurance issues. Finally, significant funding was directed at wind damage research over a number of years much of which is reviewed in Birot *et al.* (2009).

Similar measures were taken in Germany and Switzerland with government support for dealing with the consequences of the storm damage and increased funding for research into wind damage to forests.

4.1.8 19th November 2004 (Slovakia)

Meteorological Conditions

A number of cyclones formed along a cold front at 50^0 N and one of these centres of low pressure passed close to the north of the Tatra Mountains on 19th November. Under such conditions it is possible to get extremely strong down-slope winds on the lee of the mountains (Simon and Vivoda, 2005). At the mountain top (2630 m) the wind speed reached 47 ms^{-1} but at 1700 m the wind speed peaked at 55 ms^{-1} and at the tree-line (1500 m) at 64 ms^{-1}. The strong winds lasted for 6 hours.

Forest Condition

Norway spruce is the dominant tree species (95%) with some larch. Individual spruce trees can be between 60 to 100 years old. Soils are shallow and rocky and the area is affected by summer droughts. The forests in the Tatra Mountains are a mixture of planted and semi-natural forest with some natural forest. Much of the forest lies within the Tatra National Park or other nature reserves, with a large part of the affected area designated under NATURA 2000.

Impact of Storm

The storm caused almost complete destruction of large areas of the forest. The total volume of wind damaged timber was 5.3 Mm^3, which represents more than 50% of the entire timber production in Slovakia. Most of the damage was in the Tatra mountain region (2.3 Mm^3, 12,000 ha). The man-made and semi-natural forest at lower elevations were worst affected whereas the natural forest at higher elevations (lower wind speeds) were more or less unaffected (Fleischer, 2008).

The storm caused a large amount of damage to local infrastructure including roads, railway lines, electric lines, water pipes and tourist trails. Buildings were generally little affected because of the protection afforded by the forest. The result was a large impact on the income generation of the area from tourism and health spas.

The damage led to a huge increase in insect damage particularly of *Ips typographus*, but also *Ips amitinus*, *Pityogenes chalcographus*. The outbreak was the worst in 100 years and continues to the present. Removal of infected timber was restricted in some areas because of their NATURA 2000 status but permission to remove all affected timber was given in 2009. Initially the outbreak was confined to storm damaged spruce but eventually it also affected pristine spruce stands outside the damage area and Swiss pine (*Pinus cembra*) growing on the tree line (Fleischer, 2008).

The damaged timber from the storm also led to a large fire within the NATURA 2000 area which took 3 days to put out and involved 150 fireman, and an aircraft and helicopter.

Response to Storm

The response to the storm was analysed in some detail in an international workshop in Slovakia and an assessment was made of what worked well and what didn't (http://fao.org/regional/SEUR/events/storm/docs). It was felt that there was a recognition of the need for removal of the wind damaged timber, the need to regenerate the mountain forests, the application of site specific management, the provision of scientific advice, the provision of water reserves for fire-fighting, the elimination of the fire risk near to habitation and the instigation of forest monitoring. Less successful was the lack of awareness of the threat from bark beetles, administrative delays in the removal of timber, the conflict between nature conservation and forest laws, poor communication with the media, slow preparation of forest management plans, unclear responsibilities between different groups, lack of crisis contingency plans, lack of fire warning system and poor compensation for private forest owners.

4.1.9 7th – 9th January 2005 (Sweden, Latvia, Denmark, UK, Estonia, Lithuania)

Meteorological Conditions

An extra-tropical cyclone formed during the evening of 7th January to the north-west of Iceland (Alexandersson and Ivarson, 2005). The system rapidly deepened along the baroclinic line where cold air from Greenland met mild and moist air to the north-west of the British Isles. The depression was enhanced by a westerly jet stream causing divergence at upper levels. By the middle of 8th January the centre of the low pressure reached south-west Norway and then passed over Norway and Sweden before crossing the Gulf of Bosnia and heading east across Finland.

The maximum wind speeds recorded were 45 ms^{-1} (UK), 38 ms^{-1} (Latvia), 37.5 ms^{-1} (Estonia), 46 ms^{-1} (Denmark), and 42 ms^{-1} (Sweden) (Alexandersson and Ivarson, 2005). Most of these were from coastal stations and a maximum observed wind speed in inland forested areas of Sweden was 33 ms^{-1}.

Forest Condition

Southern Sweden was the worst affected area. Ownership of the forest in that region is predominately by private individuals (up to 77%) with small forest blocks (few hectares). Much of the forest was past the age at which it would normally be harvested. Much of the damaged area consisted of Norway spruce (80%) with some damage to Scots pine (18%) and relatively little to deciduous trees (2%) (SFA, 2006). The standing volume prior to the storm was 50% Norway spruce, 25% Scots pine and 19% deciduous trees suggesting proportionally more damage to the spruce (SFA, 2006).

Impact of Storm

The storm had a devastating effect on the forests of Southern Sweden with 75 Mm^3 of timber damaged, which represents approximately the annual harvest of the whole country. In some forestry districts the damage represented 20 years of harvesting. Less damage occurred to forests in Latvia, Denmark, UK, Estonia, and Lithuania but still represented a large percentage of the growing stock in countries like Denmark (3.4%).

Although there were large efforts to clear up the storm damage as quickly as possible there were outbreaks of bark beetles (in particular *Ips typographus*) in the affected areas that were made worse by a second storm in January 2007 (Långström *et al.*, 2009). The mortality in Sweden due to bark beetles was less than expected (3 Mm^3) although population levels were still high by 2009 (Bergquist, 2009).

There was an enormous impact on infrastructure and services in most of the countries affected but particularly in Sweden, Denmark, Latvia and Estonia with many households left without electricity, roads and trains blocked, telecommunications systems destroyed and extensive coastal flooding (Alexandersson and Ivarsson, 2005). In the Gulf of Finland water levels rose more than 2.5m above normal (Alexandersson and Ivarsson, 2005). In Sweden the impact on people in certain parts of the country was enormous with a loss of services for many weeks (e.g. up to 45 days without electricity) (FMV, 2006). The emergency services were at the absolute limit and there would have been much more severe consequences if the weather had not been so mild following the storm (KBM, 2005).

There were a total of 19 deaths due to the storm with 3 people killed in England, 4 in Denmark, 11 in Sweden and 2 in Germany (Alexandersson and Ivarsson, 2005; Guldåker, 2009). There were also huge psychological impacts on people particularly in Southern Sweden and a year after the storm approximately 1/3rd of private forest owners claimed that their wellbeing was reduced (SFA, 2006).

There were some environmental benefits resulting from the storm with the new environments created by the storm providing ecological niches for many species. However, benefits were reduced because a large amount of salvage took place without adequate concern for environmental impacts (SFA, 2006). In addition there was increased leaching from the soil of a number of chemicals including nitrates and mercury and methyl mercury (SFA, 2006; Munthe *et al*., 2007; Hellsten *et al.*, 2009). In the affected parts of Sweden it was found that 40% of ancient remains had been damaged by trees falling during the storm (SFA, 2006).

The average price of logs in Southern and Central Sweden reduced immediately following the storm (up to 38% reduction) but prices recovered well in 2007 and 2008 (SFA, 2010) in the strong global economic conditions, before the global economic slowdown in 2009.

Response to Storm

The European Solidarity Fund provided €92.88 to Sweden, Estonia, Latvia and Lithuania as compensation for the storm (European Commission, 2006c).

Immediately following the storm a number of forest related regulations were relaxed in Sweden in order to facilitate the clear-up of damage and to help the restoration of the forest (SFA, 2006). This also included financial support for repairing roads damaged by timber transport, and subsidies for timber storage and forest regeneration. There were also monitoring programmes initiated to check for insect outbreaks and regulations introduced in 2007 to combat the infestation.

In Sweden a new law was passed to reduce the vulnerability of local communities and municipalities to such events and to improve the civil response. The storm did not result in major changes to recommended forestry practice although there were recommendations that Swedish forestry should more actively manage risk by requiring forest consultants to clearly inform forest owners of how to reduce the risk of wind and snow damage through early pre-commercial thinning and commercial thinning (SFA, 2006). Insurance companies also changed their policies following the storm.

4.1.10 14th – 18th January 2007 (Germany, Sweden, Czech Republic, Poland, Austria, Latvia, Slovakia, Lithuania, Belgium, France, Netherlands, Romania)

Meteorological Conditions

There were two damaging storms in the middle of January 2007, Per (14th January) and Kyrill (18th January). Per tracked across central Scandinavia with wind speeds up to 40 ms^{-1} and led to forest damage in Sweden. Kyrill formed over Newfoundland on 15th January 2007 and moved across the Atlantic Ocean reaching Ireland and Great Britain by the evening of 17th January, moving rapidly because of the strong jet stream. It then crossed the North Sea on 18th January, arriving at the German and Dutch coasts on the afternoon of 18th January, before moving eastwards across Poland and the Baltic Sea. Wind speeds of 44 ms^{-1}, 41 ms^{-1} and 36 ms^{-1} were recorded in the UK, Ireland and the Netherlands respectively at coastal stations. In Germany and the Czech Republic wind speeds of over 50 ms^{-1} were recorded at mountain stations. The storm was unusual in that it affected a very wide area and was long lasting with some areas experiencing gale force winds for over 24 hours.

Forest Condition

The forested area most affected by Per was Sweden, while Kyrill affected Germany, Czech Republic, Poland and Austria (Dedrick *et al.*, 2007). However, there was also damage in Latvia, Slovakia, Lithuania, Belgium, France, Netherlands, Romania and very small amounts in UK and Denmark (~50,000 m^3). The predominant species affected by both storms was Norway spruce.

Impact of Storm

Per caused 12 Mm^3 of damage to forests in Sweden. Kyrill caused losses of 54 Mm^3 of standing timber across Europe. The most heavily hit countries were Germany with 28 Mm^3 (20% of annual allowable cut), the Czech Republic with 12 million cubic meters (65% of annual allowable cut) and Austria with 2.25 Mm^3 (15% of allowable cut) (Dedrick *et al.*, 2007).

The storm caused 55 deaths across Europe including Germany (13), UK (13), Ireland (7 – lost at sea), Netherlands (7), Poland (6), Czech Republic (4), Belgium (2), France (2) and Austria (1). There were also deaths and injuries during the clear up (e.g. 8 deaths and 795 accidents in Nordheim-Westfalen, Germany alone) (Ministerium, 2010).

Kyrill caused massive disruption to communications and to electricity supplies across Europe but in particular Germany and Czech Republic. In southern England 25,000 homes were without electricity whilst in Germany there were 52,000 homes affected in Brandenburg, Saxony and Saxony-Anhalt.

It was estimated that there was €1 billion in lost revenue for the forest industry in Germany in addition to the direct damage caused by the storm (http://www.dwworld.de/dw/article/0,2144,2323760,00.html).

Response to Storm

In Germany, forest owners were offered subsidised loans to restock their forest. Several additional measures were taken to aid the salvage of the timber, such as short-term (1 year) exceptions regarding allowable transport weights and working hours.

In North Rhine Westphalia there was a swift response to the storm to deal with the immediate impact of Kyrill but also to develop a more coherent response to future storms. They established a "Crisis and Activity Committee" (KaFoS) as a communication platform for the Ministry, the State Forest Enterprise and interest groups of different forest enterprises. Following the storm there was an evaluation of what had been successful and what had not worked. The response to that evaluation has been the development of contingency plans and a storm handbook for dealing with the aftermath of the storms. In addition, there now exists in Germany a cooperation of State Forestry Administrations for risk related knowledge management (www.waldwissen.net). (Further details are available in Appendix 2, which details the reports and discussion of the 1st July 2010 workshop in Brussels).

4.1.11 24th January 2009 (France, Spain, Portugal, Italy)

Meteorological Conditions

Klaus developed as an Atlantic depression travelling across the Bay of Biscay and making landfall near to Bordeaux, France early in the morning of 24th January. It travelled south-eastwards to the south-east coast of France and then continued eastwards over Italy. The lowest pressure recorded was 967 mb. Wind speeds reached 54 ms^{-1} in France, 56 ms^{-1} in Spain and 60 ms^{-1} in Andorra.

http://france.meteofrance.com/jsp/site/Portal.jsp?page_id=11330&page_id=10539
http://www.alertes-meteo.com/hiver-08-09/vague-de-froid-hiver-2008-2009-24-01-

Forest Condition

The storm was the second in 10 years to affect the Les Landes area of France and Northern Spain. The majority of the forest affected in France was Maritime pine (90%) with some oak (10%). In Spain and Portugal most of the damage was to Radiata pine and *Eucalyptus globulus*. Much of the area of forest affected in France had generally escaped damage from storm Martin in 1999 and was further to the south than the previously damaged forest. In effect the whole Les Landes forest was affected by the two damaging storms (Martin and Klaus) within a period of 10 years.

Impact of Storm

The total affected volume was 43.1 Mm^3 (14% of the standing volume). In Aquitaine region, 41 Mm^3 out of 175 Mm^3 of standing timber were affected. The private forest sector was mainly affected, while the public forest estate along the coastal zone suffered only 3% damage. The difference appears to be due to the public forest being planted on deep coastal sand dunes with good rooting whereas the private forests further inland were on sites with the water-table closer to the surface and with more restricted rooting. Most of the trees were uprooted (62%) and only 14% were broken. In Spain, the two most affected regions were Galicia and Euskadi. The total affected volume was 1.1 Mm^3 with 1.025 m^3 in Galicia

The storm caused 31 fatalities (12 in France, 15 in Spain, 4 in Italy), as well as extensive disruptions to public transport and power supplies, with approximately 1.7 million homes in south-west France and tens of thousands of homes in Spain experiencing power cuts. The storm caused severe damage to property with a number of buildings collapsing.

Within the damaged stands more than 40% of trees were found to have been affected by bark beetles. The latest figure for the loss due to beetles is 3.9 Mm^3 (http://draaf.aquitaine.agriculture.gouv.fr/IMG/pdf/resultats_road_sampling_octobre_cle4c472f.pdf)". The bark beetle damage is compounded by a parallel outbreak of defoliation due to pine processionary moth.

Prices of Maritime pine fell from a maximum of €45 per m^3 before the storm to a maximum of €10 per m^3 in 2009. Timber from the region has proven very attractive to wood buyers from Germany and Austria in particular, because of subsidies for transport. However, initial analysis suggests that this will lead to a shortfall over the next 10 to 15 years for local sawmills and wood-based industries. Therefore, although the storm may have a short term benefit for some wood processors, overall the impact on wood-based industries is likely to be detrimental.

The damage caused by Klaus is estimated to have had a €1 billion impact on the local forest industry (loss of market value). If other direct (loss of future value, increased restoration costs) or indirect costs (secondary damage, delayed exploitation) are included then the total loss for forest owners is between €1.6 to 2 billion. And when other impacts on the wood processing industry and to climate regulation services (carbon sequestration capacity) are added, the total economic loss is in the order of €3 billion (Peyron *et al.* in CIAG 2009; Lecocq, *et al*., 2009)

Response to Storm

The French state and the local region provided grants, loans and training to help with the immediate requirements (road clearing, damage inventory, support of organisations, human resources, etc.), post storm forest operations (construction of storage infrastructures, wood extraction, transportation and storage, support of forest enterprises, etc.), and forest protection and restoration (forest cleanup, restoration of infrastructures, pest control, forest regeneration, support of nurseries, etc.).

4.2 Analysis of Overall Impacts of the 11 Storms/Storm Series

The impacts of the storms have been assessed against a range of ecological, social and economic indicators that were selected based on information that is most commonly available in reports of storm damage. Generally, the economic indicators are the easiest to evaluate because information such as claims made against insurance are available (e.g. Swiss Re, 2000). However, insurance against wind damage to forest is not available everywhere, and where it is, not all owners have bought insurance policies. Social impact can be ascertained by reports in the media following the storm and consequences such as the number of casualties or number of homes with disrupted electric supplies. The impacts on the environment are much more difficult to determine because these often take a substantial time (years) to manifest themselves and it can be difficult to ascribe changes directly to a storm event.

The criteria for the different levels of impact (High/Medium/Low) are set out in Table 5 and an assessment of the impact of the 11 selected storms is provided in Table 6. The assessment is done at local, regional, national and European scales. The scale is defined by the NUTS classification (http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction) with Local equivalent to NUTS2 areas and Regional equivalent to NUTS1 areas.

Table 5: Criteria for Different Impact Levels Applied to Storms (any indicator can classify a specific impact level)

Impact	Indicator	Low	Medium	High
Ecological	Reduction in carbon budget of forests	Within annual fluctuations	Measureable decrease in carbon assimilation due to storm damage	Decrease in carbon assimilation due to storms greater than impact of all clear-felling across Europe
	Increased deadwood	No discernable increase outside normal fluctuations	Above normal fluctuations	At same or higher level than annual dead wood production in all European forests
	Land-use change	No change in land-use	Delay in reforestation	Loss of forest
	Water Quality	No impact	Temporary impact for a few years	Long term reduction in water quality
Social	Accidents clearing up damage in forests	No discernable increase outside normal fluctuations	Above normal fluctuations	At same or higher level than annual accidents in all European forests
	Any casualties due to the storm	Not reported	Casualties due to storm reported in local/national media	Casualties due to storm reported in international media
	Homes without electricity	Low level of disruption and able to be handled within 1-2 days of storm by local electricity service	Disruption lasting more than 2 days but less than 2 weeks and handled by local electricity service	Major disruption to majority of houses in affected region and lasting > 2 weeks. Additional assistance required from outside region
Economic	Timber Prices	No discernable change	Noticeable price reductions but without long-term (>5 year) economic impact	Large reduction leading to economic difficulties, bankruptcies, job losses
	Additional Forest Workers Required	Local recruitment sufficient to deal with any increased requirements	Forest workers recruited outside affected region	Forester workers recruited from outside affected area
	Income and Costs	Isolated damage leading to income reduction and increased costs only for damaged forest	Economic loss but damage volumes are below the annual harvest volumes of the area. Increased costs for restoration and postponement of intervention in undamaged stands	Regional or national intervention required to regulate flow of timber and to organise storage of wind damaged timber. Market saturated with timber from storm with European impact
	Increased outbreak of forest pests	No measureable increase in damage due to forest pests	Measurable increase in damage due to pests	Substantial damage caused by increased pests

Table 6: Impacts of 11 Selected Storms at Different Scales. (Local = NUTS2, Regional = NUTS1) is an expert judgement based on the experience of the consortia.

