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Elmar Schwarzlmüller

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Institute of Social Ecology
IFF - Faculty for Interdisciplinary Studies (Klagenfurt, Graz, Vienna)
Klagenfurt University
Schottenfeldgasse 29
A-1070 Vienna
+43-(0)1-522 40 00-401
www.iff.ac.at/socec
iff.socec@uni-klu.ac.at

Human Appropriation of Net Primary Production (HANPP) in Spain, 1955-2003: a socio-ecological analysis

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Kurzfassung

Nettoprimärproduktion (NPP) ist die jährliche Menge an Energie, die von Pflanzen durch Photosynthese gebunden und in Form von Biomasse gespeichert wird, abzüglich des Anteils den die Pflanzen für ihren eigenen Stoffwechsel verbrauchen. Sie bildet die energetische Grundlage für alle Nahrungsketten.[1] Das Konzept der „menschlichen Aneignung von Nettoprimärproduktion", kurz HANPP (für *„Human Appropriation of Net Primary Production“*), wurde von Vitousek et al. (1986) eingeführt und misst das Ausmaß in dem die Verfügbarkeit von NPP in terrestrischen Ökosystemen durch menschliche Eingriffe verringert wird. Derzeit eignet sich die Menschheit auf globaler Ebene etwa ein knappes Viertel der potentiell verfügbaren NPP an (Haberl et al. 2007).

Die vorliegende Studie analysiert die Entwicklung der HANPP in Spanien im Zeitraum von 1955 bis 2003. Spanien hat eine Landesfläche von etwa 506.000 km^2 und ist das zweithöchst-gelegene Land Europas (durchschnittliche Seehöhe: 660m). Die klimatischen Bedingungen sind höchst unterschiedlich, mit ozeanischem Klima in den nördlichen Küstenregionen, ozeanisch-kontinentalem und mediterran-kontinentalem Klima im Bereich des zentralen Hochplateaus, mediterranem Klima in den südlichen und östlichen Küstenregionen und auf den Balearischen Inseln, subtropischem Klima auf den Kanarischen Inseln, und Gebirgsklima in den Höhenlagen. Während des untersuchten Zeitraumes kam es in Spanien zu einer rasch fortschreitenden Intensivierung der Landwirtschaft, welche einen deutlichen Anstieg der Erträge bei gleichzeitiger Reduzierung der Fläche bewirkte. Die Bevölkerung stieg von 29 Millionen im Jahr 1955 auf knapp 42 Millionen im Jahr 2003 an, wobei in den ländlichen Gebieten ein Bevölkerungsrückgang und in den urbanen Gebieten ein starker Bevölkerungsanstieg zu verzeichnen war. Die derzeitige Bevölkerungsdichte beträgt 88 Einwohner pro km^2. Bis 1975 war Spanien eine Militärdiktatur und ist seit 1978 eine konstitutionelle Monarchie. Seit 1986 ist Spanien Mitglied der Europäischen Union.

Die Aneignung von Nettoprimärproduktion durch den Menschen kann im Wesentlichen durch zwei Prozesse erfolgen: durch die Veränderung der Produktivität von Ökosystemen und durch die Entnahme oder Zerstörung von Biomasse. Produktivitätsveränderungen können durch Veränderungen der Landnutzung und Landbedeckung oder durch Bodendegradation

[1] Die Primärproduktion durch chemolithoautotrophe Organismen ist vergleichsweise gering und wird hier nicht weiter berücksichtigt.

verursacht werden. Die Entnahme oder Zerstörung von Biomasse umfasst geerntete Biomasse und während des Erntevorganges oder im Rahmen von anthropogen verursachten Feuern zerstörte, nicht gesellschaftlich genutzte Biomasse.

Zur Berechnung der HANPP ist es notwendig, die potentielle NPP (NPP_0; NPP ohne menschlichem Einfluss), die aktuelle NPP (NPP_{act}), sowie die Menge an jährlich entnommener Biomasse (NPP_h) zu ermitteln. Die HANPP kann als die Differenz zwischen der potentiellen NPP und der nach der Biomasseentnahme im Ökosystem verbleibenden NPP (NPP_t) errechnet werden:

$$HANPP = NPP_0 - NPP_t$$
$$NPP_t = NPP_{act} - NPP_h$$

Aufgrund der schlechten Datenlage zur unterirdischen NPP ist die vorliegende Studie ausschließlich auf die Untersuchung oberirdischer NPP-Flüsse beschränkt.

Für die Ermittlung der NPP_0 konnte auf bereits vorhandene Daten zurückgegriffen werden, welche mittels eines dynamischen globalen Vegetationsmodells (LPJ-DGVM; Sitch et al., 2003) ermittelt worden waren. Zur Ermittlung der NPP_{act} wurde ein Landnutzungsdatensatz in Form einer Zeitreihe erstellt und für jede Landnutzungskategorie die durchschnittliche NPP pro Fläche ermittelt (auf Basis von Literaturwerten oder Modellannahmen). Für die Erstellung des Landnutzungsdatensatzes wurden mehrere Quellen herangezogen, welche allerdings vor allem in Bezug auf die Größe der bewaldeten Flächen teils sehr widersprüchliche Informationen lieferten. Hauptsächlich wegen der besseren Vollständigkeit wurde schließlich zum Großteil der Landnutzungsdatensatz aus den Landwirtschaftlichen Statistischen Jahrbüchern Spaniens verwendet. Vor allem für die Zeit vor 1973 musste die Entwicklung einiger Landnutzungskategorien allerdings wegen mangelnder Konsistenz in den Originaldaten auf Basis von einfachen Modellannahmen rekonstruiert werden. Zur Berechnung der NPP_h wurden vor allem auf land- und forstwirtschaftliche Erntestatistiken zurückgegriffen. Im Rahmen einer umfangreichen Literaturrecherche wurden spezifische Faktoren zur Berechnung der Erntenebenprodukte ermittelt. Die durch Beweidung geerntete Biomasse wurde anhand einer Futterbilanzrechnung abgeschätzt. Anhand von Statistiken über verbrannte Flächen und Literaturdaten zur verbrannten Biomasse pro Fläche konnte eine plausible Abschätzung der durch anthropogen verursachte Feuer zerstörten Biomasse erstellt werden.

Die Ergebnisse der Studie zeigen eine Abnahme der HANPP von 67% im Jahr 1955 auf 61% im Jahr 2003. Dies bedeutet, dass die durchschnittliche Menge der in den Ökosystemen verbleibenden NPP pro Hektar Landfläche in diesem Zeitraum um 19% (0,3 t/ha/a) zugenommen hat. Während die Aneignung von NPP 1955 noch großteils auf anthropogen verursachte Produktivitätsveränderungen zurückzuführen war, stieg die Bedeutung der Aneignung durch Biomasseentnahme kontinuierlich an und machte 2003 bereits fast ⅔ der gesamten HANPP aus. Offensichtlich war es durch eine erhöhte Produktivität möglich die gesellschaftliche Biomasseentnahme vehement zu steigern, ohne dadurch die Menge der im Ökosystem verbleibenden NPP zu verringern. Gemessen in Pro-Kopf-Werten zeigt die HANPP eine noch viel deutlichere Abnahme, und zwar um 36% (von 6,4 t/cap/a auf 4,5 t/cap/a). Die Pro-Kopf-Entnahme von Biomasse stieg geringfügig an, von 2,3 t/cap/a im Jahr 1955 auf 2,5 t/cap/a im Jahr 2003 (Minimum 1981: 2,0 t/cap/a; Maximum 2000: 2,8 t/cap/a).

Die NPP der aktuellen Vegetation stieg im Verlauf des Untersuchungszeitraumes um 33% an. Lediglich während einzelner Dürreperioden (vor allem in den frühen 80er und 90er Jahren) kam es zu leichten Einbrüchen in der NPP_{act}. Während die NPP_{act} im Jahr 1955 nur 58% der potentiellen NPP ausmachte, erhöhte sich dieser Wert bis 2003 auf 77% der NPP_0. Vor allem am Ackerland (Anbauflächen (mit Feldfrüchten oder Dauerkulturen) und Brachflächen) konnte durch die Intensivierung der Landwirtschaft ein enormer Produktivitätsanstieg erreicht werden. Auf den mit Feldfrüchten bebauten Flächen erreichte die NPP_{act} im Jahr 2000 bereits 6,7 t/ha/a, ein Wert der deutlich über der durchschnittlichen NPP_0 Spaniens (5,6 t/ha/a) und sogar über der NPP_0 der derzeitigen Waldflächen (6,4 t/ha/a) liegt. Die Intensivierung der Landwirtschaft führte zu einer Halbierung der Brachflächen und dadurch zu einer deutlichen Flächenreduktion des gesamten Ackerlandes. Die bewaldete Fläche nahm hingegen zu, was aufgrund der hohen Produktivität dieser Flächen eine weitere wesentliche Ursache für den starken Anstieg der gesamten NPP_{act} darstellt.

Die Biomasseentnahme stieg während des untersuchten Zeitraumes um 56% an. Diese deutliche Steigerung ist fast ausschließlich auf eine Zunahme der Ernte am Ackerland zurückzuführen. Diese machte (inklusive der Erntenebenprodukte) gegen Ende der Zeitreihe bereits etwa ⅔ der gesamten Biomasseentnahme aus.

Trotz des rückläufigen Trends beträgt die HANPP zum Ende der Zeitreihe noch immer 61%. Dies bedeutet, dass die Menge der in den Ökosystemen verbleibenden, und damit für andere

Arten verfügbaren NPP durch den menschlichen Einfluss um mehr als die Hälfte reduziert ist. Die HANPP in Spanien liegt deutlich über dem globalen Durchschnitt (28,8% oberirdische HANPP (Haberl et al., 2007; Erb, persönliche Mitteilung, 2007)) und über den Ergebnissen für andere europäische Länder oder Regionen. Besonders auffallend ist dabei das verhältnismäßig hohe Ausmaß an anthropogen verursachtem Produktivitätsverlust. Eine wesentliche Ursache hierfür ist sicherlich die großflächige Entwaldung Spaniens (durch Rodungen zur Gewinnung von Acker- und Weideland, großflächige Holzschlägerungen (z.B. zum Schiffsbau), Übernutzung durch Brennholzentnahme oder Beweidung, etc.). Während Spanien ursprünglich zum Großteil mit Wald bedeckt war, war die Waldfläche zur Mitte des 20. Jahrhunderts bereits auf etwa 20% der Landesfläche reduziert. Wenn auch die Waldfläche seither wieder zugenommen hat (durch Aufforstungen und durch die Aufgabe traditioneller Nutzungen (extensive Landwirtschaft, Beweidung, Brennholzentnahme) in vielen ländlichen Gebieten), so konnte doch der Produktivitätsverlust durch jahrhundertelange Entwaldung in dieser kurzen Zeit nicht vollständig wettgemacht werden. Die verringerte Produktivität ist neben der Entwaldung auch auf in Spanien teils gravierende, anthropogen verursachte Probleme wie Bodenerosion, Bodenversalzung oder Überbeweidung zurückzuführen.