Event	Scale	Social Impact	Economic Impact	Ecological Impact	OVERALL
1953	Local	High	High	High	High
	Regional	Medium	Medium	Low	Medium
	National	Low	Low	Low	Low
	European	Low	Low	Low	Low
1967	Local	High	High	High	High
	Regional	Medium	High	Medium	High
	National	Medium	High	Medium	Medium
	European	Low	Medium	Low	Low
1969	Local	High	High	High	High
	Regional	High	High	High	High
	National	Medium	Medium	Medium	Medium
	European	Low	Low	Low	Low
1972	Local	High	High	High	High
	Regional	Medium	Medium	Medium	Medium
	National	Low	Medium	Low	Medium
	European	Low	Low	Low	Low
1987	Local	High	High	High	High
	Regional	High	High	High	High
	National	Medium	Medium	Low	Medium
	European	Low	Low	Low	Low
1990	Local	High	High	High	High
	Regional	High	High	High	High
	National	High	High	Medium	High
	European	Medium	Medium	Low	Medium
1999	Local	High	High	High	High
	Regional	High	High	High	High
	National	High	High	High	High
	European	Medium	Medium	Low	Medium
2004	Local	High	High	High	High
	Regional	Low	Low	Medium	Medium
	National	Low	Low	Low	Low
	European	Low	Low	Low	Low
2005	Local	High	High	High	High
	Regional	High	High	High	High
	National	Medium	Medium	Medium	Medium
	European	Low	Low	Low	Low
2007	Local	High	High	High	High
	Regional	High	High	High	High
	National	Low	Medium	Low	Medium
	European	Low	Low	Low	Low
2009	Local	High	High	High	High
	Regional	High	High	High	High
	National	Low	Medium	Low	Medium
	European	Low	Low	Low	Low

5. Alleviation of Storm Damage Impacts

- **The influences of local conditions and forest management on wind risk are now well understood, but there are areas where data is insufficient.**
- **The severity of storms may be compared using Severity Indices, commonly based on the maximum gust wind speed, storm duration and area damaged.**
- **Maximum gust wind speed indicates the potential levels of damage: no appreciable damage for <30 ms^{-1} wind, moderate damage between 30 ms^{-1} and 40 ms^{-1}, high damage between 40 ms^{-1} and 45 ms^{-1}, and severe damage above 45 ms^{-1}.**
- **Tree species appear to vary in susceptibility to wind damage, and conifers appear generally more vulnerable than broadleaves. However, direct comparison is difficult because species are managed differently, grow to different heights and tend to be grown on different soils or site types.**
- **Tree height is the most important factor determining vulnerability. Stand structure appears to be much less important. Soil and landscape characteristics explain a large amount of variation in damage between stands. Wind risk management tools are now available that incorporate these factors.**
- **Effective wind risk management tools are available but these are not yet used in most European countries**

5.1 Link between Storm Damage and Local Conditions

When faced with severe storm damage, foresters commonly ask if the damage was inevitable, because, for example, it may be related to locally extreme winds, or whether a different silvicultural regime could have significantly reduced the amount of damage. An incomplete understanding of the complex mechanisms underlying wind damage has in the past resulted in controversies in the scientific and professional literature and in the media. However, the substantial research effort dedicated to this issue over recent decades, has dramatically improved our knowledge. Developments in our understanding of risk management now provide opportunities for forest managers to use and develop silvicultural methods that achieve forest management objectives at the same time as minimising biotic and abiotic risks (Jactel *et al.*, 2009).

Destructive storms cause physical damage to forests in a range of ways that may either be immediate or delayed. Physical damage may weaken trees progressively until death, and may not always be immediately visible. Forest damage can be modified by changes in forest activities (Jactel, *et al.* 2009), and has consequences for all forest services and activities.

5.2 Recent Progress in Understanding of Forest Wind Damage

The progress in our understanding is related to the evolution of scientific approaches to wind damage. While field-based assessment and small experimental studies were the basis of earlier work (1960s and 1970s), statistical studies based on large samples (hundred or even thousands of plots) and newly available statistical tools have allowed some new insights over the two past decades. The Danish work by Lohmander and Helles (1987) and recent studies in Germany (Albrecht *et al.*, 2010) are examples of such "phenomenological" studies. However, these statistical approaches have their limits: factors may be redundant and difficult to separate, and the results are sometimes difficult to interpret in causal terms. Their most important role is in providing observations that are used to develop testable hypotheses, followed by controlled experimentation such as tree pulling, modelling, wind tunnel studies, etc. In parallel to these studies, mechanistic studies, based on the description and modelling of the turbulent air flows together with the modelling of the mechanical behaviour of the tree when exposed to wind loading (for example see Cucchi *et al.*, 2005; Gardiner *et al.*, 2008; Brunet *et al.*, 2009) have provided more detailed descriptions of the processes involved in wind damage. These approaches should, when further developed, help to test the influence of interrelated factors which cannot be separated using statistical analyses and explore specific or even currently non-existing, silvicultural practices.

In the following sections, we provide an overall description of the factors involved in storm damage at local (stand) and landscape level, and stress the key features that forest managers may influence to reduce or minimise future damage. This description refers to storm damage in general, with some specific references to certain major storms. In principle, each major storm can be analyzed according to these key factors, in order to identify the factors that explain the severity of the damage, and formulate specific mitigation measures. The difficulty is that reliable information on all these factors may not exist for all storms. In this study, the available data for storms was too variable and partial to carry out a rigorous comparative analysis, and so it has been necessary to make comparisons based on expert judgement in many cases.

5.3 Managing Wind Risk and Mitigating Storm Damage

In terms of the management of wind damage risk, it is essential that both the probability of occurrence and the value of what is at stake are taken into account. Given the opportunities to moderate the risk of wind damage through adapted silviculture and forestry planning, what is considered a reasonable level of risk will depend on the perspective applied (Blennow, 2008), for example at a national or regional scale, or at the level of the individual forest owner.

5.3.1 Wind Characteristics

The level of damage can be explained at an initial level by the wind speed, and specifically the peak gust wind. However, this is often difficult to document as in many cases only interpolated (and thus approximate) values derived from existing meteorological stations are available at the local scale. Despite this limitation, large scale statistical studies of the 1999 storms (France: Colin *et al.*, 2009) and analyses of long-term series of wind speed and damage impact (Switzerland: Usbeck *et al.*, 2010a) have shown strong correlations between wind speed and storm damage (Colin *et al.*, 2009).

An analysis of data from our storms catalogue reveals that in broad terms there is no appreciable forest damage for gust peak wind speeds below 30 ms^{-1}, moderate damage (<2% of growing stock) between 30 and 40 ms^{-1}, a high amount of damage (maximum potential damage 2 – 4% of growing stock) between 40 and 45 ms^{-1}, and severe damage (maximum potential damage > 4% of growing stock) above 45 ms^{-1} (see Figure 4).

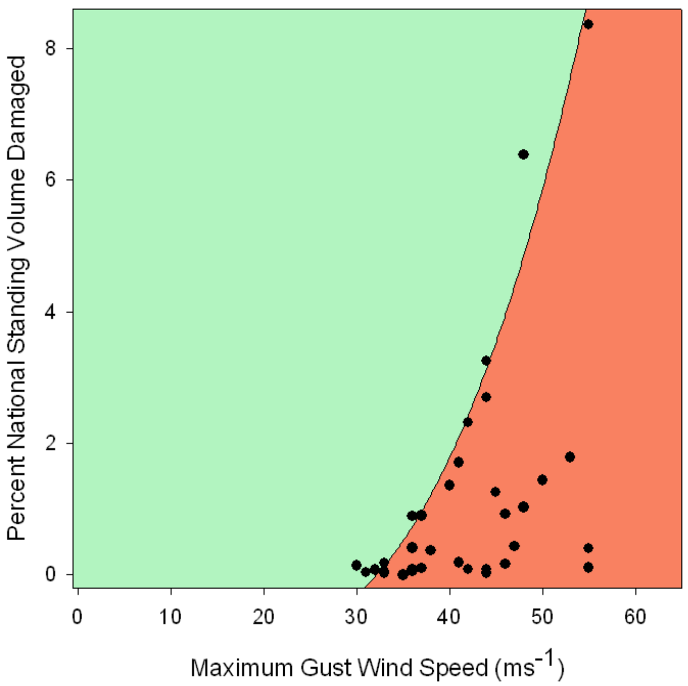

Figure 4: Annual damage to forests from storms in Europe based on data from the STORMS database, expressed as % national growing stock (standing volume) damaged, in relation to maximum gust wind speed. The line indicates the largest percent volume of damage that may be expected from a maximum gust wind speed, but depending on the characteristics of the storm and the forest area, points from storms to the right of the line show that the percent volume damaged can be considerably less

In general, the storms affecting large areas in Europe imply western winds, but other wind directions can occur during smaller, for example, summer storms (e.g. http://www.forest.fi/smyforest/foresteng.nsf/tiedotteetlookup/069B8BE8D721A6BBC22577CB002BBB48). As trees are known to adapt their anchorage to resist the local prevailing wind (Nicoll and Ray, 1996), they may be expected to be more vulnerable to these other wind directions (Quine *et al.*, 1995).

5.3.2 Tree Species

Tree species probably vary in their vulnerability to wind, as a result of characteristics including variation in the anchorage provided by the root system (Nicoll *et al*., 2006a) and wood resistance (Lavers, 1983). For example, it is known that stem weight and rooting resistance are highly correlated but differences in the slope of the regression for different conifer species tend to be small (Nicoll *et al.*, 2006a). In addition, species differences and inter-species variation in crown characteristics and growth features that influence wind loading make objective assessment or modelling of stability differences difficult and subject to a high degree of uncertainty. Observations of damage to tree species following storms, has provided a number of classifications of resistance to windthrow, for example: Bazzhiger and Schmid, 1969; Lohmander and Helles, 1987; Grayson, 1989; Bouchon, 1987; Lüpke and Spellmann, 1997; Jalkanen and Mattila, 2000; Kohnle and Gauckler, 2003; Colin *et al.*, 2009. However, these classifications show contradictions, presumably reflecting the influence of specific site and stand conditions, especially tree height and the rooting depth of the soil on which trees are growing, as well as methodological differences.

Overall, conifers appear to be more sensitive than broadleaves based on storm damage statistics, which generally show a larger proportion of the share of damaged conifers as compared with the share of conifer area/growing stock (Laiho, 1987; Grayson, 1989). For example, Albrecht *et al.* (2010) found Norway spruce and Douglas fir the most susceptible and oak and beech the least susceptible to damage from an analysis of storm damage in South-west Germany. However, it is not always clear to what extent conifers appear to be less stable because they are commonly planted on shallower, wetter soils. Also the extensive use of fast growing conifers in the reforestation of much of Europe has meant that the tallest trees in forests are often conifers, and height is a well known determinant vulnerability (see Section 5.3.2 below). Unfortunately, there has never been a direct, controlled experimental comparison of the wind stability of a range of conifer and broadleaved trees of similar height, growing on the same soil, and therefore there is so far no conclusive evidence of any inherent difference in vulnerability (Quine *et al.* 1995). The use of risk models outlined in Section 5.4 can help elucidate species differences within the predictive limits of the models, but in general such models are only available for conifers. Otherwise local knowledge and the suitability of species for particular sites should be important determinants in species choice.

Based on statistical studies of windthrow, there is also reported variation between and within broadleaves and conifers. Some hardwoods appear to be as vulnerable as certain conifers, and some conifers, e.g. silver fir, appear more resistant than some hardwoods. The more resistant hardwoods include sessile and pedunculate oak, ash, and hornbeam, while cultivated poplars, locust and chestnut appear generally more sensitive. The stability of conifers is also reported to vary: silver fir generally appears relatively stable, while Norway and Sitka spruce are reported to be sensitive (Maurer, 1982; Lüpke and Spellmann, 1997; Bosshard, 1967; Jalkanen and Mattila, 2000; Nicoll *et al.*, 2006a). The position of Scots pine varies between sensitive or intermediate depending on the context. The same holds for larch which often appears among the more stable species (Birot *et al.* 2009). Again this variation will partly reflect differences in above and below-ground growth of species, but largely it will reflect the site and soil differences on which particular species are grown. In a comprehensive study of the 1999 storm damage in south-western Germany, which attempted to separate species effects from site conditions and topography, Schmidt *et al.* (2010) showed vulnerability to wind damage increasing from Scots pine and larch (least vulnerable) through silver fir and Douglas fir to Norway spruce (most vulnerable). Broadleaves were generally found to be less vulnerable than conifers but tree height, waterlogged soils and exposed locations were the dominating factors.

Overall species differences are likely to be a secondary effect in comparison to soil conditions, tree height and recent thinning (see sections below).

5.3.3 Stand Characteristics

Basic (slowly changing) characteristics

Tree dimensional factors (height/ diameter, crown length, etc.), within stand variability of tree height and related canopy roughness, and species composition, were examined as these variables directly relate to silviculture (see recent evaluations by Colin *et al.*, 2009).

Tree Height

Tree height means not only a higher wind loading on the tree crown, but also a higher centre of gravity and a longer lever arm. Mechanistic experiments and modelling (e.g. Gardiner *et al.*, 2000; Cucchi *et al.*, 2005) give consistent results with statistical approaches (FAO, 2000; Colin *et al.*, 2009 and references therein, Peterson, 2000 and references therein; Albrecht *et al.*, 2010) showing that at individual tree and stand level, height is well correlated to damage. One example of this finding is a study by Lohmander and Helles (1987) of 612 conifer stands in Denmark damaged by a storm in 1981. They found a very strong relationship between observed percentage damage and stand height, and results of their study are shown in Figure 5. In the UK tree height has been used, in conjunction with site windiness and rooting depth, as an indication of when the risk of wind damage has become unacceptably high and stands need felling (Miller, 1985).

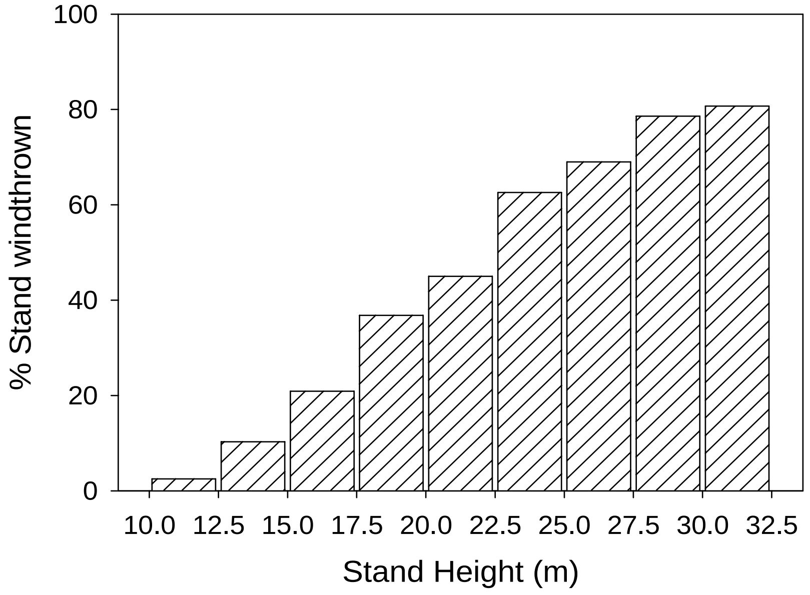

Figure 5. Observed windthrow percentage in 612 stands damaged in Denmark in a storm in 1981. Graph redrawn from Lohmander and Helles (1987).

The tree height increase for many species in various parts of Europe, resulting from environmental influences, ageing and genetic improvement, will therefore have contributed to the increase in vulnerability of European forests to strong winds.

While tree height/tree diameter (H:D) ratio (commonly used as a "stability" indicator) is relevant for most conifers, it is generally not for hardwoods, and many of the commonly used descriptors in silviculture (e.g. density of the stands, basal area) have no clear influence on the level of damage.

Stand Structure

Stand structure (irregular versus regular stands) has overall no clear influence (Colin *et al.*, 2008; Colin *et al.*, 2010; Gardiner *et al.*, 2005). Statistical studies give contradictory results and mechanistic approaches are not yet advanced enough to decipher the opposing influences involved.

Stand Mixture

Stand mixture also shows no clear stability effects in the literature. A better interpenetration of the crowns, a more complex social structure of the trees within the stands, and a better vertical stratification of the root systems are among the mechanisms which may be expected to provide a beneficial effect of stand mixture. While some authors state that species mixture has a beneficial influence on the overall stability of stands (e.g. Slodicák, 1995 ; Schütz *et al.*, 2006) others do not find such effects. Some recent studies, based on silvicultural (controlled) experiments (Schelhaas, 2008b) and evaluations of large scale field studies based on forest inventory data (Colin *et al.*, 2008; Colin *et al.*, 2009), do not indicate a clear intrinsic beneficial influence of mixture. While it may be advantageous to mix a perceived sensitive species with a more resistant one, the resistance of mixed stands broadly has an intermediate resistance in proportion to the species in the stand, and extra "synergistic" resistance does not appear clearly (Colin *et al.*, 2008). In other words the mixture of more "stable" species in a stand does not improve the overall stability of the more "vulnerable" species and the same benefit of spreading risk could be achieved by planting the species separately. The differences between studies, especially local ones, might be explained by differences in stand history, or preference of mixed stands on certain sites, such as those with lower fertility (Schelhaas, 2008b). In British conifer plantations, on water-logged soils, deep rooting Lodgepole pine is known to lower the water-table and increase rooting depth (and hence stability) of Sitka spruce with which it is mixed (Pyatt, 1993). There is also some evidence that the presence of an understorey underneath a thinned overstorey may provide some stability benefits, as shown by wind tunnel studies (Gardiner *et al.*, 2005) and field studies (Wellpott, 2008).

Although the role of the stand structure and mixture on the vulnerability of forest stands to storms is uncertain or inconsistent, these characteristics play a positive role on the resilience of stands, i.e. structured stands may be able to recover from damage with less technical and financial input than pure or regular stands.

Short term fluctuations of stand characteristics

Thus, while stand structure and stand mixture may have less influence on the vulnerability of forest stands than many foresters believe thinning has a marked impact. Shortly after a thinning, stands are particularly sensitive to wind (Lohmander and Helles, 1987), making thinning operations unrealistic in particularly windy locations. With time the thinned trees adapt to their increased wind environment, and the relationship between stem weight and root anchorage appears to be unaffected by stand density (Nicoll *et al.*, 2009). However, while the critical wind speed required for stem breakage appears to increase with spacing, the critical wind speed required for uprooting may decrease, due to increasing wind exposure and crown size (Gardiner *et al.*, 2005).

The practical conclusion is that where thinning is possible, frequent/intensive thinning should commence earlier rather than later during the life span of stands. Higher planting densities may be beneficial by providing cross-anchorage between trees, which remains even after thinning. Similarly, any stand newly exposed to wind, when neighbouring stands are cut, or opened up to allow natural regeneration, are also sensitive.

5.3.4 Soil Characteristics (and related effects on root system)

Soil conditions slowly altered by silviculture practices

Soil conditions have a large influence on the level of damage. Physical limitations to root development appear to be more important than soil chemical limitations which are, however, less documented. Soil rootable depth and root development are difficult to measure, except on uprooted trees. Where these measurements have been included in field studies, the influence of soil and root conditions have been confirmed. For example, beech grown on superficial calcareous soils in Lorraine (NE France) was extensively damaged during the 1999 (Lothar) storm (Bock *et al.* 2005). Another problem for rooting can be the presence of indurations or ironpans forming in the soil within the first 1m. If ironpans are not broken by cultivation, roots may be restricted to the top soil layers and root anchorage strength will be compromised (Danjon *et al.* 2005). A further example of the importance of rooting was that during the Klaus storm in south-west France maritime pine in public forests on coastal sand dunes, that allow deep rooting, suffered little damage in comparison to maritime pine stands further inland, which were on sites with the water table closer to the surface and shallower rooting (http://www.ifn.fr/spip/spip.php?article613).

Where sites that are naturally wet are used for plantation forestry, good drainage systems and drain maintenance are particularly important to avoid wind damage early in the crop rotation. For example, Ray and Nicoll (1998) found that rooting depth was affected by the intensity of drainage and this had an impact on resistance to overturning.

Short term fluctuations in soil conditions

Another source of climatologically-driven instability is temporary excessive soil moisture. Water saturated soils following very rainy periods, such as before the December 1999 storms (Usbeck *et al.* 2010a), are considered to make trees more sensitive to wind. This is because the physical structure of the soils is altered, thereby reducing root anchorage (Valinger and Fridman, 1999). In Northern Europe, soils are normally deeply frozen in winter, making trees more resistant to wind (Silins *et al.* 2000). Mild winter conditions may thus make trees and stands more vulnerable than usual in some northern European countries.

5.3.5 Landscape Characteristics

Tree root architecture and therefore anchorage (Nicoll *et al.*, 2005; Nicoll *et al.*, 2006b) can be influenced by slope, although the effect of this on overall wind risk is small compared to the influence of topography on wind loading. Air flow is locally influenced by topographical factors and understanding of these influences has been better developed in recent years (Finnigan and Belcher, 2004; Ross and Vosper, 2005).

In hilly or mountainous situations, the effects of exposure and slope are complex (Finnigan and Brunet, 1995; Finnigan, 2007). Nevertheless observation and air flow modelling indicate features related to higher or reduced wind risk. Stands situated in sheltered situations on the lee side of hills relative to the prevailing wind are somewhat protected. Forests on flat/plateau areas are reported to be more susceptible to damage than those on slopes. More locally, forest edges and any significant unevenness in the forest canopy (open land/forest transitions, recent cuts, stands of different heights) influence the turbulence regime, which strongly influence the spatial distribution of damage (Quine *et al*, 1995). Recent mechanistic studies confirm the importance of these factors (Brunet *et al.*, 2009), which may not always be easy to identify by field observers.

5.3.6 Summary of Managing Wind Risk and Mitigating Storm Damage

In summary, the impact of storms is closely related the peak gust wind, the area of damaging winds and the storm duration. Because extensive periods of high wind over a wide area tend to occur mostly in winter in Europe (summer winds associated with thunderstorms tend to be of limited duration and area), they often coincide with wet periods which render trees less stable. Mitigating the damage can be achieved to some extent (without here considering economic and practicality considerations) by:

- Modifying thinning regimes (e.g. avoid late/severe thinning)
- Optimizing the spatiotemporal organization of cuttings, species choice and management regime
- Ensuring silvicultural systems are appropriate to the local conditions
- Selecting more resistant species/provenances (which must be suitable for the site)
- Reduction of rotation age (and thus mean height).
- Using appropriate site preparation
- Minimizing the fragmentation of the forest resulting from many small clear-felling areas, which overall creates long lengths of vulnerable new edges.

It is always difficult to give general advice on management to minimise forest risk because of the complex interactions between site and stand conditions, local climate, and past stand management (Quine *et al.*, 1995). These multiple considerations are incorporated in forest wind risk models and management tools which have been developed in recent years and are discussed in the following section. It needs to be recognised that managing forests for the risk of wind damage is only one of the considerations taken into account in any management plan, along with the objectives for the site or forest and other constraints that may be applicable. Managers and planners have to balance risks against benefits and risk management tools have been developed to help them in this process.

5.4 Available Wind Risk Management Tools

5.4.1 UK

ForestGALES (Gardiner *et al.* 2004) is a decision support tool developed to assist forest managers and owners manage wind risk in conifer forest plantations. It was produced for use in UK forests, but has been successfully modified for use in other European countries. This computer model uses data about the forest site, tree species and management, and local wind climate to predict the return period of damaging wind. The model allows calculation of current risk to single or multiple stands, or will provide graphs of how risk will change as the forest grows, in relation to its thinning regime. Managers can examine the risk implications of management alternatives, such as species choice, thinning regime, and selection for long term retention. ForestGALES is available online (www.eforestry.gov.uk/forestdss) as a single stand version, either for Britain (standard version), or an adaptable version using Weibull a and k wind climate data for other European countries ('STORMRISK' version). The full version allows calculation of risk for multiple stands and over time and may be requested from www.forestry.gov.uk/forestgales, as can the adaptable 'Research' version for use outside UK. ForestGALES has been provided to all state forest districts in Britain, and many private sector forestry companies. It has slowly been embedded in systems within the Forestry Commission (who manage state forests) through inclusion in Operational

Guidance for operations including thinning and conversion to continuous cover forestry. Recently, ForestGALES has been run for all stands in the Forestry Commission estate to provide GIS wind risk maps for Scotland, England and Wales to assist in forest planning and management.

5.4.2 Netherlands:

In the Netherlands, a decision support tool has been developed to help forest managers to make decisions in relation to clearing storm felled timber, or not, taking into consideration different aspects including economy, biodiversity, insect risks etc. The tool is in the form of a table within a report on storm and forest management produced by Alterra (Oosterbaan *et al.* 2009). The table is very simple, and partly based on only a few years of monitoring after a storm. This simple approach may be appealing to forest managers, but has not yet been tested in practice.

5.4.3 Sweden:

The WINDA model is an integrated system of models for assessing the probability of wind damage to forest stands (Blennow and Sallnäs 2004). It provides a geographically explicit environment for stand-wise calculation of the probability of exceeding critical wind speeds for wind damage in a landscape. The calculations are sensitive to the stability of the forest as well as to the local wind climate and uses extreme value theory for the statistical calculations. The model can be used to evaluate silviculture strategies and forest planning options with respect to the probability of wind damage. The model was recently modified to enable the calculation of the potential probability of wind damage under a changed climate based on climate scenario data (Blennow and Olofsson 2008) and has been used together with the climate sensitive FTM model (Andersson *et al.*, 2005) to calculate the probability of wind damage under climate change (Blennow *et al.*, 2010).

5.4.4 Finland

The HWIND model (Peltola *et al.*, 1999) is a mechanistic model that is similar in structure to ForestGALES and which gives similar results (Gardiner *et al.*, 2000). The model is parameterised for Norway spruce, Scots pine and birch and is a key component of the WINDA model above. It is generally used as a research tool although recent work on optimised forest planning (Zeng *et al.*, 2007a and 2007b) have demonstrated the potential use of the model as a management tool.

5.4.5 France

A computer system was constructed to simulate the mechanical stability of Maritime pine (Pinus pinaster Ait.) stands growing under the silvicultural conditions relevant to the Landes de Gascogne region, SW France. This chain of models integrated (i) a tree growth model, PP3, as implemented in the software CAPSIS (http://www.inra.fr/capsis) able to predict the development of Maritime pine stands over time under different silvicultural scenarios and (ii) a wind risk assessment model (GALES; Gardiner *et al.* 2000) which predicts the critical mean wind speed required to break or overturn the mean tree in a stand. The species-dependent relationships for Maritime pine in the

GALES model were adjusted (Cucchi *et al.* 2004) from winching tests. The link between CAPSIS and GALES follows a loose-coupling approach based on file exchange. The files contain the information required to estimate the critical wind speeds extracted from PP3 and the results calculated by GALES. With this method, it is possible to simulate multiple scenarios with changes in the forest stand parameters. This information is then stored in the CAPSIS project in order to be analyzed by CAPSIS tools (viewers and graphics). The effect of different spacings, thinning intensity, site fertility index and the effect of soil types on the critical wind speeds (CWS) were analysed for different silvicultural scenarios (Cucchi *et al.* 2005).

6 Operational Planning and Response to Storms

- **There is a range of effective operational measures for planning for, and responding to, forest storm damage that may be applied across all European countries.**
- **Planning for forest storm damage provides clear benefits to member states in terms of the efficiency and safety of post-storm actions.**
- **Alert and emergency responses, infrastructure restoration, salvage operations and marketing of products should all be considered in storm contingency plans.**
- **Additional financial support is often needed to support the forest industry following major storm damage.**
- **Careful post-storm consideration must be given to forest protection, restoration and regeneration.**
- **Consideration should be given to establishment of post storm monitoring to record damage and responses, with the aim of using experience to improve future systems.**

The impact of storm damage can be reduced by a combination of prior planning and coordinated management of the aftermath of the storm. The Interventions to reduce direct and indirect consequences of storms belong to three categories: 1. prevention, 2. crisis management, and 3. post-storm forest management. Many of these measures are surprisingly consistent between European countries that have dealt with catastrophic storm damage to forests. These actions and interactions are illustrated in Figure 6.

In the sections below we summarise the best practice that has been developed over a number of years based on lessons learned from storm response to past catastrophic events in a number of countries. We also summarise potential administrative and technical changes that could be implemented to further improve planning and response.

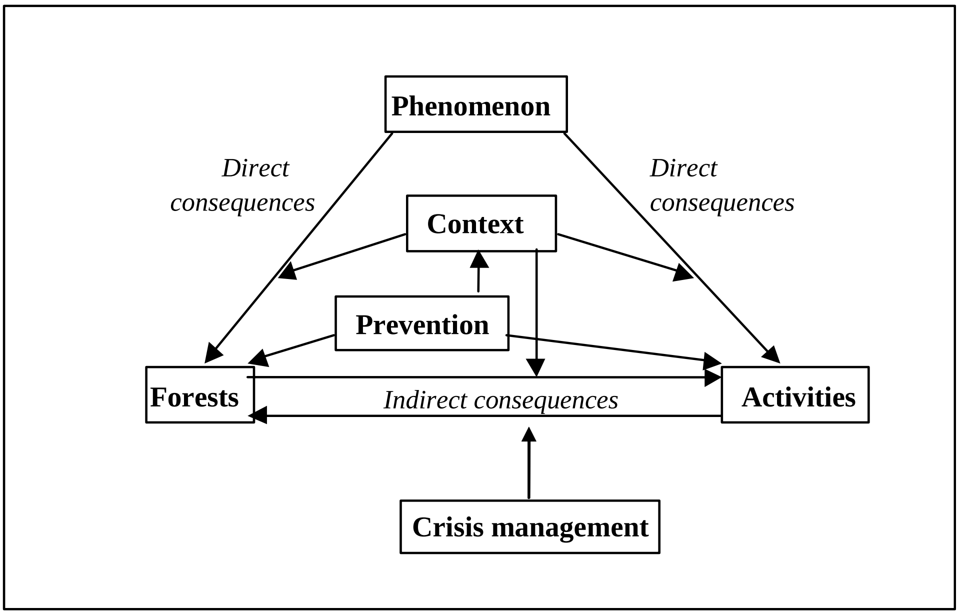

Figure 6: Analytical framework of impacts on forests due to natural or human threats

6.1 Alert and Emergency

There are benefits of informing relevant professionals and putting them on alert when a potential destructive storm is imminent. They should be aware of what they have to do in order to secure the forests and prevent or restrict public access. They should themselves stay in a safe place and prepare their post-storm activities. As soon as the exceptional nature of the event is apparent, crisis committees and appropriate communication modes need to be activated. Once the event has occurred, a first and rough damage assessment should be made in order to confirm if the situation is 'exceptional', and that crisis management and crisis committees need to be put in place, if this has not been done earlier. This primary assessment will also inform decisions on the first emergency measures to be taken. Safety should be paramount, and rules are generally issued in order to prevent or restrict public access to dangerous areas, including for recreational and hunting reasons. A priority is that damage from the storm must be cleared in order to re-establish essential services such as electricity, telephone, and public and forest roads. It is then necessary to analyze the situation in more detail in order to implement appropriate strategies and measures. The inventory of damage should be expressed in both volume and monetary terms if possible, in order to quantify the losses. Among the first activities is the provision of support to those who have been severely affected by the event.

6.2 Infrastructure Restoration

As well as emergency action, it is necessary to restore infrastructure and equipment, and to start the processes of salvaging of windthrown timber and preparing for the future forest restoration. Forest roads and trails should be cleared, and fire infrastructure and equipment should be repaired, as necessary. It is likely that recreational infrastructure and equipment will need to be repaired or rebuilt, as will other forest infrastructure, such as the drainage network.

6.3 Salvage Operations

The market value of windthrown timber can be as good as conventionally harvested timber if it can be used before any appreciable reduction in wood quality. The storage conditions and other natural, technical and economic circumstances must be considered in relation to tree species. The salvage of windthrown trees provides revenue to forest owners, although the revenue will be based on larger timber quantities usually at lower prices than usual. It also provides employment. Harvesting is the first stage in preparation of the forest for regeneration, and the salvage of windthrown timber, together with forest cleanup activities, is therefore a major goal. It requires efficient forest operations such as logging, transportation and storage within difficult conditions. Organisation of wood removals may require that priority is given to windthrown timber, high quality wood, and some ownership categories. Biomass for bio-energy could be a strategy to deal with salvage wood but it needs to be remembered that the increased costs of salvaging wind damaged timber is more likely to exceed the value of the timber as biomass than as logs for sawn timber. If it is not profitable to harvest the wood it will often stay on the ground. In fact, incentives for harvesting of windthrown timber may be needed, as may incentives to assist the acquisition of new forest machines, such as harvesters and logging machines. Consideration should be given to the professional retraining of previously experienced wood cutters and training of new ones. In some cases, new infrastructures may be needed to facilitate wood removal, and restoration of existing forest infrastructure may be necessary if it has been damaged by post storm forest operations. Other considerations in accelerating removal of timber may be the adaptation of transportation regulations, and the facilitation of long distance transportation. Finally, facilities will be needed for the storage of roundwood and other wood raw materials, and for storage of sawn wood and other processed products.

6.4 Marketing of Forest Products

If they are efficient these forest operations reduce the gap between potential supply and demand of roundwood after a destructive storm. If they are supported by incentives, they also increase the stumpage price, the chance to develop the salvage of blown timber and the return to the forest owner. However, this windthrown timber has to be sold, and marketing measures that may help include: collective agreements between purchasers and sellers of wood raw material, financing roundwood removals and logging costs, financial guarantees for roundwood buyers, facilitating exports, limiting imports, and promoting the use of wood products. It will be necessary to explore international timber markets, if necessary taking into account the effects on the market of large amounts of storm timber from several countries.

6.5 Additional Financial Support for Forestry

All available measures aimed at ensuring the development of removals and supporting stumpage prices may not in themselves be sufficient for some owners and operators who bear high opportunity costs and have to pay taxes that may no longer appear justified after the storm. It may be necessary to support the revenues of owners and operators. Possible measures here either relate to owners who have had considerable damage to their holdings or owners who have not been directly affected by the storm but who have to change their management, at least temporarily, because of the storm. In particular consideration should be given to; direct support of forest income for both damaged forests, and non-damaged forests, reduction of taxes on capital, wealth and income, reduction of value added tax, and accelerated depreciation of logging equipment because of more intensive use of the equipment.

6.6 Forest Protection

Forests are subject to a range of threats following a destructive storm. In particular, they have much higher risk of damage by pests, disease, game and fire. Protection measures that may need to be implemented include: protection against pests and diseases, prevention against forest fires, and restoration of the ecological balance between game species and forests.

6.7 Forest Restoration and Regeneration

It will usually be necessary to prepare and implement a forest sector strategy to restore the forest that could include: foresight studies, restructuring where necessary, regulation of forest restoration, cleaning of compartments and plots, special support for nurseries and regeneration, and restoration of damaged regeneration areas.

6.8 Risk Management

Post storms periods provide an opportunity to improve prevention measures and risk management. In particular, consideration should be given to suitable forest species, stand structure, landscape structure, forest edges, planting direction, thinning regimes, and rotation age or dimensions. This may be achieved with assistance from forest wind risk decision support systems (see Section 5.4). Other considerations may include the use of forest insurance, the development of a crisis management plan, and analysis of the potential effects of other policies.