Die große Steigerung der Biomasseentnahme ist fast ausschließlich auf eine Steigerung der Ernte am Ackerland zurückzuführen, welche nur durch eine Intensivierung der Landwirtschaft möglich wurde. Wenn die Ernte gegen Ende der Zeitreihe mit der Produktivität der Kulturflächen (Anbauflächen und Brachflächen) zu Beginn der Zeitreihe erzielt werden müsste, würde man dafür eine hypothetische Fläche von der Größe des gesamten Landes benötigen. Die Produktivitätssteigerung wurde im Wesentlichen durch den massiven Einsatz externer Energieinputs (vor allem Fossilenergie) ermöglicht (in Form von Kunstdünger, Pestiziden, Herbiziden, Maschinen, Bewässerung, etc.). Da eine höhere Produktivität der Anbauflächen üblicherweise mit einer entsprechenden Steigerung der Biomasseentnahme verbunden ist, ändert sich dadurch die HANPP pro Flächeneinheit auf den Anbauflächen kaum. Die landwirtschaftliche Intensivierung Spaniens wirkt sich jedoch über die damit verbundenen Landnutzungsveränderungen (Reduzierung der Ackerlandfläche) auf die Entwicklung der HANPP aus.

Zur Entwicklung der Biomasseentnahme ist anzumerken, dass hierbei nur die in Spanien entnommene Biomasse berücksichtigt wurde. Vergleicht man die Mengen an Biomasseimporten und –exporten, so wird deutlich, dass Spanien ein Nettoimporteur von

Biomasse ist, und dass sich die Nettoimporte seit den frühen 60er Jahren etwa verzehnfacht haben. In Geldeinheiten betrachtet übersteigen hingegen die Exporte die Importe ab Mitte der 90er Jahre. Die sinkende HANPP ist daher auch im Kontext einer zunehmenden Auslagerung der Biomasseentnahme in andere Länder zu sehen.

Die wesentlichen Prozesse, die die Entwicklung der HANPP im untersuchten Zeitraum geprägt haben, lassen sich folgendermaßen zusammenfassen: Im Zuge der Industrialisierung kam es zu Veränderungen der Landnutzung, von welchen vor allem der Rückgang der Ackerfläche (mit sehr hoher HANPP pro Flächeneinheit) und die Ausweitung der Waldfläche (mit vergleichsweise geringer HANPP pro Flächeneinheit) hervorzuheben sind. Auch die Ausweitung des Gras- und Buschlandes, in Kombination mit dem Produktivitätsanstieg am Grasland und der verringerten Biomasseentnahme am Buschland (vor allem starker Rückgang der Brennholzentnahme), haben zum abnehmenden Trend der HANPP beigetragen. Andere Landnutzungsveränderungen, wie etwa die deutliche Zunahme der verbauten Fläche hatten geringere Auswirkungen auf die Entwicklung der HANPP. Der starke Anstieg der Biomasseentnahme wurde durch einen noch stärkeren Anstieg der NPP der aktuellen Vegetation (beides vor allem auf den landwirtschaftlichen Anbauflächen) mehr als ausgeglichen.

Bei der Betrachtung der sinkenden HANPP sollten auch die „Kosten“ dieser Entwicklung nicht unerwähnt bleiben. So ist es zum Beispiel unbestritten, dass die landwirtschaftliche Intensivierung teilweise gravierende Umweltprobleme verursacht hat, wie etwa die Verschmutzung von Boden, Wasser und Luft, Bodenerosion, Bodenversalzung oder die Erschöpfung von Wasserressourcen. Klarerweise ist in diesem Zusammenhang auch die Problematik der Fossilenergienutzung zu nennen, welche bekanntermaßen die wesentliche Ursache des Klimawandels darstellt. Abgesehen von den dramatischen Auswirkungen des CO_2-Ausstoßes ist die Nutzung der Fossilenergie bereits per definitionem nicht nachhaltig, da es sich dabei um den Verbrauch nicht-erneuerbarer Ressourcen handelt. Der Fossilenergieverbrauch Spaniens wurde während des untersuchten Zeitraumes massiv gesteigert, was vor allem in Zusammenhang mit der Intensivierung der Landwirtschaft als eine wesentliche Ursache für den Rückgang der HANPP zu sehen ist.

Der starke Anstieg der Biomasseentnahme wurde in erster Linie durch eine deutlich erhöhte Produktivität des Ackerlandes ermöglicht. Diese Produktivitätssteigerung ist jedoch nicht unbegrenzt fortsetzbar (z.B. aufgrund von pflanzenphysiologischen Einschränkungen, Grenzen des Ertragszuwachses durch Düngung, limitierten Wasserressourcen, etc.). Es ist daher fraglich, in welchem Ausmaß eine weitere Steigerung der Biomasseentnahme möglich ist, ohne dass dies zu einem Anstieg der HANPP führen würde. Ein Rückgang der Nachfrage nach Biomasse erscheint allerdings zurzeit eher unwahrscheinlich. Sollte Biomasse in Zukunft vermehrt als Ersatz für fossile Energieträger Verwendung finden, so wäre möglicherweise sogar mit einem noch deutlicheren Anstieg des Biomasseverbrauchs zu rechnen. Es besteht zwar die Möglichkeit, den Biomassekonsum vermehrt durch Importe abzudecken, und so den Anstieg der Biomasseentnahme im eigenen Land zu begrenzen, auf lange Sicht wird es aber unumgänglich sein, die Effizienz der Biomassenutzung zu erhöhen. Diesbezüglich sollte zum Beispiel der starke Anstieg und die Förderung der Fleischproduktion Spaniens in den letzten Jahrzehnten hinterfragt werden, da bei der Produktion tierischer Biomasse ein Vielfaches an pflanzlicher Biomasse verbraucht wird. Im Hinblick auf den Erhalt des produktiven Potentials der Ökosysteme werden große Anstrengungen notwendig sein, um dem in Spanien teils schwerwiegenden Problem der Bodendegradation entgegenzuwirken. Dies wird noch deutlicher in Anbetracht der relativ hohen HANPP Spaniens und des im Vergleich zu anderen Industriestaaten nach wie vor großen anthropogen verursachten Produktivitätsverlustes.

Human Appropriation of Net Primary Production in Spain, 1955-2003

Abstract

Human Appropriation of Net Primary Production (HANPP) assesses human domination of ecosystems by measuring to which extent human activities reduce the amount of biomass available each year in ecosystems. This paper analyses the development of aboveground HANPP in Spain for the period from 1955 to 2003. During this period, Spain's agriculture underwent a transition from a largely pre-industrial to a highly intensified production system. Changes in land use patterns include a reduction of cropland area and an expansion of forest area. Results show that HANPP declined from 67% of potential NPP in 1955 to 61% in 2003. Biomass harvest strongly increased from 68 Mt/yr (million tons dry matter biomass per year) to 106 Mt/yr, with nearly all of this increase occurring on cropland. Productivity losses due to human-induced land conversions were reduced significantly from 117 Mt/yr to 63 Mt/yr, mainly as a result of the surge in cropland productivity and the increase in forest area. Despite its decrease during the last decades, HANPP in Spain still lies at a remarkably high level in comparison with the global average or other industrialized countries.

Key words: Human Appropriation of Net Primary Production (HANPP), Land use change, Biophysical indicators, Human impact, physical economy, Spain

Introduction

Human Appropriation of Net Primary Production, commonly abbreviated as HANPP, has been developed as a measure for the human domination of terrestrial ecosystems (Vitousek et al., 1986; Haberl, 1997; Haberl et al., 2004a). Net Primary Production (NPP) is the net amount of biomass produced by autotrophic organisms (green plants) over a defined period of time (mostly a year), and forms the main nutritional basis for all food chains. HANPP measures the extent to which humans reduce the amount of NPP available for other species. It indicates the impact of socioeconomic activities on fundamental ecosystem functions (Wright, 1990; Daily et al., 1997; Haberl, 1997; Field, 2001; DeFries, 2002; Wackernagel et al., 2002; Haberl et al., 2004b; Gerten et al., 2005).

Conventional economic analyses, following a "chrematistic" approach and mainly accounting in monetary terms, have failed in sufficiently integrating the environmental impacts of economic activities (Martínez Alier, 1987). In the past decades, several methods have been developed to describe the economy using a biophysical approach, with the objective of improving the ability to adequately tackle sustainability problems. By analysing socio-economic biomass flows, HANPP describes an important aspect of the physical economy and of its impacts on ecosystem functions. It constitutes an extension of the methodological framework that has been developed to analyse the physical dimensions of economic processes (Daniels and Moore 2002; Daniels 2002).

In recent years, a number of studies have been carried out to analyse Spain's physical economy, as well as its development over time (e.g. Simón Fernández, 1999; Arto Olaizola, 2003; Cañellas et al., 2004; Carpintero, 2005 Cussó et al., 2005). The detailed study by Carpintero (2005) showed the dramatic changes in Spain's social metabolism covering the period from 1955 to 2000, during which the total material requirement of the Spanish economy increased more than fivefold and the area of Spain’s total ecological footprint more than threefold.

With this study I would like to contribute to the achievements that have been made in quantifying the biophysical dimensions of society-nature-interactions in Spain, by presenting the first detailed assessment of HANPP in Spain on a national level. The aim of the study is not only to quantify the magnitude of HANPP, but also to deepen the understanding of how patterns of HANPP have evolved over time in the context of socioeconomic change. What are the main pathways through which appropriation of NPP occurs? To which extent do the different changes in land use patterns contribute to the development of HANPP? What conclusions can be drawn for future developments?