According to the results of a questionnaire of south Swedish private individual forest owners before the Gudrun storm in 2005, the risk of wind damage was perceived to be one of the worst risks to their forest from a financial point of view (Blennow and Sallnäs, 2002; Blennow 2008). Furthermore, it was one of the risks they were prepared to pay the most to reduce in terms of risk reducing management and insurance. Before the Gudrun storm about one third of the respondents to each of two different questionnaires stated that they were taking action to reduce the risk of wind damage. In the area affected by Gudrun approximately 40% of the private individual forest owners responding to the questionnaire stated that they were insured against wind damage. In an enquiry sent out in 2004 (less than one year before the storm), forest owners were asked what tree species they would want to grow if their current spruce forest was severely damaged by wind. A majority of the respondents answered that they would plant spruce again (Blennow, 2008). After having experienced extensive wind damage in 2005, forest owners were again asked about their planned future management of the risk of wind damage. 56% of the respondents in the area affected by the storm stated that they planned to take risk-reducing action. By the end of 2008 financial support for replanting 50,000 ha storm damaged areas with conifers and 3,000 ha with deciduous forest had been applied for by forest owners (ATL, 2008). The proportion of replanted broadleaves (6%) was less than the percentage of standing volume of broadleaves prior to the storm (19%).

6.9 Research

The aftermath of a storm provides an opportunity to better understand the vulnerability of forests and, more generally, the functioning of forest ecosystems. A lack of information can hamper the ability to make the right choices for the future and a storm can therefore provide opportunities to start or increase wind risk related research studies. Priorities for consideration include forest vulnerability assessment and mapping, improvement of forest restoration, and publication of technical handbooks and guidelines (See Section 9 for summary of recommendations).

6.10 Cross-cutting Measures

Some measures may be general and cross-cut several of the categories described above. These include possibilities to promote special public/private efforts aimed at collecting donations for the forests, and reinforcing temporary forest staff. Agreements may be needed between different public policies, and between public policies at different scales (Regions, States, Europe). Agreements may also be needed between the administration, the forest-based sector and the bank system. Developing post-storm forest plans must be given a high priority and should be seen as an opportunity to develop more storm resistant forests and implement risk-aware forest management systems, at the same time as implementing climate change adaptation strategies.

6.11 Differences in Response

The post-storm measures described above largely reflect the common responses of a range of countries to events at various times covering many geographical, ecological and economic circumstances. However, our analysis has revealed some differences.

Measures consist of various instruments implemented at national or more local levels. These are mainly regulations, exemptions, subsidies, reduced interest loans, financial guaranties, contracts and agreements, improvements of information, and improvement of knowledge. The choice of instrument depends both on who makes the decision, and on the institutional context: for example, exemptions depend on current regulations and tax reductions on the fiscal system. The level of subsidies differ from country to country, but must be adapted to the event itself.

Our analysis has revealed five aspects of response that may vary between countries:

1. The assessment of damage is done using three methods: field surveys, aerial surveys and statistical inventories; although field or aerial surveys are the most frequently used, they provide approximate results, and a statistical inventory is sometimes preferred. This was the case in France where experiments were done in 2000 after the 1999 storms and where statistical methods were used in 2009 after storm Klaus, using sample plots that had been measured during the last four

years in the normal inventory. It was possible to carry out this inventory within about one month and with a good accuracy.

2. Several timber storage methods exist: wet storage (spraying or immersion), dry storage, dry storage without any air. Wet storage is the most common method.
3. The respective advantages and disadvantages of storage and long distance transportation or exports needs consideration. After Klaus in Landes de Gascogne (France) in 2009, the support given to long-distance transportation was criticized as the timber resource was more or less in balance with industrial capacity before the storm and thus could be in short supply in the future. Therefore exports from the affercted region may need to be controlled to limit a likely future shortage.
4. For protection against pests and diseases, chemical or biological treatments are available, and limitations are sometimes placed on unbarked wood in forest. But it is most important to remove as much windthrown timber from the forest as soon as possible, and to take particular care of dry storage.
5. The forest strategy for regeneration is likely to differ much from one country to another, with consequences for target species, stand composition and structure.

6.12 Main Issues for the Future

To improve future responses to storms, we recommend continuing to reduce administrative delays for major decisions regarding post-storm policy. At the same time, an adapted system of insurance should be developed, as should crisis management plans that take into account the different types and levels of damage. It will be important to develop a post-storm monitoring system in order to record the scale of damage, to control the development of stands after the storm, and to evaluate carefully the different applied measures some years after storms, in order to improve the system.

7. Forest Storm Damage in a Future Climate

- **There is some evidence that storm intensity is increasing and that storm tracks are penetrating further into mainland Europe and along a wider swathe.**
- **Higher temperatures will lead to longer periods of unfrozen soils during European winters, potentially leading to an increase in damage particularly in Fennoscandia.**
- **Storms will tend to be accompanied by heavier rainfall leading to more saturated soils and increased risk of wind damage.**
- **These trends together with an increasing and ageing forest stock are expected to result in substantial increases (at least double) in forest damage by the end of the century**
- **There is no consistent recording and reporting system for wind damage across Europe or for reporting damage from different hazards. This leads to uncertainties in relative levels of wind damage within different parts of Europe and in comparing the importance of hazards.**
- **Estimates suggest that storm damage to European forests results in an annual reduction of 2 % in their carbon sequestration. This could exceed 5 % by the end of the century if growing stocks remains at current levels or even increase if there are further increases in growing stock.**

7.1 Future Damage Scenarios

We analysed past and future trends in climatic forcing and damage risk based on the current state of knowledge in the literature to assess likely scenarios of future storm damage. Several factors will contribute to the future damage risk:

1. Trends in storm activity in Europe, including changes in severity
2. Changes in other climatic characteristics influencing storm damage
3. The development of forest structure and composition which influences the susceptibility to storm damage

7.1.1 Trends in Storm Activity

The frequency of cyclone activity undergoes decadal variability (e.g. Bärring and von Storch, 2004), but a recent decline in activity is projected to continue also under climate change (Ulbrich *et al.*, 2009). However, regional trends in activity are expected to deviate from the overall decline. For example, storm activity over the British Isles is projected to increase (Pinto *et al.*, 2007). Storm tracks may also shift further north (Bengtsson *et al.*, 2006, Ulbrich *et al.*, 2008), with the consequent possibility of increased risk of damage, for example in Scandinavian countries.

In addition to the number of storms, it is important to consider changes in storm intensity. Many measures can be used to compare storm intensity. Leckebusch *et al.* (2008a) developed an index for the estimation of storm severity based on the exceedance of local thresholds of daily maximum wind speed. The index shows positive trends in the severity of storms for both the period of 1960-2000 and under anthropogenic climate change conditions (SRES scenarios A1B and A2). Measured wind gust speeds have increased strongly in Switzerland since the beginning of records in 1933 (Usbeck *et al.*, 2010b). Additionally an increase in the spatial extent of storms was predicted, amounting to about 10% increase as compared to the present day climate (Leckebusch *et al.*, 2008b). The main reasons for the increase in severity are the occurrence of higher wind speeds, and larger areas affected by storms. These larger areas result from longer tracks combined with a common broadening along the path. Eastern Central Europe may therefore be exposed to more intense storms by the end of the 21st century (Fink *et al.*, 2009). As a consequence of higher storm intensity, the return period of damaging storms is projected to reduce significantly (Della-Marta and Pinto, 2009). For example in the British Isles/North Sea/Western Europe region (45° - 60° N; 10° W - 30° E), high intensity storms with an average return period of 20 years under the 20th century climate would become a 10 year event by 2040 and 2030 in the A1B and A2 climate change scenarios, respectively. The return period for such strong storms would further decrease to 5.3 and 5.8 years by 2100 under the two climate scenarios (Della-Marta and Pinto, 2009).

7.1.2 Changes in Other Climatic Characteristics

The analysis of pre-disposing factors favouring storm damage in Section 5 has shown that temperature and precipitation are critical factors influencing risk of damage (Usbeck *et al.*, 2010a). Climate change induced temperature increases extend the duration of unfrozen soil conditions. This will reduce the root anchorage of trees in regions where soil has been commonly frozen during the winter (Valinger and Fridman, 1999). Moreover, projections of extreme events under a changing climate indicate increased amounts of precipitation during cyclone activities (Bengtsson *et al.*, 2009), which is likely to increase periods with excessive soil moisture. As it has been shown that trees on water saturated soils are much more vulnerable to wind damage (Usbeck *et al.*, 2010a) this will further aggravate damage risk in the future climate. The regional climate change projections of the latest IPCC assessment report (Christensen *et al.*, 2007) suggest that winter temperatures will increase on average by 3-7 degrees with the largest increases in the boreal and continental regions. Winter precipitation is expected to increase particularly in mid and northern latitudes (Räisänen *et al.*, 2004). Consequently, periods with wet unfrozen soils are going to be much longer across northern and eastern Europe, thereby increasing the susceptibility of forest stands to storm damage. Peltola *et al.* (1999) estimated that the period when the ground is frozen will decrease by 1-2 months in Finland. However, reverse effects can also occur - when the thickness of the snow pack is reduced, the insulation provided by the snow will reduce and the presence and depth of the ground frost may increase (see Blennow *et al.*, 2010).

7.1.3 The Development of Forest Structure and Composition

Composition and characteristics of European forests have changed significantly since 1950 and this has contributed to the increased amount of damaged timber in European forests (Schelhaas *et al.* 2003). Forests have grown older and denser. Growing stock in managed European forests has continued to increase strongly after 1990, because in most countries the harvest removals are significantly lower than increment rates (Kauppi *et al.*, 2009, Rautiainen *et al.*, 2010). Projections for the future show that European forests will continue to accumulate growing stock and on average will become older (Nabuurs *et al.*, 2007; Schelhaas *et al.*, 2010) and this trend is likely to continue under changing climate conditions (Eggers *et al.*, 2008).

With the recent trends towards close-to-nature forestry and the conversion of coniferous monocultures into mixed stands (e.g. Spiecker *et al.*, 2004), the share of deciduous tree species and mixed stands has substantially increased (Knoke *et al.*, 2008, MCPFE Liaison Unit Warsaw *et al.*, 2007). The declining share of spruce forests may contribute to storm damage abatement because spruce, which tends to grow faster and taller than broadleaves, has statistically been more affected by storm damage (however, see the difficulties in precisely defining species differences in Section 5.3.2). At the same time if there is a continued trend of increasing growing stocks and a larger share of old forests, the vulnerability to storm damage is likely to increase further (Schelhaas *et al.*, 2010). Therefore, the management of European forests will have a distinctive influence on future levels of storm damage.

7.1.4 Assessment of Projected Changes in Storm Damage in European Forests

We have reviewed the relevant scientific literature and synthesized the most accurate bio-climatic projections regarding storm occurrence, forest cover and forest damage up to 2100. A critical assessment of the trends identified in existing data and model projections suggests that (i) there are clear indications of increasing exposure to storm damages because the intensity of storms is likely to further increase under climate change. Storm tracks are also projected to affect larger areas and particularly Northern and Eastern Europe are likely to experience significantly increased damage risks; (ii) warmer temperatures and increasing precipitation during the winter season increase the susceptibility of forest stands to storm damage through weaker anchorage of roots in unfrozen and water saturated soils; (iii) increasing growing stocks and ageing forests will further aggravate the vulnerability to storm damage across Europe, unless management intensity increases substantially.

Making detailed projections of future damage would require a European forest simulation model, that includes windthrow and wind-acclimation processes, climate change effects on wood increment, and which can be coupled directly to climate change models. As such a model is not available, we can currently only make some simple calculations, combining the outcomes of earlier studies. The percentage of growing stock that has been damaged by storms in the period 1950-2010 appears to be fairly constant at both national and European scale (Figure 7). If we assume no change in wind climate and no change in vulnerability due to changes in age class distributions, we can estimate future damage by multiplying projected future growing stocks by the percentage that is annually damaged. The EFISCEN model (Schelhaas *et al.*, 2007) has been used widely to make projections of growing stocks in Europe. For projections for the EU27 plus Norway and Switzerland up to 2050, we used the results of the FP6 ADAM project (Jochem *et al.* 2009). For four individual countries, projections until 2100 are available in Schelhaas *et al.* (2010).

Table 7: Observed and projected growing stocks and damage in four selected countries and in EU27 plus Norway and Switzerland (referred to as Europe; source: Schelhaas *et al.* 2010)

		growing stock		average annual damage		maximum damage	
	scenario	2000		1950-2010		1950-2010	
	unit	Mm^3		Mm^3	%	Mm^3	%
	UK	267		0.30	0.149	6.0	2.70
	Finland	2091		0.33	0.018	7.0	0.36
	Denmark	74		0.27	0.551	3.5	7.23
	Czech Republic	631		1.80	0.265	12.0	1.31
observed	Europe	23219		17.50	0.090	201.0	0.85
	scenario	business as usual	high demand	business as usual	high demand	business as usual	high demand
	unit	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
	UK	818	549	1.2	0.8	22.1	14.8
	Finland	2674	1568	0.5	0.3	9.6	5.6
	Denmark	182	130	1.0	0.7	13.1	9.4
	Czech Republic	860	633	2.3	1.7	11.3	8.3
2050	Europe	34479	26801	31.0	24.1	293.1	227.8
	scenario	business as usual	high demand	business as usual	high demand	business as usual	high demand
	unit	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
	UK	1168	355	1.74	0.53	31.5	9.6
	Finland	3237	1998	0.60	0.37	11.7	7.2
	Denmark	272	146	1.50	0.80	19.7	10.5
	Czech Republic	1103	899	2.92	2.38	14.5	11.8
2100	Europe	NA	NA				

Under current harvest levels and assuming no change in wood increment as a consequence of climate change, growing stocks in Europe are expected to continue to increase. EFISCEN projections overestimate the increases in growing stock in countries with relatively young forests, such as the UK and Denmark (Table 7), but these countries store only a small proportion of the total European growing stock, and European scale growing stock trends are in line with expectations. Europe as a whole shows about 75% increase of the growing stock by 2050. Expected damage levels change likewise, increasing from the current average of 17.5 Mm^3 in the whole of Europe to 31 Mm^3 by 2050. If we apply the highest observed storm damage percentage in a single year (1999) to this increased stock, we get an estimate of damage from a singular event of 293 Mm^3 that would be possible around 2050. For 2100, no projection is available, but the total of the four countries in Table 7 indicate a 2.5-fold increase as compared to 2000.

Projections of future growing stocks in the long term are very uncertain. Increased harvest will lead to slower build-up, while climate change might lead to higher growth rates. The ADAM study included a scenario for increased harvest due to increased biomass demand for bioenergy, while Schelhaas *et al.* (2010) assumed a policy-driven increase to limit the build-up of growing stock to decrease the storm risk. These projections show that increased harvest indeed can limit the build-up of growing stock, and consequently our estimate of future damage. The increase by 2050 and 2100 as compared to 2000 are about 30% and 50% respectively. Positive effects of climate on wood increment are expected especially for the boreal zone. Schelhaas *et al.* (2010) show for Finland a growing stock in 2100 that is 65% higher than the estimate in Table 7.

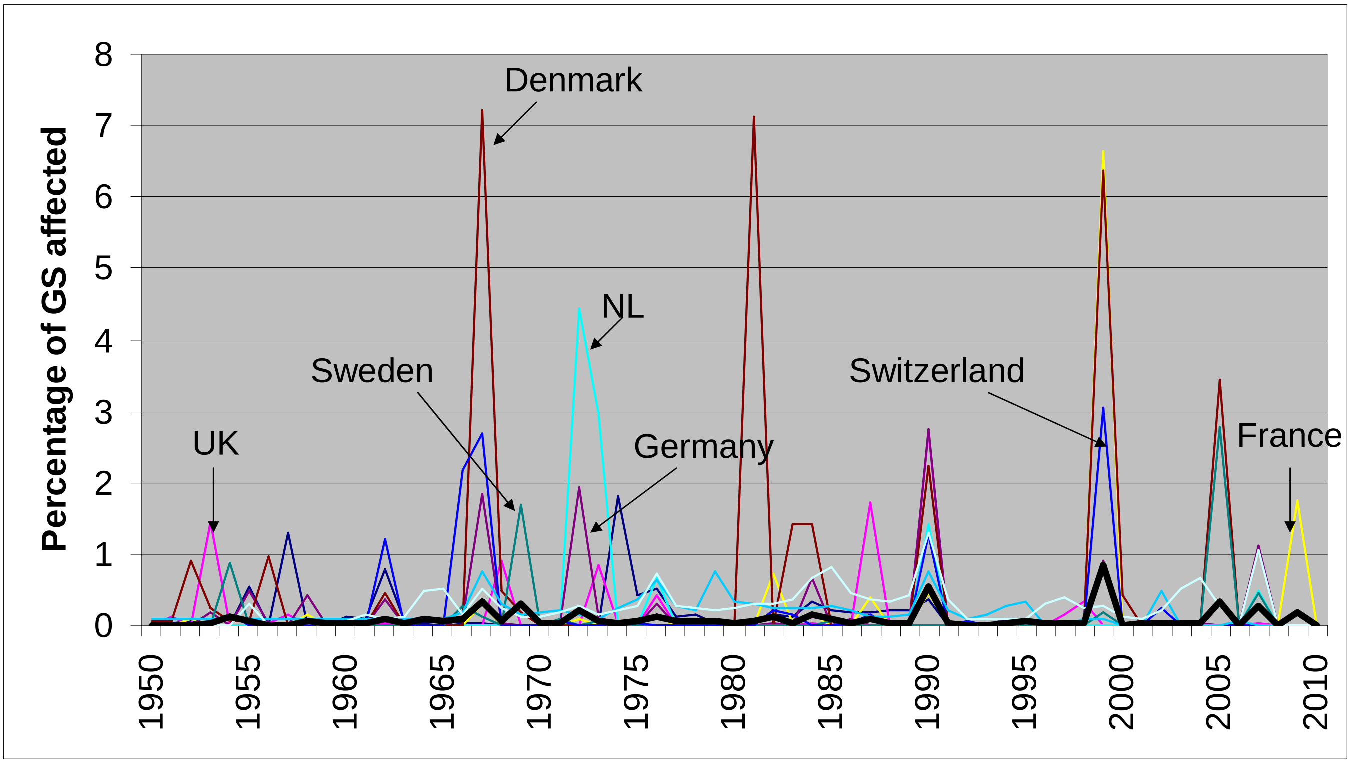

Figure 7: Damage as percentage of growing stock for different countries (adapted from Schelhaas, 2008a).