This study covers the period from 1955 to 2003. During this time, the Spanish agricultural sector underwent significant changes towards a highly industrialized intensive agricultural production system (Naredo, 2004). Population has increased by more than 40% despite a rapid depopulation of rural areas. The political system changed from a dictatorship (until 1975) to a constitutional monarchy (since 1978). In 1986 Spain joined the European Community (now EU).

Materials and Methods

Definition of HANPP

In this study I use the same definition of HANPP as Haberl et al. (2007), except that the biomass destroyed in human-induced fires is included in biomass harvest, whereas Haberl et al. treat it as a separate pathway of NPP appropriation. Due to limited availability and reliability of data on belowground NPP, my calculations are restricted to aboveground NPP flows. The unit for NPP used in this study is tons dry matter per year (t DM/yr). HANPP is given in t DM or as percent of the NPP of the potential vegetation (NPP_0). NPP can be appropriated through two pathways: through changes in productivity of ecosystems, caused by human-induced land conversions such as land use change, land cover change or soil degradation (ΔNPP_{LC}), and through the harvest of biomass (NPP_h). HANPP is defined as the difference between NPP_0 and the amount of NPP remaining in ecosystems after harvest (NPP_t). NPP_t can be calculated as the difference between the NPP of the actual vegetation (NPP_{act}) and NPP_h. HANPP can therefore be calculated by assessing NPP_0, NPP_{act} and NPP_h, as $NPP_0 - (NPP_{act} - NPP_h)$.

Description of the Study Area

Mainland Spain is situated in South-western Europe where it covers more than 85% of the Iberian Peninsula. The country of Spain also includes the Canary Islands in the Atlantic Ocean, the Balearic Islands and some other small islands in the Mediterranean Sea, as well as two small enclaves in North Africa and one in France. The total country area is about 506,000 km^2. The average population density is 88 people per km^2, with strong regional differences (densely populated areas in the coastal regions and in the region of Madrid). Spain is the second highest-lying country in Europe, with an average elevation of 660 m. Its topography is dominated by the large central plateau, which is surrounded by mountain ranges. There are a wide range of prevailing climatic conditions, with oceanic climate in the northern coastal regions, oceanic-continental and continental-mediterranean climate in the region of the central plateau, mediterranean climate in the eastern and southern coastal regions and on the Balearic Islands, subtropical climate on the Canary Islands, and mountain climates. Spatial differences in annual mean temperature surpass 18°C, and average annual precipitation ranges from barely 150 mm/yr to over 2,500 mm/yr (de Castro et al., 2005).

Land use data

To study HANPP in a historical context, it is crucial to be able to understand and quantify land use patterns that occurred throughout the observed time period. Unfortunately there are substantial discrepancies between the different data sources on land use in Spain. Apart from matters of data quality, this is mainly due to strongly differing classifications. For this reason, and because of rather imprecise definitions of categories in some cases, the different data sets are hardly comparable. For a better understanding of land use changes in the 20th century, a detailed revision of the different sources would be urgently needed.

Yearly data on the distribution of different land uses relating to the total country area are documented within the Spanish Agricultural and Food Statistics Year Book (MAPA, 1999-2006) and its predecessors (Ministerio de Agricultura, 1929-1972 and 1974-1980; MAPA, 1981-1997) as from 1955. I denominate data from this source as “MAPA land use data”. Between 1955 and 1973, classifications of land use categories were changed repeatedly. Since 1973, consistent classifications have been used. The relation of many of the categories used nowadays to those used before 1973 is not clear. Other well accepted sources for land use changes in Spain are the land use maps of 1960 and 1985, compiled by the Ministry of Agriculture, as well as the National Forest Inventories (as a source for forest area) (ICONA, 1979 and 1980; Ministerio de Medio Ambiente, 1998). Both sources have the disadvantages that they are only available for two points in time each within the studied time period, and that classification concepts have changed over time as well. For the purpose of this study, the data given in the MAPA land use data set have the advantage of temporal and spatial consistency, at least from 1973 onwards. They were therefore also taken as reference for the area of forest and shrubland, although the forest inventory data are a more widely accepted source for these areas. In the MAPA data set areas dominated by stunted trees with vegetative reproduction through sprouts from stumps or roots are not included in the forest area but in the area of shrublands. This explains why the forest area given in the MAPA data set is smaller than in the forest inventories.

The land use data set compiled for this study (Figure 1) consists of 13 categories that have been aggregated to five main land use types. Sources and assumptions used for each land use category are summarized in Table 1.

Table 1: Land use data set, main sources and assumptions.

land use type	land use category	Main sources and assumptions 1955-1972	1973-2003
cropland	annual crops	MAPA land use data *	MAPA land use data
	permanent crops		
	fallow		
forest	closed forest	difference between total area and area of all other categories; assuming that the proportions of the categories within this area followed the same trend as from the mid 1970s to the mid 1990s.	
	open forest		
shrubland	shrubland		
grassland	dry pastures		
	extensively grazed abandoned land		
	meadows	MAPA land use data	
	Esparto grassland **		
other land	inland water	constant value of 1973	
	built-up land	built-up land model from Haberl et al. (2007) ***	
	other areas	constant value of 1973	difference between total area and area of all other categories

* For the period 1955-70 the area of annual crops was adjusted by assuming the same ratio of land use area to area harvested as in 1971. The original data suggest a smaller area in this period, a trend which can not be observed in statistics on harvested area. As classifications of land use data were changed in 1971 this is likely to be rather a change in statistics than a real change in area. This assumption is supported by the data on the change of total cropland area according to the land use maps of 1960 and 1985.
** Areas dominated by the perennial grass *Stipa tenacissima L.* (Esparto), traditionally used for the production of fibre and paper
*** The estimation of built-up land is based on information on per capita area demand, population density and development status. Population Data were taken from Nicolau (2005) for the period 1955-1990, and from Instituto Nacional de Estadística (2006) for 1991-2003.

Sources and assumptions are described in more detail in Annex A.

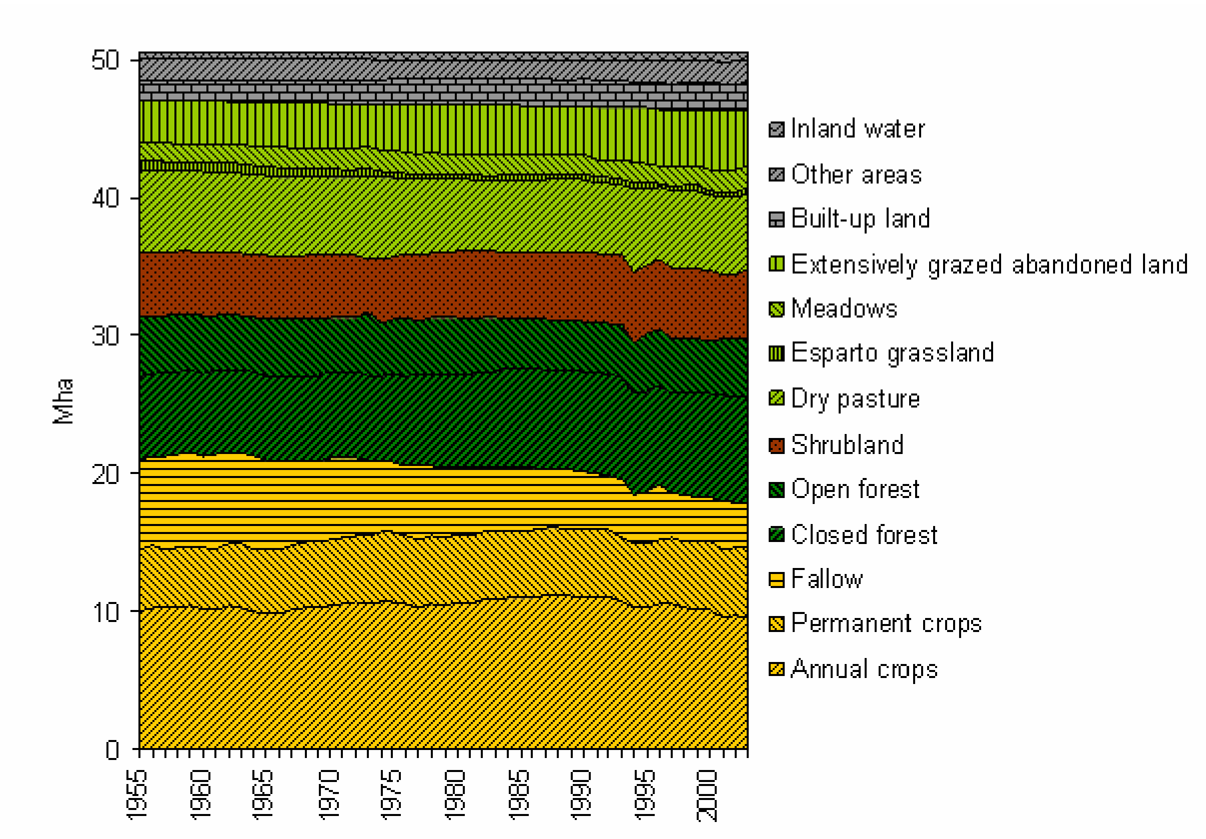

Figure 1: Development of land use in Spain, 1955-2003.
(stacked area chart)
Sources: see text.

NPP of the potential vegetation (NPP0)

NPP_0 data were taken from the work of Haberl et al. (2007) who used the Lund-Potsdam-Jena (LPJ) Dynamic Global Vegetation Model (Sitch et al., 2003) with an improved representation of hydrology (Gerten et al., 2004) for their calculations (Erb pers. comm., 2007). Data on NPP_0 were only available for the year 2000 (respectively the average of 1998-2002), and were for this reason kept constant throughout the time series. It has to be mentioned, however, that NPP_0 can vary significantly within individual years. Especially the high interannual variance of climatic conditions (particularly in precipitation) in the studied area would suggest fluctuations in NPP_0. Also the effect of changes in atmospheric carbon dioxide concentration on NPP_0 has been neglected in this study.

NPP of the actual vegetation (NPPact)

Spain has a huge diversity of vegetation types, climatic and topographic conditions. There is a wide range of aboveground productivity, with areas of highly productive forests in the north and semi-deserts in the southeast of mainland Spain. Studies on NPP in Spain are scarce, especially for non-forest areas. Using additional NPP studies from other regions with comparable climatic conditions provided a useful basis for assessing NPP_{act} of different vegetation types. As values found in the literature have a considerable variation, low and high estimates of NPP_{act} for forest, shrubland, the main grassland categories and fallow were derived, using the average value of those estimates as a "best guess". The main sources and assumptions are summarized in Table 2.