Changes in storm climate have to be added on top of the expected changes in growing stock. Table 7 shows that Denmark annually loses 0.551% of their growing stock to wind, much higher than the other countries. With increasing storm intensity, higher damage percentages could occur also in other countries. The decreases in return times of storms with very high intensity according to Della-Marta and Pinto (2009) would lead to a strong increase in damage percentage. However, climate models are still not very reliable in their wind velocity projections and thus confidence in their projections is rather low (Nikulin *et al.* 2010). Moreover, the forest might acclimate to increased wind loading (Nicoll *et al.*, 2008), and build-up of growing stocks could be reduced by regular damage events (Schelhaas *et al.*, 2002). We might take a conservative estimate of an increase of 25% and 50% in damage percent for respectively 2050 and 2100. If we take a conservative estimate of an increase of 25% and 50% in current damage percentage levels for 2050 and 2100 respectively, this would lead to an approximate doubling of the expected volume damaged by 2050 and a quadrupling by 2100.

7.2 Impact of Future Damage Scenarios on GHG Exchange

Catastrophic windthrow results in both an increase in GHG emissions and a reduction of C assimilation. Uprooting and associated soil mixture results in an enhanced decomposition of the soil organic matter and the affected sites thus lose soil carbon. In a study from Southeast Alaska, the resulting differences amounted to 27-38% of the soil carbon content of undisturbed sites (Kramer *et al.*, 2004). Relatively few studies have measured GHG exchange following storm disturbances (Knohl *et al.*, 2002, Lindroth *et al.*, 2009, Schulze *et al.*, 1999). If severe storm disturbance affect managed forests before the trees reach their planned harvesting age, this may result in additional loss of several years of C sequestration before trees are re-established. Furthermore, younger trees usually have lower assimilation rates compared to the original more mature forest stands. Lindroth *et al.* (2009) examined the impacts of historical storms on the European carbon balance and estimated that disturbance of European forest ecosystems by windthrow over the last 50 years has resulted in an average annual loss of 1.14 million tonnes C, or around 2% of the net biome production. This is not a high percentage of the total carbon assimilation of European forests. However, an extremely damaging storm such as Lothar in 1999, reduced the C sink by around 16 million tonnes C which would have been equivalent to over 30% of the European net biome production in that year and such storms appear to becoming more common (see Table 1). Pignard *et al.* (2009) worked on storms Lothar and Martin in 1999 and their impact in France and estimated the annual loss to be on average about 1.6 million tonnes C from 2003 to 2016. Both analyses excludes C losses from soil disturbance.

It should be stressed that the empirical basis for the quantification of GHG exchange following storm disturbances is very limited and consequently the values calculated by Lindroth *et al.* (2009) and Pignard *et al.* (2009) contain huge uncertainty.

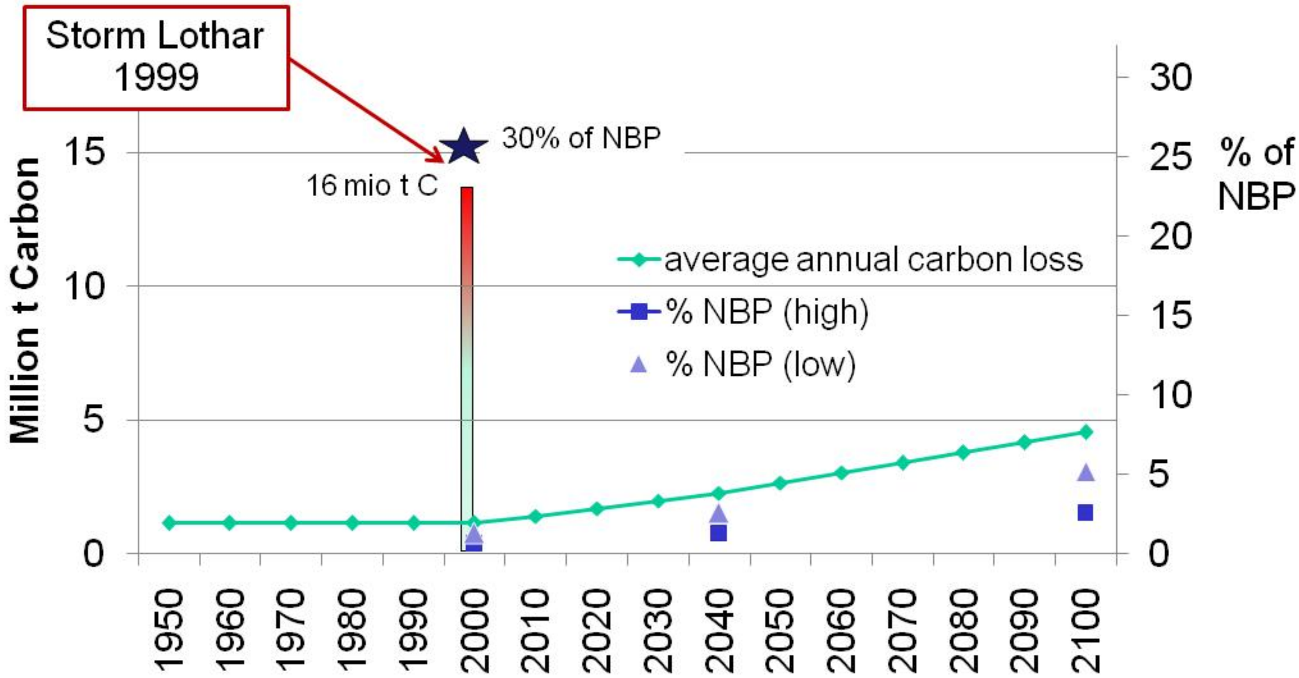

Figure 8: Average annual carbon loss 1950 – 2000 and the effect of the extreme storm event Lothar in 1999 (Lindroth *et al.* 2009) and estimated future projection of average carbon loss in European forests. The relative shares in relation to net biome production are calculated from the low and high estimates of net biome production of Luyssaert *et al.* (2010).

Using the results of Lindroth *et al.* (2009) as an approximation (Figure 8) we can speculate that the doubling of the storm damage volume estimated above would result in an annual loss of more than 2 and 4.5 million tonnes C year^{-1} by 2040 and 2100, respectively. To relate these figures to the overall forest carbon balance we use the new estimates for the net biome production of 50 to 100 g C m^{-2}yr^{-1} (Luyssaert *et al.*, 2010). Applied to the total forest area of EU 27 of 177 Mha (MCPFE Liaison Unit Warsaw, 2007) this translates to a total net biome production in the EU 27 of 88.5 to 177 million tonnes C per year. The estimated annual storm induced carbon losses would thus be 1.3 -2.6% of the current net biome production in 2040 and the loss could exceed 5% by the end of the century.

However, it seems likely that the most extreme individual events under the future climate would have more dramatic impacts on the forest carbon balance than storm Lothar. Moreover, if such storms begin to occur more frequently, the net biome productivity of European forests could decline and storm induced losses would make up an increasing share of the annual carbon exchange budget.

8. Policy Evaluation and Development

- **Existing regulative and financial instruments of the EU that are relevant to forest storm damage mitigation and restoration have been collated and examined.**
- **The forest laws in Europe widely recognize the multifunctional role of forests and the need for their sustainable management.**
- **The bodies of laws related to forest or civil protection in EU countries have been described in relation to their effectiveness in providing effective "storm proofing" or post storm measures.**
- **A workshop 'Policies for Forest Storm Damages Mitigation and Restoration' was held in Brussels on 1 July 2010. This evaluated current policies and identified where more effective systems are needed.**

8.1 Introduction

This chapter describes current regulative instruments and policies that can help provide effective "storm proofing" or post storm measures. To do this, we have examined the bodies of laws related to forests or civil protection, in EU Member States that are, or could become exposed to, storm damage, and have analysed existing regulative and financial instruments of the EU that are relevant to forest storm damage mitigation and restoration.

A workshop 'Policies for Forest Storm Damages Mitigation and Restoration' sponsored by the EC Directorate General for Environment, was held in Brussels on 1 July 2010. Policy and forest management systems were examined for their effectiveness in mitigating damage and in helping restoration after storms. During this workshop researchers, policy makers, decision makers and stakeholders shared knowledge on whether the current systems were adequate at both national and European level and identified where more effective systems are needed. This workshop provided an opportunity to share best practice and experience between countries affected by forest storm damage. A summary of the workshop outcomes are described in the final section of this chapter, with further details in Appendix 2.

8.2 Country Level

8.2.1 Regulative Instruments in Countries Affected by Storms

The analysis of policy instruments with regard to their influence on storm prevention and post-storm management will range from forest acts and national forest programmes to civil protection and crisis management to non-forest legislation and risk sharing systems in the countries most prone to storm damages (Austria, Denmark, France, Germany, the Netherlands, Sweden, Switzerland and United Kingdom). One has to be aware that different political cultures, constitutional competences and law systems in these countries affect the specified legislation. Consequently, details of regulation, content and law enforcement mechanisms show a broad variety. There can be a single comprehensive law, which extensively rules one topic in one country while in another country a general law is constituted which is supplemented by subsidiary decrees and administrative circulars. Competences are sometimes at the national and sub-national levels and sometimes exclusively with the national government.

8.2.2 Current Forest Law

The forest laws of the concerned countries widely recognize the multifunctional role of forests and the need for their sustainable management. In general, the objectives of forest laws have become more diversified and comprehensive. Regulations on management and utilization aim to balance timber production, recreational uses, biodiversity conservation and the protection of forests for soil and water conservation and against impacts from natural disasters. The promotion of sustainable forest management (SFM) aids the resistance of forests to wind damage through the fostered development of stable forests. The principles of SFM set out in the forest laws comprise the planting of site adapted tree species, maintenance of forest health, abandonment or avoidance of large clear-cut areas, use of suitable seedlings, conservation of genetic diversity, considerate stand- and soil management techniques, minimised use of pesticides, and ecologically tolerable game density.

Regulations relating to clear-cuts can be found in all national forest acts. In all countries clear-cutting is controlled, and is either forbidden, restricted or requires permission from the forestry authority. In France the forest owner who doesn’t have a management plan is obliged to ask for an authorization from the administration before conducting a clear cut of more than 4 ha. The German forest act requires the federal states to provide for at least regulations on reforestation of clear cut areas. Many Länder stipulate the avoidance or even abandonment of clear cuts as an integral element of sustainable forest management and the same is the case in Switzerland where clear cuts are forbidden. The Cantons can make exceptions for particular silvicultural measures. Detailed provisions are set up in the Austrian forest act, which prohibits large clear cuts and clearfellings that have a detrimental effect on the environment and productivity of forests. In addition, the act defines the extent of clear cuts and felling operations that require approval. The Swedish government may specify the maximum allowable percentage of the forest holding to be felled during a given period in order to promote an even age distribution of the forest stands on large forest holdings. Felling may not be granted in protected areas. The Danish forest law does not mention clear cuts as such but specifies a time limit for reforestation after logging and describes circumstances under which the individual forest area designated as forest reserve land may be kept unstocked. According to the legislation in the United Kingdom, clear cuts are not forbidden in general. The Forestry Standard which guides practice in the United Kingdom provides recommendations when using a clearfelling system on how to reduce its impacts and points out alternatives to clear cuts. However, for felling conifers in areas with high windthrow risk or extensive areas of existing windthrow, the Forestry Standard suggests it may be essential to fell very large areas in one go at the end of the first rotation.

In Appendix 5 brief summaries are presented of the present forest laws in selected European countries adapted and abridged on aspects relevant for this study from Cirelli and Schmithüsen (2000).

8.2.3 Post-storm Regulations

With regard to post-storm management, reforestation is addressed in each national forest law. According to the Forest Acts of Austria, Denmark, the Netherlands and Sweden, reforestation is obligatory and some kind of time limit for regeneration is defined. The laws of France, Germany and Switzerland provide for reforestation as part of the principle of sustainable forest management and planning. In the United Kingdom, the felling licence required prior to felling trees normally includes conditions that the felled area must be restocked and that the trees are maintained for a period of at least ten years. A review of reforestation obligations in Europe, including all countries selected in this study, observed that forest laws provide for regulations concerning obligatory reforestation either in a general manner as part of provisions addressing sustainable forestry practices and forest management plans, or in the form of specific regulations in the law (Bauer *et al.* 2004). The goals of maintaining the forest cover and the long-term productivity of forest stands are largely compatible. The review further identified a common European view on the regulation of forest regeneration after loss of forest cover due to natural disasters. The forest owner shall regenerate forest stands if destroyed due to forest fires, diseases or storm damage either by natural regeneration or artificially by planting and seeding. Species adapted to the site and quality of the planting stock are to be specified on an ecological basis by implementing relevant rules, guidelines or regulations. Changes of forest land into other forms of land use need a separate and specific regulation procedure by the national forest law.

8.2.4 Prevention of Secondary Risks

The prevention of secondary risks such as pests and fire is regulated to differing extents between European countries.

Pest Control

The Austrian forest act requires forest owners to monitor their forests, to control and combat infestation. The Federal Minister for agriculture and forest can enact further provisions with regard to time limits for salvage logging and timber storage. A review of the federal forest law of Germany revealed a lack of regulations on pest control. At the Länder level many Forest Acts prescribe pest control and encourage integrated pest control without the use of insecticides. According to the forest ordinance of Switzerland, the Cantons are responsible for purchasing and maintaining mechanisms to combat forest damaging organisms, and to remove slash to prevent insect infestations. Infected treesmust be removed and timber debarked and treated with protecting chemicals. Pest control is supported by the research institution Forest, Snow and Landscape which assists with information, data, advice and coordination. In the Netherlands, there are regulations on combating insects and pests, including obligations on the timely clearance or debarking of specified conifer stems to prevent mass outbreaks. The regulations can be activated after a major storm event. According to the Swedish forest act the government may issue regulations to forest owners for combating insect infestation in forests and measures necessary to inhibit insect breeding grounds. Common rules on pest control are not included in the Danish forest law. However, general instructions are given in cases of disease outbreak, on how to reduce the impact and to contain the spread. In the United Kingdom pest control is not addressed in forest law, but is covered in the Forestry Standard, which includes recommendations to minimize the use of pesticides.

Fire Prevention

Fire prevention, in terms of prevention of secondary risk, is not described as such in any of the forest acts. Austria, France, Germany, and Switzerland have regulations in place that can restrict access to forests in times of high fire risk and can forbid lighting of fires. To varying degrees they also contain regulations for the prevention of fire. Denmark, Sweden and the United Kingdom do not refer to fires in their forest acts. The UK Forestry Standard states that measures must be taken to protect woodlands from the consequences of fire.

8.2.5 Civil Protection and Emergency Planning

In all countries civil protection policies either on state or federal level exist which regulate risk and crisis response in case of natural disasters. Usually incident command teams on different levels assume coordination and communicative tasks, develop policy strategies, plan and prepare measures to cope with storm damages, and serve as a central information point. They can further support coordination between the involved actors and implementation of approved counter measures. Individuals involved in the incident command teams can be, for example, from ministries responsible for forestry, regional forest administrations, forest research institutes, NGOs, federal or state government, finance ministry, forest federations, forest industry, and the ministry responsible for nature conservation.

The UK and the Netherlands have established specific emergency plans on what to do after major windthrow. The Dutch windblow action plan gives responsibility to a crisis team to coordinate actions and make ad hoc decisions. Advise will be given on safety of workers and public, how to get an estimate of damage, ecological consequences, contacts with the press, etc.

Within the UK an Action Guide exists for Forestry Commission Staff which provides guidance on strategies for catastrophic storm damage to forests, and is intended for field managers. ‘Guidelines for Dealing with Windblow in Woodlands’ provides owners with advice on how to manage the harvesting and marketing of windthrown timber prior to restocking. An ‘Interim Scottish Windblow Contingency Plan’ provides advice for anyone involved in planning for and responding to a catastrophic windthrow event in Scotland including the Scottish Government, Forestry Commission Scotland, private sector forest management companies, the timber processing industry and small woodland owners. A fully functional Integrated Emergency Planning structure will be developed. The guidance in the contingency plan is based around the five core activities of Integrated Emergency Planning (IEM): assessment, prevention, preparation, response and recovery.

Switzerland and two federal states of Germany (Baden-Wuerttemberg and North-Rhine Westphalia) that were hit by severe storms in the last decade recently developed 'Storm Damage Manuals' to provide technical and practical information for forestry professionals on efficient management of storm events. Due to the increased demand for practical advice and an increase of extreme weather events, several German forest agencies and the Austrian Agricultural Ministry initiated a cooperation project to produce a guidebook on crisis management in forestry that should be ready by the end of 2012: 'A handbook for the management and prevention of biotic and abiotic damages, including storms' (Grimm and Hartebrodt 2010). In the aftermath of the Gudrun storm, the Swedish government launched the Storm Analysis Project to analyse and describe the response to the storm and to propose measures for minimizing damage from, and improving readiness for, similar events in the future. The findings of the project are presented in a series of reports and summarized in an overview document containing the most important conclusions.

From 2001 to 2004 the European Commission funded a project called STODAFOR (the European Concerted Action on Storm Damaged Forests) to create a Technical Guide for foresters and wood industry managers facing storm damaged forests (Pischedda, 2004). Experiences and knowledge have been gathered in different countries on harvesting methods and log conservation to compile a 'state of the art' in Europe concerning storm management. National laws and regulations in the language of each participating country complement the guide.

8.2.6 Other Relevant Instruments

The establishment of "National Forest Programmes" (NFP) is the outcome of international forest policy dialogues to put international agreements on sustainable forest management into practice and to initiate approaches towards forest policy formulation, planning and implementation at the sub-national and national levels. NFPs are country-specific processes which provide a framework and guidance for forest sector development and national implementation of internationally agreed concepts (such as sustainable forest management) and obligations (e.g. UN conventions). The EU Forest Action Plan considers NFPs as the main instrument for implementing international forest-related commitments. Background information on and implementation status of NFPs in Europe are presented in detail in the Forest Dieback study (Requardt et al. 2007). This study also points out that a comparison of NFPs is difficult due to varying states of formulation and implementation of NFPs as well as different interpretations of the NFP concept in the countries. Among the investigated countries, the Netherlands and Sweden do not have a NFP but Sweden has several of the components of an NFP in place although they have not been formalized as an NFP.