Table 2: NPP_{act}, main sources and assumptions.

land use type	land use category	NPP_{act} * [t/ha/yr]	Main sources and assumptions
cropland	annual crops	variable	see text
	permanent crops	variable	see text
	fallow	0.6 (0.4; 0.8)	Le Houerou, 1977
forest	closed forest	6.4	NPP_0 of areas currently covered by forest (Haberl et al., 2001; Haberl et al., 2007; Erb pers. comm., 2007)
	open forest	variable (6.4; variable)	high estimate: NPP_0 of areas currently covered by forest low estimate: average value of grassland and closed forest
shrubland	shrubland	4.5 (2.8; 6.2)	Rambal, 2001; Merino and Vicente, 1981; Navarro, 2004; Martínez Fernandez et al., 1994; Ibañez et al., 1999
grassland	dry pastures	2.7 (1.5; 3.8)	Le Houerou and Hoste, 1977; Biddiscombe, 1987; Olea et al., 1991; Gomez Gutierrez et al., 1980
	extensively grazed abandoned land	1.6 (1.0; 2.3)	average value of fallow and dry pastures
	meadows	variable	irrigated: NPP_{act} of areas sown with grasses and legumes for fodder non-irrigated: high estimate: NPP_{act} of areas sown with grasses and legumes for fodder; low estimate: high estimate of NPP_{act} on dry pastures
	Esparto grassland	3.1	Puigdefábregas et al., 1997, cited by Puigdefábregas and Mendizabal, 1998
other land	inland water	0	(only terrestrial NPP considered)
	built-up land	2.3	⅔ sealed, ⅓ carrying vegetation with NPP_{act} = NPP_0 with unlimited water supply (Haberl et al., 2007; Erb pers. comm., 2007)
	other areas	2.3	½ unproductive, ½ NPP_{act} of shrublands

* Values in brackets give the low respectively high estimates for NPP_{act}.
Sources and assumptions are described in more detail in Annex A.

NPP_{act} on cropland in production consists of harvested NPP, NPP of weeds and NPP losses before harvesting (e.g. through herbivory). NPP losses and NPP of weeds are not accounted for in agricultural statistics. On the basis of Oerke (1994) and Haberl et al. (2007) this part of NPP_{act} was estimated as 23% of NPP_h in 1955 and as 14% from 1980 onwards, assuming a linear development of this percentage between 1955 and 1980. The difference between the land use area of permanent crops and the area of permanent crops harvested was considered as permanent cultures not yet producing. NPP_{act} on these areas was assumed to equal the average NPP_{act} of permanent cultures already in production.

Harvested NPP (NPPh)

NPP_h on cropland consists of primary crop harvest and of harvested, grazed and unrecovered crop residues. The rationale of including unrecovered residues in NPP_h is that they are usually either ploughed in or burned on site. Data on primary crop harvest were taken from the Spanish Agricultural Year Books, and were converted to dry matter using crop specific data on water content from the literature (for references see Annex A, 2007). For reasons of consistency with previous studies (Haberl, 1997; Haberl et al., 2001; Krausmann, 2001) I also accounted for crop harvest of roots and tubers. Crop residues were calculated using crop-specific or crop-aggregate-specific harvest indices (HI) from the literature (for references see Annex A, 2007). The harvest index is the ratio of crop harvest to the total aboveground biomass of this crop (Evans, 1993). In the case of permanent crops, I applied this term to the ratio of crop harvest to the total annual aboveground increment of this crop. Harvest indices of many crops have changed over time, as a result of plant breeding, which aims to increase the proportion of crop biomass to total aboveground biomass. The HI of wheat for example increased from 0.37 to 0.55 during the examined time period, which means that the same amount of biomass growing on the field would yield 50% more wheat than in 1955. For those annual crops, where no information on HI was available (less than 3% of the total cropped area accounting for less than 6% of primary crop production throughout the timeseries), NPP_h per unit area was estimated to equal NPP_h on the area of all other annual crops, or at least 125% of primary crop harvest, as HI values were assumed not to exceed 0.8 (Smil, 2000). For areas of permanent cultures not yet producing I assume that, apart from NPP of weeds and NPP losses before harvest, 50% of NPP_{act} remain within the ecosystem (as growing stock) and 50% are harvested through cultivation practices (e.g. pruning). Data on harvested residues were taken from Spanish agricultural statistics (straw harvest), or were calculated by multiplying the amount of residues with specific recovery rates from literature (for references see Annex A).

The amount of annually grazed biomass was calculated as the difference between feed demand and feed supply. Feed demand of pigs and poultry was calculated using efficiency factors (i.e. required feed intake per unit of product output). To consider improvements in feed efficiency, I assume that in 1955 feed intake per unit of product output was 50% higher than at the end of the time series, and that feed efficiency has increased linearly. Feed demand of cattle was calculated for each year based on average carcass weights. For all other livestock species, estimates on average daily feed intake were applied. All factors for the calculation of feed demand were taken from Haberl et al. (2007). Data on animal stocks and production were taken from FAO (2006), Ministerio de Agricultura (1963-1973) and Barciela et al. (2005). Table 3 gives values of feed demand per head and day for selected years.