In the context of storm related policies, only a few NFPs discuss natural disasters and risk management. For instance, the Austrian Forest Programme, which is structured along seven thematic areas, addresses storms in the second area 'Health and vitality of Austrian forests': "*In the case of extreme storms, though, the damage is, as a rule, independent of the type of forest management applied. However, clear-cutting systems can, depending on their type and size, increase its susceptibility. In the case of low wind speed experts see a connection between the composition (texture and structure) of the site and its border with the susceptibility of the forest. Thus, an appropriate selection of* *tree species, the harvest type and the selection of regeneration procedures particularly adapted to site and stand conditions, as well as adequate forest tending measures become important factors for the vitality and stability of forest ecosystems."* A number of the strategy recommendations drawn up by the German NFP have potentially positive effects on the resistance of forests to storm, e.g. use of site adapted tree species, abandonment of clear cuts, use of seedlings from appropriate provenances, stratification of the forest stand. However, the outputs of the NFP have not resulted in concrete political action on the federal level.

According to the Water Framework Directive European Member States must develop a Programme of Measures for river basins. Due to different implementations of the measures derived from the WFD in each country, it is difficult to estimate the influence of the WFD on forest management. Also national water acts are designed differently in the countries. Generally, one has to take into account that regulations resulting from water acts affect a limited forest area, preliminary forests in riparian zones and watersheds. Furthermore, not all derived regulations have a relation to resistance of forests to storms.

Nature conservation acts in the selected countries are constituted either on state or federal level with the objective to conserve nature (and landscape) as a fundamental natural resource for humans, animals and plants. Protection includes the diversity, beauty and recreation value of nature and landscape; fauna and flora, including their habitats; the sustained availability of natural resources for human use; and the functioning of ecosystems and their services. Forestry and forest interventions usually follow the principles of sustainable forest management and take account of the aims of nature conservation. Clear provisions for the management of forests outside protected areas are rare and the influence of nature conservation acts on forestry is in some cases weakened as the national forest acts is given higher priority (e.g. in Germany). Hence, the resistance of forests to storms is indirectly improved through the emphasis on sustainable forest management. Measures aimed at the conservation of biodiversity such as increasing the amount of old forest stands and managing forests with long rotation periods may increase the susceptibility of forests to wind throw.

The establishment of the NATURA 2000 network under the Habitats Directive (European Commission 1992a) to ensure the preservation of biodiversity in the area of the European Union includes also forests. In some countries the NATURA 2000 network is based mainly on the existing network of protected areas, including strictly protected areas, while in other countries the continuation of commercial forestry is allowed, and sometimes even considered essential for the preservation of the site (Frank *et al.*, 2007). Any activities inside the NATURA 2000 specified areas that deteriorate the status of the natural habitat are prohibited and the European Commission recommends developing management plans. The nature of the measures depends on the agreement between the competent authorities and individual forest owners. The influence on forest management thus differs locally.

8.2.7 Financial Instruments in Countries Affected by Storms

Large storms can overwhelm the capacity of forest owners to cope with the resulting damage. Therefore most states provide financial support after a devastating storm event either through their regular forest funding programmes or specific ad hoc measures approved in the aftermath. The scope of regular forest funding programmes is too broad to be covered in this study. An extensive analysis was conducted by the EFI within the research project 'Evaluating Financing of Forestry in Europe (EFFE)' and results are described in the final report (EFI 2005). Although there is a large amount of information on expenditure, it is inconsistent and not easily comparable due to the different measures and sources of funding considered. However a few ad hoc measures are presented here to provide a figure for the amount spent in covering storm damage.

During the lifetime (1990-1995) of the 'Special Programme for the coverage of Storm Damages' (SPCSD), the Federal State and the four Länder; Lower Saxony, Schleswig-Holstein, Baden-Württemberg and North-Rhine Westphalia paid out nearly 322 million € (EFI 2005). Reafforestation (47.2%) and storage premiums (42.2%) accounted for the largest amounts paid by SPCSD, while bark beetle control (6.0%), removal of wood (1.4%) and interest allowances for salvage logging and skidding (3.1%) were much lower (Table 8)

Table 8: Overview of the results of SPCSD during 1990 through 1995 (EFI 2005)

Measure category	**Measure**	**Public support (million €*)**
Urgent measures	Interest premium for salvage logging and forwarding	9.79
	Timber storage	134.55
	Bark beetle control	19.0
	Clearing up the damaged stands from wood without market value	4.55
Long-term measures	Site-adapted reafforestation, advanced- and underplanting, repair plantings	153.26

* Conversion in EURO prices by using the conversion rate of 1999: 1€ = 1.95580 DM

Baden-Württemberg, which was worst affected, paid €39.7 million alone for the storm damage programme (EFI 2005).

Hänsli *et al.* (2002) conducted a comparative analysis of the funds paid after the Vivian and Wiebke storms in 1990 and Lothar in 1999 in Baden-Württemberg (Table 9). However, a direct comparison is difficult to make due to the different situations after each storm.

Table 9: Overview on measures to cope with storm damage 1990 and 1999/2000 in Baden-Wuerttemberg (adapted from Hänsli *et al.* 2002)

	1990	**1999**
Amount of storm damaged timber	15 million m³	29 million m³
Storm aid means	Bund-Länder-Programme 1990-1995:	Immediate Aid Programme of Ba-Wue complemented with a restoration subvention for private forests of 20-200 ha size
	Financing: Länder 50%, Bund 50% but max. 30.04 million €*	Bund: 12.78 million €* in the scope of GAK EU: 50% share through MEPL
	Amounts: Bund: 30.04 million €* Laender: 43.55 million €* EU: 30.88 Million €* Total: 122.87 Million €*	Total subsidies 2000: Bund: 5.11 million €* Land: 9.71 million €* EU: 14.83 million €* Total 2000: 29.66 million €*
	61% for private forests 39% for communal forests	61% for private forests 39% for communal forests
	State forest: 1990-1992: 87.23 million €* (includes measures that are of benefit also for private and communal forest	State forest: operating expenses in the year 2000: 249.51 million €*

* Conversion in EURO prices by using the conversion rate of 1999: 1€ = 1.95580 DM

An analysis conducted by Erb *et al.* (2004) revealed a total 117.2 million € of subsidies were paid in the period 2000 – 2002, of which about 78.1 million € (67%) were purely paid as storm subsidies after Lothar in Baden-Württemberg (Table 10). The forest administration of Baden-Württemberg estimates that almost the double this figure was spent in total funding: 154 million € (Forst BW 2009).

Table 10: Total amount of subsidies (€) paid by the Land, the federal government and the EU in the years 2000, 2001, and 2002 according to subsidy programmes and forest ownership (Erb *et al.* 2004). PF = private forest, CF = communal forest, Sum = PF+CF.

Million Euro	**2000**			**2001**			**2002**		
Measure	**PF**	**CF**	**Sum**	**PF**	**CF**	**Sum**	**PF**	**CF**	**Sum**
Immediate Aid (for storage, road repairing, wood removal, timber transport)	10.0	10.9	21.0	2.6	3.9	6.6	2.1	4.4	6.4
Subsidy for Investment in storage places	1.0	1.3	2.2	-	0.1	0.1	-	-	-
Silvicultural measures (reforestation, advance planting, natural regeneration, maintenance, liming etc.)	4.6	7.0	11.7	6.1	12.3	18.4	6.1	14.3	20.6
Miscellaneous (road construction, forest federations, ecological measures)	0.7	-	0.8	0.7	-	0.7	1.0	-	1.0
Reforestation Subsidy Forest	1.8	-	1.8	1.8	-	1.8	1.8	-	1.8
Compensation Allowance Forest	6.6	-	6.6	7.2	-	7.2	7.4	-	7.4
Afforestation premium	0.4	-	0.4	0.3	-	0.3	0.4	-	0.4
Sum	**25.2**	**19.3**	**44.4**	**18.8**	**16.4**	**35.2**	**18.9**	**18.7**	**37.5**

In Switzerland, the Bund, Cantons, communities and the Funds for Natural Hazards paid for the consequences of Lothar. This amounted to 469 – 625 million € between 2000 and 2003 (Hänsli *et al.* 2002, Table 11).

Table 11: Subsidies after the storms in 1990 and 1999 in Switzerland (Hänsli *et al.* 2002)

	1990	**1999**
Total amount of storm subsidies of the State 1990-1993 / 2000-2003, without investment credits	138 million € (250 million €)	241 million €
Amount of storm subsidies of the State per m³ storm timber	28 €/m³ (51 €/m³)	19 €/m³

* Conversion in EURO prices by using the exchange rate in 1999: 1€ = 1.6003 Swiss francs

8.3 Regulative and Financial Instruments of the EU

8.3.1 Introduction

As the treaties establishing the European Union do not provide for a specific common forest policy, the formulation and implementation of forest policy lies in the competences of the EU Member States. However many policy measures and actions adopted at the EU level directly or indirectly influence the forest sector and have an impact on national forest policy and vice versa. EU Member States may have to adjust their national forest policies to EU requirements.

Following the principle of subsidiarity and the concept of shared responsibility, the regulative and financial instruments of the EU are:

- Non-binding policy frameworks, like the EU Forest Strategy
- Binding directives, regulations and decisions, like the Rural Development Regulation
- Funds and financial instruments, like the European Agricultural Rural Development Fund (EARDF)

The policy evaluation of storm-relevant policies describes the most relevant instruments and measures towards the objective of forest storm damage mitigation and restoration that are currently in place at European level.

8.3.2 EU Forest Policy Framework

The EU Forestry Strategy is the core instrument of EU forest policy and constitutes the framework for forest-related actions. As an attempt to establish a more coordinated and coherent European forest policy, it defines common principles of EU forestry and names international processes and activities to be followed at EU level. Emphasis is given to the importance of the multifunctional role of forests and to sustainable forest management (SFM) as an overall principle for action. The Strategy acknowledges that forest policy is the responsibility of the Member States and the EU can contribute to the implementation of SFM through common policies based on subsidiarity and shared responsibility.
Unlike fire and pollutions, storms are not explicitly stated as a requiring action. However, the support of SFM contributes to the development of stable forests.

After an evaluation of the implementation of the EU Forestry Strategy, the Council adopted in 2006 as a consequence of the conclusions of the report, the EU Forest Action Plan (FAP), to enforce the coherence and coordination between the forest policies of the Member States and forest-related activities at the EU level. Hence, the actions determined in the FAP predominantly target coordination, including the exchange of information and experience, communication and research. The FAP still respects the main principles and elements identified in the EU Forestry Strategy.

The FAP consists of a set of key actions proposed by the Commission to be implemented jointly with the Member States in the period 2007-2011 in order to achieve four main objectives (European Commission, 2006a):

- improving long-term competitiveness
- improving and protect the environment
- contributing to the quality of life; and
- fostering coordination and communication.

The activity most related to storms is Key Action 9 "Enhance the protection of EU forests", which is described as follows:
"*Forest fires, biotic agents and atmospheric pollution have a sizeable influence on the ecological condition and productive capacity of forests in the EU. Global trade and climate change have increased the potential vectors for harmful organisms and invasive species. As protection of forests against biotic and abiotic agents is one of the main priorities of forest policy, it is essential to have up-to-date information about the state of forests in the EU.*"

The Commission will: "*carry out a study, which will analyse the main factors influencing the evolution of forest condition in Europe (including forest fires), the efficiency of current Community instruments and measures for forest protection, and potential future options to improve the efficiency of the measures; (This refers basically to the objectives of the "Forest Dieback" feasibility study) encourage Member States to form groupings to study particular regional problems with the condition of forests; support research on protection of forests and phytosanitary issues under the 7th Research Framework Programme.*"

In addition, with support from the EARDF and the Life+ instrument (see below), the Member States may, inter alia:

- develop national afforestation guidelines and promote afforestation for environmental and protective objectives;
- promote investments, which enhance the ecological value of forests;
- support restoration of forests damaged by natural disasters and fire;
- review and update broader protection strategies against biotic and abiotic agents, including studies on risk assessment in relation to harmful organisms and invasive species.

One of the objectives of the Forest Action Plan is to improve and protect the environment by maintaining and appropriately enhancing biodiversity, carbon sequestration, integrity, health and resilience of forest ecosystems at multiple geographical scales (Forest Action Plan, Section 3.2). Key action 8 "Work towards a European Forest Monitoring System" is indirectly relevant to storms. The monitoring system shall draw on existing forest databases and monitoring systems to meet the reporting needs for scientific purposes and decision making on particular EU policy and measures.

Requardt *et al.* (2007) concluded that the issue of protecting EU forests is well covered within the EU Forest Action Plan and within the EU Forest Strategy. Future challenges were perceived in developing the existing FAP further beyond the period 2007-2011 and identifying new forest protection measures, which could be applied at the EU level, in particular prevention and mitigation measures against border-crossing damage.

8.3.3 Regulative Instruments

In this section we describe an analysis of policies to reduce storm damage and to cope with severe storm events, and present legislation and measures that are relevant to storms on the European level. We outline one instrument directly related to forest and various non-forest policies that have an effect on storm management and vulnerability of forests to storm.

The Council Directive 1999/105/EC on the marketing of forest reproductive material (European Commission, 1999) ensures the plentiful supply of high quality forestry reproductive material within the Community by stipulating that the marketing of forest reproductive material must comply with one of four categories specified by the Directive and that only approved basic material (the trees from which reproductive material is harvested) may be used for its production. All material must fulfil conditions regarding species purity in lots of fruit and seed, 'fair marketable quality' of parts of plants, hybrids and planting stock as well as conditions specific to *Populus* spp. The directive may indirectly influence the resistance of forests to storms, their stability and adaptation by assuring the supply of high quality reproductive material suited to the site in question.

Article 18 is relevant for post-storm management if reproductive material is in short supply after a storm event. The article regulates that in order to remove any temporary difficulties in the general supply to the end user of forest reproductive material in one or more Member States, the Commission can approve forest reproductive material of one or more species which satisfies less stringent requirements for marketing for a certain period.

The European water framework directive (WFD) (European Parliament, Council of the European Union, 2000) aims to maintain and improve the water quality of inland surface waters, groundwater, transitional waters and coastal waters as well as to prevent and reduce pollution, promote sustainable water use, protect the aquatic environment, improve the status of aquatic ecosystems and mitigate the effects of floods and droughts. The main goal is the "*avoidance of a further deterioration as well as protection and improvement of the condition of aquatic ecosystems and their directly dependent terrestrial ecosystems and wetlands with respect to their water supply*".

A management plan and programme of measures must be produced for each river basin, and must contain basic (minimum requirements such as existing policies) and supplementary measures to reduce negative effects from the agricultural and other sectors. The Programmes of Measures had to be established by 2009 by the Member States and will be made operational by 2012. Measures within the Programmes of Measures are directly linked with measures under Axis 2 of the Rural Development Programme. The implementation of the WFD to achieve nominated protection goals affects almost every forestry work area. Depending on the type and state of water body, and whether they are to be protected or developed, different areas have to be considered: stream banks, wetlands or the whole river basin of streams and water catchment. However, the influence of the WFD on forests can vary between the countries and the river basins as the implementation depend on the specific measures each country derives from the WFD.

The Habitats Directive (European Commission, 1992a) is intended to help maintain biodiversity in the Member States by defining a common framework for the conservation of wild plants and animals and habitats of Community interest. The Directive established a European ecological network known as "NATURA 2000". The network comprises "special areas of conservation" designated by Member States in accordance with the provisions of the Habitats Directive, and special protection areas classified pursuant to the Birds Directive (79/409/EEC).
Criteria for the designation of forest sites to the NATURA 2000 network are:

- forests of native species, forests with a high degree of naturalness
- forests of tall trees
- presence of old and dead trees
- forests having benefited from continuous sustainable management over a significant period

Member States are required to take appropriate measures to avoid deterioration of natural habitats, including forests (Article 6 (2)). As a consequence, forest management can be affected as economic activities are of lower priority than conservation objectives in the assigned areas. Measures conflicting with the conservation aim might have to be modified. Impact assessments are obligatory before the implementation of new plans and activities to avoid or minimize negative effects on the designated sites (Article 6 (3)). However, a proposed programme that is likely to cause significant damage to a site, may still be applied if it is of overriding public interest and if compensation is envisaged. Furthermore, Member States are requested to restore selected habitats and to develop detailed management plans to achieve this requirement (Article 6 (1)). The Commission has outlined non-legally binding guidelines with principles and examples of best practice which also recommend the development of management plans. Winkel *et al.* (2009) concluded that a limited number of forest management requirements can be derived from the Directives and that it is not possible to foresee specific indications on areas, such as the dimensions of clearings, as these depend on management measures that have to be negotiated at a local level between the authorities in charge and the forestry owners.

8.3.4 Financial Instruments

The EU provides various financial instruments and funds to support actions and measures at regional, national and EU level that are relevant to cope with storm damages in forests.

The most important financial instruments related to storms are the Civil Protection Mechanism, the Civil Protection Financial Instrument and the European Solidarity Fund. With regard to storm prevention and sustainable forest management the European Agricultural Fund for Rural Development (EAFRD) and the European Regional Development Fund (ERDF) are the main sources for financial support. The analysis of a single funding mechanism is limited to a certain extent due to interlinks of programmes, contradictory aims, incomplete data, and lack of evaluation and monitoring at EU and national level. However, the Evaluation of Financing Forestry in Europe (EFFE study, EFI 2005) revealed that national and EU funds are the most significant sources of public funding. The study showed that 4.1% were spent for assistance after catastrophic events and 12.6% went to afforestation and reforestation measures between 1990 and 1999 (Figure 9)

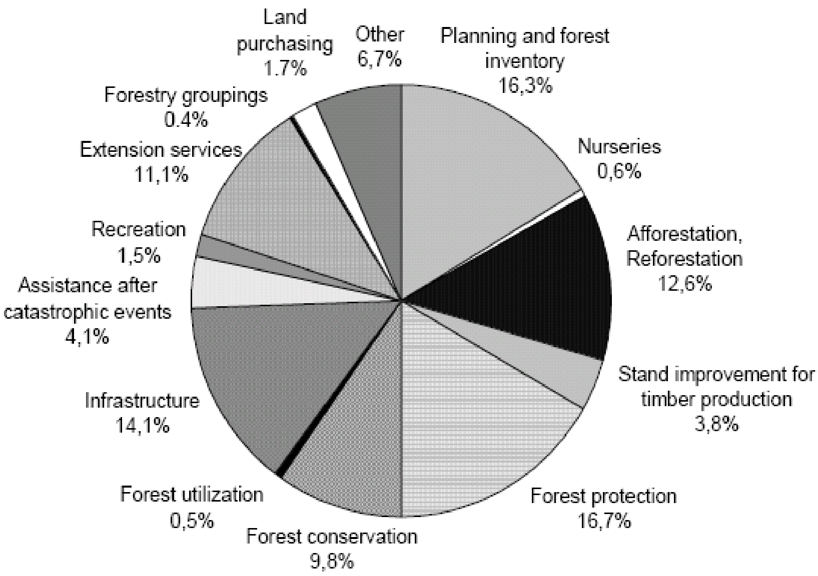

Figure 9: The aggregate distribution of public funding (1990-1999) by the types of activities supported in twelve EU countries (EFI 2005)

The Community Civil Protection Mechanism (European Commission, 2001) was first established by Council Decision 2001/792 in 2001. A recast of this Council Decision was adopted on 8 November 2007. Its purpose is to support and facilitate cooperation between the Community and the Member States in civil protection assistance interventions in the event of major emergencies, or the imminent threat thereof.

It improves the coordination of emergency services by defining the obligations of Member States and the Commission and by establishing a common emergency communication and information system. A number of tools were set up to enhance the preparedness and effective response to disasters at community level, such as the Monitoring and Information Centre. The Mechanism can be applied in cases of natural and man-made disasters. If a major emergency overwhelms the response capabilities of an affected Member State, this State can appeal to the Mechanism to supplement its own civil protection resources. Most recently, Sweden requested assistance in dealing with the consequences of the storm Gudrun in 2005.

Countries hit by storms can request assistance from the Member States through the Monitoring and Information Centre (MIC), which is the operational centre of the Mechanism. The MIC can provide technical support, including improved access to satellite images, and acts as an information centre, collects data and distributes regular updates to all participating countries. The Mechanism facilitates access to equipment and transport by providing information on the resources available from Member States. It can further mobilise and send small teams of experts to the site of the emergency to assess their needs and to help coordinate operations there. A programme of lessons learned from interventions and the dissemination of these lessons throughout the information system is also assumed by the Mechanism.

Today, 30 States – the EU27, plus Liechtenstein, Norway and Iceland – participate in the Mechanism. It receives a financial allocation on a year-by-year basis. This instrument has no financial mechanism, rather it focuses on the operational obligations of the Member States and the Commission. According to the rules of the Mechanism, the state requesting assistance bears the expenses of assistance provided by the participating states.

To finance the preparation and implementation of civil protection measures, the European Council approved the Decision 2007/162/EC, Euratom on establishing a Civil Protection Financial Instrument (European Commission 2007a). Financial support encompasses rapid response and preparedness measures for major emergencies, whether these result from natural, industrial and technological disasters or terrorist acts. The objective is to contribute to the effectiveness of national systems for preparedness and response to risk situations for people, the environment or property either by improving the capacity of such systems or by encouraging coordination.

Eligible actions are specified in the Decision and include:
- Studies, surveys, modelling and scenario building
- Training, exercises, workshops, exchange of staff and experts, creation of networks, demonstration projects and technology transfer to enhance prevention, preparedness and effective response
- Public information, education and awareness raising and associated dissemination actions
- Maintaining the functions provided by the Monitoring and Information Centre of the Mechanism (MIC) to facilitate a rapid response in the event of a major emergency
- Communication actions and measures to promote the visibility of the Community's response
- Contributing to the development of detection and early warning systems for disasters which may affect the territory of the Member States
- Establishment and maintenance of a secure common emergency communication and information system (CECIS) and tools to enable communication and sharing of information between the MIC and the contact points of the Member States
- Monitoring, assessment and evaluation activities
- Establishment of a programme of lessons learnt from interventions and exercises in the context of the Mechanism

Beneficiaries may be natural or legal persons, whether governed by private or public law. The community provisional funding is €189.80 million. Actions and measures funded by this instrument are complementary to other European Union instruments and policies, such as the European Union Solidarity Fund (EUSF).

The main financial instrument for high emergency aid is the European Union Solidarity Fund (EUSF). It was created after the devastating floods in Central Europe in August 2002 (Council Regulation (EC) No 2012/2002). EUSF is designed to provide fast, effective and flexible emergency financial aid in case of natural disasters like large scale forest fires in the Mediterranean regions or extensive storms like Kyrill in Germany. The EUSF supplements public expenditure by the Member States concerned for the following essential emergency operations:
- Immediate restoration to working order of infrastructure and plant in the fields of energy, drinking water, waste water, transport, telecommunications, health and education;
- Providing temporary accommodation and emergency services to meet the immediate needs of the population;

- Immediate securing of prevention infrastructures and measures to protect the cultural heritage;
- Cleaning up of disaster-stricken areas, including natural zones.

The EUSF was not set up with the aim of meeting all the costs linked to natural disasters. The Fund is limited in principle to non-insurable damage and does not compensate for private losses.

At the request of a Member State, assistance from the Fund may be mainly mobilized following a major natural disaster with serious repercussions on living condition, the natural environment or the economy in one or more regions or one or more countries occurs on the territory of that State. A 'major disaster' within the meaning of this Regulation means any disaster resulting, in at least one of the States concerned, in damage estimated either at over €3 billion in 2002 prices, or more than 0.6 % of its Gross National Income (GNI) (Council Regulation (EC) No 2012/2002). The Fund has an annual budget of one billion Euros.

In the case of a storm event, funded measures can comprise, for instance, repair of forest roads, cleaning of forest roads for the fire service as a measure to prevent forest fires, or additional personnel for the rapid cleaning of storm damages in the forest. Germany received €166.9 million in 2007 for dealing with the damages from storm Kyrill (MUNLV, 2010). This was the second highest amount a country has received so far from the EUSF at that time. After the Gudrun storm, the European Solidarity Fund paid nearly €93 million to Sweden, Estonia, Latvia and Lithuania as compensation for the consequences of the storm (Haanpää *et al.*, 2007). The vast majority (€82 million) was granted to Sweden.

Direct funding of EU forest policy does not exist but is embedded in the Common Agricultural Policy (CAP). The CAP sets out principles and priorities to be pursued in rural areas, and thus includes forests too as the major land-use besides agriculture. In order to overcome imbalances between regions and to strengthen less developed areas, the CAP provides funding under its second pillar for the development of rural areas through national or regional rural development programmes.

For the financing of expenditure under the common agricultural policy (CAP) two new funds were created: the European Agricultural Guarantee Fund (EAGF) and the European Agricultural Fund for Rural Development (EAFRD). While the EAGF finances predominantly measures in the agricultural sector, the EAFRD supports expenditures for rural development, including forestry. The EAFRD aims at strengthening the EU's rural development policy and simplifying its implementation (European Commission 2005). In particular, it improves the management and controls of the rural development policy for the period 2007-2013.
The Rural Development Programme offers a broad range of rural assistance measures grouped around four priority areas:

- Improving the competitiveness of the agricultural and forest sectors (axis 1),
- Improving the environment and countryside (axis 2),
- Improving the quality of life in rural areas and encouraging diversification of the rural economy (axis 3),
- Building local capacity for employment and diversification (promotion of the LEADER approach).

Member States can select the measures which meet their needs to be integrated in their national or regional rural development programmes.

Forestry measures with respect to storm protection and rehabilitation are part of axis 2 (Improving the environment and the countryside). Axis 2 supports the prevention of natural hazards. Article 48 of the EAFRD states that support shall be granted for restoring forestry potential in forests damaged by natural disasters and fire and for introducing appropriate prevention actions.

The total budget of the EAFRD for the period 2007-2013 is €88 billion. It is envisaged that the rural development programmes will make around €8 billion of EAFRD funds available for forestry measures, and together with national co-funding the sum will amount to €16 billion in 2007-2013 (Pelli *et al.* 2009).

Similar to the EAFRD the European Regional Development Fund (ERDF) (European Commission 2006) aims to strengthen economic and social cohesion in the European Union by correcting imbalances between its regions. This is achieved by supporting the development and structural adjustment of regional economies. The Regulation defines the types of action eligible for financing from ERDF. It also establishes the tasks of the ERDF and the scope of its assistance with regard to the three objectives "Convergence", "Regional competitiveness and employment" and "European territorial cooperation" for the period 2007-2013.

Assistance for risk prevention is indicated under each objective:

- Under the "Convergence" and the "Regional Competitiveness and Employment" objective of the Structural Fund assistance shall focus, besides others, on the prevention of risks, including development and implementation of plans and measures to prevent and cope with natural and technological risks (Article 4(5) and 5(2e)).
- Under the "European Territorial Cooperation" objective priority is given on the establishment and development of transnational cooperation through the financing of networks and of actions conducive to integrated territorial development. It shall concentrate on, besides others, the area of environment and therein on risk prevention and environmental protection activities with a clear transnational dimension (Article 6(2b)).

Besides the structural funds the EU established the Financial Instrument for the Environment (LIFE) in 1992 (European Commission 1992b). The Commission provides grants for proposals submitted by the Member States that aim to contribute to the implementation, updating and development of Community environmental policy and legislation. The current programme for the period 2007-2013 is called LIFE+ and shall support the implementation of the 6th Environmental Action Programme and measures and projects with European added value in Member States (European Commission 2007c).

LIFE+ is based on three pillars:

- Nature and Biodiversity
- Environment Policy and Governance
- Information and Communication.

LIFE+ replaces the Forest Focus scheme which formerly guaranteed the harmonized, long-term monitoring of forest condition in the EU.
Forest monitoring is now covered under the specific objectives of the LIFE+ Environment Policy and Governance component, which shall inter alia support the design and implementation of approaches to monitoring and assessment of the state of the environment and the drivers, pressures and responses that impact on it. Basically the scope of the former Forest Focus regulation is reflected in the LIFE + programme. However, the LIFE+ programme no longer supports regular monitoring of sample plots. Instead it co-finances monitoring projects on a voluntary basis to which Member States can apply for.

Currently the project "Further Development and Implementation of an EU-level Forest Monitoring System" (FutMon) is co-financed by the LIFE+ programme. Its main objective is the creation of a pan-European forest monitoring system which can serve as a basis for the provision of policy relevant information on forests in the European Union as required under international obligations and key action 8 of the Forest Action Plan. During the project quantitative and qualitative forest data related to climate change, air pollution, biodiversity, and forest condition are collected.

In the LIFE+ multi-annual strategic programme the principal objective for "Forests" is defined as follows:
"*To provide, especially through an EU coordination network, a concise and comprehensive basis for policy relevant information on forests in relation to climate change (impact on forest ecosystems, mitigation, substitution effects), biodiversity (baseline information and protected forest areas), forest fires, forest condition and the protective functions of forests (water, soil and infrastructure) as well as contributing to the protection of forests against fires*".

Priority areas of action are:
- promoting the collection, analysis and dissemination of policy-relevant information concerning forests and environmental interactions,
- promoting harmonisation and effectiveness of forest monitoring activities and data collection systems and making use of synergies by creating links between monitoring mechanisms established at regional, national, Community and global level,
- stimulating synergies between specific forest-related issues and environmental initiatives and legislation (e.g. Thematic Strategy for soil protection, NATURA 2000, Directive 2000/60/EC),
- contributing to sustainable forest management, in particular, by collecting data related to the improved Pan-European Indicators for Sustainable Forest Management as adopted by the Ministerial Conference on the Protection of Forests in Europe (MCPFE) Expert Level Meeting 7-8 October 2002, Vienna, Austria,
- building capacities at national and Community level to allow for coordination and guidance on forest monitoring.

The mid-term evaluation of the Forest Action Plan revealed that the monitoring of forest damage caused by storms, insects and diseases is less well developed and harmonized compared to the monitoring, assessment and reporting of forest fire and air pollutants effect (Pelli *et al.* 2009).

Table 12: Instruments and their relevance for storm damage management.

Instrument	Prevention	Post-storm management	Long-term policy
Forestry Strategy	X (indirect)		X (indirect)
Forest Action Plan	X (indirect)		X (indirect)
Council Directive on the marketing of forest reproductive material	X (indirect)	X (direct)	
Water Framework Directive			X (indirect)
Habitats Directive			X (indirect)
Civil Protection Mechanism		X (direct)	
Civil Protection Financial Instrument	X (direct)	X (indirect)	
European Union Solidarity Fund (EUSF)		X (direct)	
European Agricultural Fund for Rural Development (EAFRD)	X (indirect)	X (direct)	X (indirect)
European Regional Development Fund (ERDF)	X (indirect)		X (indirect)
Financial Instrument for the Environment (LIFE)			X (indirect)

8.4 Workshop on 'Policies for Forest Storm Damages Mitigation and Restoration', Brussels 1st July 2010.

The aim of the one-day workshop (see Appendix 2) was to provide a forum for sharing of knowledge and experience. Following presentations from project partners and invited experts, participants were divided into four groups. Each group was asked to assess current management, policy and responses relating to storm damage and identify where more effective systems are needed. Group 1 focussed on European policies, Group 2 on policies and responses relating to storm Martin and Klaus, Group 3 concentrated on storms Lothar and Kyrill, and Group 4 on storms Gudrun and Per.

Relevant policies at the EU level have been identified earlier in this chapter. Group 1 noted that there is often a delay in making financial support available to countries impacted by storms. In cases of an emergency, the EU 'Monitoring and Information Centre' (MIC) can facilitate requests from countries for civil protection assistance, but the Group recommended that expertise on storms is needed. Moreover, not all Member States may be aware of the existence and function of MIC and thus it would be useful for national/regional crises management plans to incorporate the role of MIC. Overall, it was felt that sharing of information on crisis management relating to storms is not as advanced at the EU and national level as other forest hazards such as fire. The EU could facilitate exchange of knowledge, expertise and resources between countries and act as a repository, and have responsibility for dissemination of 'state-of-the-art' scientific and practical information.

Based on experiences from storm Martin and Klaus, Group 2 identified a range of measures that could be improved. For example, to assist countries acting quickly, it was felt that European legislation should automatically allow national governments to contribute to emergency measures such as opening roads and assessing damage. It was also felt that there should be more flexibility when plans are adopted and validated by European authorities to allow countries to adapt to changing circumstances. As storms generate large volumes of wood that need to be stored or sold quickly, long-term maintenance of storage centres would reduce delays, and initial financial resources are needed to set up the required infrastructure. Moreover, information on current timber prices and trends would be a particularly useful tool that could be centrally coordinated by the relevant European authorities.

Focussing on Germany and Switzerland, Group 3 also identified problems with accessing emergency funds quickly. Immediate access to a set amount of emergency funds, which are released when certain thresholds have been passed (e.g. damage being greater than a percentage of growing stock), would be beneficial. This Group identified a continuing demand for spruce despite concerns that it may be less wind resistant than other species. Current knowledge on prevention measures relating to wind risk are not fully effective because of lack of awareness amongst forest owners and certain sectors of the industry and continuing demands of the processing sector and markets for particular forest products. Wider dissemination and discussion of available guidelines on forest management, provenance and species choice and use of natural regeneration could start to address these issues.

While discussing experiences from storms Gudrun and Per, Group 4 identified a need to systematically review and update storm crisis management plans. Salvage operations were delayed because of regulations on using lorries and equipment from other countries. A noticeable difference in safety standards also emerged when forest workers from different countries were drafted in to help storm-damaged countries. It may be necessary to develop common standards. This Group also identified a need for a common system of inventory at national, and possibly EU levels.

A range of requirements relating to policies and measures at national and EU level were identified at the workshop including:

- Flexibility in regulations relating to forest management and storm damage
- Standardised methods for monitoring and inventory
- Quicker access to EU funding and assistance
- Better insurance system standards across Europe
- EU standards/regulations for machinery and transport to allow countries to assist each other following storm damage
- The role of the MIC to be included in national/regional crises plans
- EU to coordinate efforts for mapping and remote sensing
- EU to coordinate and disseminate 'state-of-the-art' knowledge in the field of wind damage management
- EU to provide up-to-date data on timber prices and trends
- Long-term planning and maintenance of storage systems

8.4 Synthesis

All analyzed national forest acts consider sustainable forest management as the core principle of forestry and thus generally contribute to storm prevention by promoting the establishment of stable forests. Principal elements to maintain forest land, to reforest devastated areas or to control pests are regulated to a differing extent in all countries and often financially supported. These regulations and grants could partially be fostered and used to encourage appropriate forest reconstitution and management to mitigate future storm risks. For instance, this could mean binding financial support to the use of site-adapted species and provenances. A great deal could also be achieved through non legally binding measures such as providing information for forest owners on appropriate silvicultural measures improving stand stability and resilience.

The modification of thinning regimes and rotation ages may interfere with nature conservation and biodiversity aims and requires the recognition of exposure to high storm risk in forest planning and adequate allocation of nature conservation (including NATURA 2000) and timber production areas. Storm risks as a hazard for habitats and genetic resources should be integrated in nature protection policies.

Windblow emergency plans and technical guidelines for the management of storm events have been developed in many countries, often at regional level. Efforts are currently underway to exchange information and develop common guidebooks. There is a good opportunity for the EU to enhance the cooperation and exchange between storm-stricken countries by providing a European-wide information platform on storm management practices and emergency procedures.

On the European level the Civil Protection Mechanism is seen as a useful instrument by the Member States to ask for assistance in emergency cases. Its performance could be improved by adding storms expertise to its operational unit, the Monitoring and Information Centre. Its effective implementation depends also on common rules and uniform regulations, for example transport that should be harmonized within the EU. The Financial Instrument for the Civil Protection could be further disseminated and increasingly used for the training and exchange of specialized workers and storm experts.

The available funds of the EU like the EUSF or the EAFRD play a significant role in post-storm management and regeneration of destroyed forests. In the event of storms when fast reaction is required, a quick access to financial support is crucial. It is recommended to investigate where bureaucratic standards could be reduced and access facilitated.

Considering the vast damage and the large amount of resources invested to cope with storm losses, it is essential to have sound information on the extent of damages available in order to provide a reliable basis for policy decisions and distribution of financial aid. A legal basis for storm monitoring on the European level is currently lacking and the envisaged monitoring under the LIFE+ program is not a long-term approach. Having a uniform reporting system on storm occurrence and damage would enhance more comprehensive information towards storms under the Forest Europe SFM indicator 2.4 Forest Damage. This could be developed for example under LIFE+. The Joint Research Centre could be responsible for compiling the information and integrating it into the European Forest Data Centre as has been done for the European Forest Fire Information System.

9. Discussion and Policy

- **Assistance is needed by the forest industry in understanding forest storm risk and storm planning. This could be through the provision of best practice guidelines.**
- **Post-storm coordination should be encouraged between affected countries. This could be through training and by aiding the implementation of cooperation plans following storms.**
- **A central source of up-to-date, appropriate and easily available information is needed prior to and following storm events, including early warning systems, immediate maps of affected areas, and information on global timber prices.**
- **A harmonised and equitable insurance system is needed across storm affected member states that adequately compensates owners for the value of services provided by their forests.**
- **A rapid response to storm damage should be facilitated so that the necessary procedures to reduce the impact are quickly implemented.**
- **There is an urgent need to harmonize the monitoring and reporting of storm damage and other hazards (abiotic and biotic) across Europe.**
- **Forest risks (abiotic and biotic) need to be managed in an active integrated manner.**

9.1 Overall Findings

A complete set of storms that have caused noteworthy damage (>0.01 Mm^3) to European forests since 1950 has been drawn up together with a set of basic information on damage levels and economic, social and environmental impacts. The database is available online at http://www.efiatlantic.efi.int/portal/databases/European_storms_catalogue and will be made publically available after the end of the project and final project approval from DG Environment. It will also continue to be checked, updated and maintained by EFI after the project ends.

From the selection of storms a representative selection of 11 storms/storm series was selected for more detailed analysis. This was to illustrate a number of factors such as storm impact on markets, impact on forest policy and different levels and areas of damage (from local to European). In addition the storms were selected to cover every decade in order that changes in levels of damage, conditions prior to the storm, policy responses following the storm and impacts on markets at local to European scale could be evaluated.

We have identified an average of 2 storms per year that have caused noticeable damage to European forests over the last 60 years. The evidence suggests that the level of storm damage to European forests has increased over this period with the four most severe storms occurring since 1990. Most of this increased damage appears to be due to an increase in the growing stock of European forests. In other words the reason for the increase does not appear to be primarily due to changes in forest practice or meteorological conditions but simply due to the fact that there has been a steadily increasing standing volume of European forests that had the potential to be damaged.

Factors that are important in predisposing forests to damage are stand height, soil waterlogging, restriction to rooting and recent thinning. It is extremely difficult to determine differences in the inherent vulnerability of tree species to wind damage. The apparent higher general susceptibility of conifers is probably due principally to their faster growth leading to higher average heights, and the choice of sites on which they are planted. Some species do appear to be more resistant to damage (see Section 5.3.2) and it might be tempting to recommend particular species for managing wind risk but other considerations such as species suitability for the site and the objectives of forest management need to be also taken into consideration.

In addition there is no clear evidence for the benefits of irregular over regular stand structures. The mixture of more "stable" species does not provide a synergistic improvement for the other more "vulnerable" species.

It is clear that there is a large body of knowledge on the factors influencing storm damage risk and how to manage for this risk. In addition many countries have good experience of dealing with the aftermath of storm damage. However, this knowledge and experience is dispersed and often has limited availability and with time becomes forgotten or out of date. Experience from past storms shows that the losses from storms in terms of forests, timber, revenue, environmental services (including protection functions) and human life can be reduced or avoided through access to best practice guidelines, contingency plans, up to date, and reliable information (e.g. damage maps, timber prices, etc.) and adequate training. There are also important lessons to be learnt about avoiding policy conflicts and ensuring that all risks to the forest (abiotic and biotic) are managed in an active integrated manner. The danger of managing forests by focussing only on individual issues or hazards is that the future health of our forests will be compromised.

There is evidence that the trend of storm damage is likely to increase into the future partly as a result of increasing growing stocks and the increased age of European forests. Although it is self-evident that you cannot have damage without forests to damage, it is important to emphasise the primary factor controlling the total volume of damage to European forests is the standing volume. Other factors such as site conditions, species choice, and forest management are also important but tend to be secondary factors that change the vulnerability of specific stands but have had less overall influence than standing volume on storm damage levels. In addition climate change appears to be creating more intense storms, which are penetrating further across Europe with broader tracks and this will increase the risk of forest damage to many areas, but in particular Eastern Europe. The increased precipitation forecast to accompany these storms and higher winter temperatures, which leads to longer periods of unfrozen soils, will both also contribute to increased levels of storm damage to European forests with current management regimes.

The overall conclusion is that if growing stock keeps increasing in Europe damage levels (by volume) are likely to at least double by the end of the century. Such an increase could have profound implications for forest health, carbon budgets, timber prices and the sustainability of the forestry sector. Therefore, active risk management needs to become an integral part of forestry in Europe. It is also possible that current trends in forest growing stock will change with the increasing demand for wood feedstock by industry. Such changes would have a marked influence on damage levels if they modified the standing volume of European forests.

9.2 Policy Implications and Recommendations

Based on our analysis of current regulations, and the procedures and adaptive measures applied by the Member States, and considering the advice provided by experts involved in storm management issues at the workshop held in Brussels on 1 July 2010 (Appendix 2), we consider that European Commission has the potential to improve the situation of European forest with regard to mitigation of storm damage and restoration measures. The European Commission has the opportunity to improve the situation by:

1. Supporting Member States in understanding storm risk and planning for storms
2. Enhancing post-storm coordination between countries
3. Providing appropriate, easily available, and up-to-date information pertinent to storm risk and damage
4. Facilitating post-storm procedures
5. Harmonizing the integrated monitoring of damage across Europe
6. Considering storm risk in all relevant European regulations
7. Providing a link between Member States at the appropriate level for effective policy implementation

9.2.1 Supporting Members States in Understanding Storm Risk and Planning for Storms

There is an obvious need for national and regional risk mapping and contingency plans. A feature of storms is that they are low frequency risk at the national scale. Thus memory of the prevention and of the management is usually lost after 10 or 15 years. Much time is required to identify the stakeholders, consider the real level of damages, negotiate the appropriate measures and comply with European procedures. Response times are much better in countries where contingency plans exist. Such plans define the appropriate reaction according to the level of damage, the participants and the objectives and responsibilities of crisis committees, list potential emergency measures, identify necessary national/local derogations, provide a safety plan, a communication plan and monitoring tools. Such plans contribute to a prompt and appropriate reaction, can be improved after each storm, and can increase overall knowledge and effectiveness.

The European Commission can contribute by supporting projects to draft such plans using ERDF funds, and/or by incentive measures for Member States that are in areas at risk.

9.2.2 Improved Insurance Systems

The country reports and the reports from the insurance sector have demonstrated that the proportion of insured forest stands is reducing in many European countries. The combination of an increase in vulnerability and an increase in exposure inflates the insurance cost. In addition, as forest owners with insurance are often from the same area or producing the same type of timber, the risk mitigation is low. Because in many countries storm risk is considered as a definable risk that can be insured by private companies and is not considered as a natural disaster, the European Commission could act at many levels in the coordination of Member States:

- Ensure that all countries in exposed areas consider storm hazard in the same way (insurable or not insurable) to avoid distortion in post storm management.
- Studies have demonstrated that the value of all forest services for society is 900€ per hectare (Chevassus *et al.*, 2009) while the value of the timber is 100€. Therefore, the EC could consider contributing to national or international analyses to examine to what extent storm risk is of greater consequence to European society than the obvious damage to trees and loss of revenue to owners.
- If the storm risk is still considered as insurable after this study, political measures to improve the insurance guarantee should be undertaken. The main aim should be to extend the areas covered by insurance and the number of insured owners. Many options are available, such as:
  - Share the risk between very large areas and various type of stands,
  - Set-up public/private mechanisms to support the development of private insurance
  - Contribute to reduction of the cost of insurance to forest owners through regulation.
- If storm risk is considered as non-insurable, then Member States should be allowed to compensate the loss of value from the stand directly to forest owners without changing the existing level of support to the rest of the sector. In addition, maintenance of forests is a legal requirement in many countries. Consideration could also be given to the European Commission supporting Member States by setting up a specific fund for forest reconstitution after major disasters. This is due to the important existing and potential contribution of forests to carbon sequestration, biodiversity protection, climate mitigation and water quality[3].

These types of measures would complement the existing Solidarity Fund, which is aimed at supporting Member States through emergency measures, but is not specifically related to the forest sector.

9.2.3 Enhancing Post-storm Coordination between Member States

Coordination between Member States of the EU is a short-term measure that can have the greatest and most immediate impact. At the moment the available European tools for civil safety include remote sensing pictures from the International Charter - Space and Major Disasters (http://www.disasterscharter.org), and the community civil protection mechanism that improves communication, and communication tools between

[3] It should be noted that the European Commission only has existing responsibility for biodiversity protection and no change to this position is foreseen.

the national emergency services, so that countries can support each other. The last time this mechanism was used was for the storms in Sweden in 2005, but it dealt only with civil protection.

The EU could contribute to establishing an equivalent mechanism dedicated to forest post-storm management. Many tasks could be devoted to a European centre for storm management:

- Before the storm, training could be provided on coordination of foresters, harvesting crews and machines and transport operators.
- The European Commission could contribute to this coordination by identifying countries in storm risk areas and asking them to develop multilateral or bilateral cooperation plans.

At the national level, the frequency of very damaging storms is fairly low and possibly explains the poor interest of some Member States in maintaining storage platforms over the longer term. As such platforms are costly to maintain, private companies also face difficulty in keeping them for decades after a storm. Thus the European Commission could facilitate the implementation of long-term storage by estimating the storage capacity required in different parts of Europe and setting up rules according to location and ownership of the platforms to help avoid market disruption.

9.2.4 Providing Appropriate, Easily Available, and Up-to-date Information

Considerable knowledge is accumulated at a regional or national level in an informal way, although reports or information sheets are available only in local languages. The European Commission could contribute to improving the sharing of information on procedures, best practices and advice by hosting a web portal with translations and comments on the most relevant documents from each country.
This portal could also be used to make available information prior to, and after, storms such as mapping the areas likely to be affected by predicted damaging storms and providing immediate damage assessments following storms.
It could also provide useful information for foreign companies who would like to harvest or buy the wood from the damaged areas, providing the following information in several languages:

- Contact points with their language skills,
- Translations of the national/regional regulation concerning: truck itineraries, wood transportation, infrastructures facilities, work regulation, customs regulations, etc.
- Training facilities.

An important request from post-storm management stakeholders is to have an overview of the market, prior to and after the event. Usually, commercial bodies in a region know the prices, volumes and capacities of the sector, but when exceptionally large amounts of wood are available, buyers from other countries or continents may also be interested in the opportunity to purchase timber. Thus international monitoring of prices would provide information needed to take the appropriate decisions after a storm. With such information, the type of products, the potential buyers, the offers, and the demand could be anticipated with more accuracy.

9.2.5 Facilitating Post-storm Procedures

Attendees at the 1st July Workshop in Brussels raised the following points:

- Some species can lie on the floor for long time periods, while others cannot without degradation and after few months their use for furniture and decoration is no longer possible. The losses in value can be very high so it is important to collect, store or transform them as soon as possible.
- Negotiation of an emergency plan with regional authorities can require many weeks or several months. This needs to be speeded up.
- Approval of national plans by the European Commission requires many months and needs to be quicker
- Setting up of new storage platforms requires a few months which is too slow.
- To harvest the timber with the best value you also often need to harvest timber with a lower value.
- Regulations on transport need to be suspended over short time periods (3, 6 or 12 months) in order to maximise timber movement from storm affected areas.
- Once the European Commission has validated a plan, there is no way to change it, without a delay of many months. These plans need to have built-in flexibility.
- One of the main aims of the European Community is to avoid bias in regulations applied to Member States. However, because prices are supposed to be only regulated by the market and they often fall after a storm, this threatens the sustainability of wood producers.

To answer these issues, we suggest that the European Commission could set up mechanisms to reduce the delays in harvesting damaged wood. This set of measures could include:

- Accelerated procedures for plan validation, as in most cases, each country takes similar measures following a storm. We imagine a two step validation from the European Commission, a first agreement in a few days, and a definitive validation with a more formal procedure as a second step.
- Predefined emergency measures for the wood sector. A list of measures that are commonly undertaken by countries after a storm (grants for storage, grants for cleaning, grant for transportation, etc.) should not require authorisation as soon as storm damages exceedes a certain designated level. A post-crisis evaluation could be done by the European Commission and if some measures were not part of the agreed list penalties could be imposed.
- Predefined derogations: for a very short period of 3, 6 or 9 months according to the storm damage, derogation of the transportation and working rules could be accepted to facilitate the mobilisation of high value wood that would otherwise become degraded.
- Simplified renegotiation procedures between the EC and Members States to facilitate adaptation of the plans
- A specific price regulation system should be authorized by Europe after large storms, according to the affected timber volumes.

9.2.6 Harmonizing the Monitoring of Damage across Europe

The suggested set of measures outlined above would introduce more flexibility in regulation and access to funds. But because the threshold to implement such measures will rely on the volumes of damaged timber, there is a need to set up a harmonised

procedure for monitoring forest damage. At the moment, Europe is able to provide the yearly area of burnt forest, and it is able to provide a percentage of trees affected by biotic diseases. However, timber volumes damaged by storms are only provided by states in an ad-hoc manner and without any standard procedure, which makes comparison difficult. Yet these data are key for policy makers to allow comparisons of the damage by different agents at a European level, and to initiate some of the procedures listed above following a catastrophic storm. Harmonised monitoring would also help to separate primary from secondary damage, and could also provide specific information for clearing and restoration of the forest.
Existing information platforms such as the European Forest Data Centre could be used and extended to include information on storms. The Joint Research Centre could be responsible for compiling the information and integrating it with the European Forest Data Centre.

9.2.7 Storm Compliant European Policies

Once a harmonised integrated monitoring tool is established, it will be possible to add additional conditions to promote forest stability in certain areas. These can be proposed by Member States that wish to use European funds for forest reconstitution, or for any supporting mechanism for reconstitution.

It will then also be possible to identify the most at risk areas and adapt European policies to the following constraints:

- Avoiding the development of high value timber production or high forest for protection (NATURA 2000, protected areas) in countries/regions exposed to high storm risk
- Supporting measures to improve stand stability in exposed areas
- Identifying areas/countries/regions exposed to storms where biomass production or short-rotation forestry might be a precautionary management option.
- Integrating storm risk in the European strategy of preservation of genetic resources
- Funding research on tree stability and appropriate forest management considering current and future climate, including storm damage risk mapping and mapping of damage following storms (see next section).

9.3 Research Gaps

The following areas are seen as being of high priority for future research:

- Understanding the interaction between different hazards (e.g. wind damage and bark beetles)
- Development of risk aware forest management
- Understanding risk perception in the forest sector
- Development of methods for standardising damage assessment for different forest hazards
- Quantifying the impacts of disturbance to forests including ecosystem services and protection
- Improved predictions of future risks to European forests under a changing climate

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11. Glossary

Acclimation	The morphological and/or physiological adaptation of an organism to changing environmental conditions.
Catastrophic damage	Damage to trees on a scale that causes wide-scale or long-lasting social, economic or ecological disruption.
Clear felling /Clear cut	Harvesting of all trees in a stand or area within a single operation.
Cyclone	An area of closed, circular air motion, characterized in the Northern Hemisphere by inward spiralling winds that rotate counter clockwise, centred on an area of low atmospheric pressure.
Deadwood	Non-living woody biomass (excluding the litter layer), either standing, on the ground or in the soil.
Disturbance	An event leading to interruption and derangement of normal activities.
Growing stock	The living tree component of the standing volume. Volume (m3) over bark (>7cm) of all living trees.
Gust wind speed	The highest wind speed measured over a 3 second period
Harvester	A type of heavy vehicle employed in cut-to-length harvesting operations. Typically used together with a forwarder that hauls timber to the roadside.
High forest	Forest stands, generally of seed or seedling origin, that normally develop a high closed canopy.
Induration	Compacted or hard layers in the soil profile that restrict downward root growth.
Iron pan	Soil in which iron compounds have been washed from the upper layers and deposited as a hard layer lower down. The layer can prevent root penetration unless it is broken mechanically.
Logging	The harvesting and removal of forest trees
Mounding	Cultivation of forest soil by machine, to make raised planting positions
Net biome production	The Net Ecosystem Production minus the carbon lost due to a disturbance, e.g. a forest fire or a forest harvest.
Primary damage	Direct damage to forest by wind
Reaction wood	Wood with distinctive anatomical and physical characteristics, formed typically in parts of leaning stems and in branches, that tends to restore the original position of the branch or stem when it has been disturbed; known as tension wood (in deciduous trees) and compression wood (in conifers)
Restocking	Regeneration of forest stands after harvesting or disturbance, by planting or natural regeneration.
Return period	An estimate of the average interval of time between events such as the occurrence of a defined wind speed

Rooting depth	The average depth reached by tree roots in a stand or forest area.
Rotation	The planned or actual time (years) between planting or regenerating a stand of trees and harvesting
Roundwood	All wood obtained from removals, both harvested and recovered from windthrow. Reported in m^3 volume under bark.
Secondary damage	Damage (not including primary damage) to trees or timber following a storm from biotic or abiotic agents
Severity index	An index of the severity of a storm, usually based wind speed, but also commonly including area and duration.
Shelterbelt	One or more rows of trees planted to provide shelter from the wind and to protect soil from erosion. They are commonly planted around the edges of fields on farms.
Stumpage	The price charged by a land owner to companies or operators for the right to harvest timber on that land.
Sustainable Forest Management (SFM)	The stewardship and use of forests in such a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfil, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems (MCPFE, 1993).
Tertiary damage	Damage to production, ecology, or social value as a result of storm damage, excluding primary and secondary damage, such as reduced forest productivity.
Thinning	Removal of trees from a forest stand, to improve growth of the remainder.
Understorey	The area of a forest which grows at the lowest height level below the forest canopy. Plants in the understory consist of a mixture of seedlings and saplings of canopy trees together with understorey shrubs and herbs.
Windblow	See “windthrow”
Windthrow	Trees uprooted or broken by wind