Table 3: Species specific feed demand [kg DM/head/day] for selected years.

	1955	1965	1975	1985	1995	2003
Cattle	6.0	7.4	9.8	9.7	11.0	11.0
Sheep	1.5	1.5	1.5	1.5	1.5	1.5
Goats	1.5	1.5	1.5	1.5	1.5	1.5
Pigs	0.5	1.0	1.1	1.6	1.3	1.5
Poultry	0.10	0.16	0.13	0.12	0.11	0.12
Horses	10.0	10.0	10.0	10.0	10.0	10.0
Asses	6.0	6.0	6.0	6.0	6.0	6.0
Mules	6.0	6.0	6.0	6.0	6.0	6.0
Rabbits	0.1	0.1	0.1	0.1	0.1	0.1

Sources: Haberl et al. (2007); own calculations, see text.

Feed supply consists of market feed, fodder crops, crop residues and hay harvest on meadows. Market feed consists of feed from primary crops and processed feedstuff, and was taken from FAO (2006). For 1955-60 market feed was estimated assuming the same average yearly increase as during the period 1961-70. Fodder crop harvest was taken from Spanish agricultural statistics. The amount of crop residues used as feed was estimated at 15% of all recovered crop residues, which is slightly higher than the estimates of Wirsenius (2000) for industrial regions or that of Haberl et al. (2007) for Western Europe, as the share of crop by-products used as feed is supposedly higher in the Mediterranean regions than in Northern and Western European countries (Orskov, 1992). To consider the state of industrialization, a higher share (25%) was assumed at the beginning of the time series and was interpolated linearly between 1955 and 1980, from where on the value of 15% was applied. Hay harvest on meadows is reported in Spanish agricultural statistics. For years where data were not available, harvest per unit area was assumed to be constant. Data were converted to dry matter using values on water content taken from Löhr (1990). Total harvest through grazing was assigned to different land use categories using the following assumptions: 20% of NPP_{act} on fallow were supposed to be consumed through livestock grazing, as well as 10% of the NPP remaining on the field after harvest on the areas of cereals, pulses, and grasses and legumes for fodder. On meadows, total harvest (hay harvest and grazing) was assumed to account for ⅔ of NPP_{act}. The remaining part of harvest through livestock grazing was assigned to other grassland, shrubland and forest categories in the same proportions as the total weight of grazing animals per year was distributed amongst them. Estimates on this are given in the Spanish agricultural statistics since 1973. Before 1973 proportions of the different amounts of grazed biomass per unit area and year between these land use categories were assumed to remain constant at the average of the years from 1973 to 1982.

Forestry harvest includes harvest of wood, cork and resin. In the case of wood and cork this is the harvest of NPP accumulated over several years. This has been discussed as a problem in HANPP definitions (Haberl et al., 2004a; Krausmann, 2001), as it could result in negative NPP_t values in the case of stock-depleting destructive forestry harvest. This is however not the case for Spain within the observed time period, where the forest area has steadily increased, and large areas have been subject to afforestation since 1940. Wood harvest consists of removals of roundwood and wood fuel and of felling losses. Data on removals were taken from the Spanish Forestry Statistics Year Books and the Spanish Agricultural Statistics and were converted to dry matter using wood density values of 41% for coniferous and 58% for non-coniferous wood (derived from Penman et al., 2003). Data on wood fuel removals are given in stacked cubic metres and were converted to solid cubic metres using a factor of 0.7 (FAO, 1986; ÖSTAT, 1992). Wood fuel harvest in 1955 was estimated on the basis of per capita harvest in 1956, as statistics do not include the harvest of gorse *(Ulex europaeus L.)* until 1956, which made up a considerable part of wood fuel harvest. Up to 1972 statistics include wood fuel used for livestock bedding. From 1961-73 official data include an estimate of wood fuel considered as “unclassified or from outside the forest”, which was not accounted for in this study, as it could not be ruled out that this category also includes agricultural residues. Felling losses consist of all aboveground components of felled trees that are not removed from the felling site (including silvicultural and pre-commercial thinnings and cleanings). Based on the country-specific estimates of felling residues presented by Karjalainen et al. (2004), a recovery rate (i.e. the share of removed wood on total fellings) of 71% was applied to calculate felling losses. All roundwood harvest was supposed to take place in forest, while 50% of the wood fuel harvest was assigned to shrubland. Production data for cork and resin were taken from Spanish Agricultural Statistics and Barciela et al. (2005) and converted to dry matter with water contents taken from Scharnow (2007).

The amount of aboveground biomass burned in human-induced fires is accounted as part of NPP_h in this study. All fires in Spain except those caused by lightning can be considered as human-induced (Prieto, 1990). Data on burned areas were taken from Ministerio de Medio Ambiente (2006). Due to the absence of data on burned areas from 1955-60, the amount of biomass burned each year was estimated as the average value of burned biomass in the 1960s for that period. The share of the area burned through human-induced fires on the total burned area was estimated separately for forest areas and non-forest areas on the basis of the detailed data for the period 1995-2005 presented in Ministerio de Medio Ambiente (2006). The same data were used to estimate the share of shrubland and grassland on burned non-forest area. The burned biomass was calculated by multiplying the burned area with the average aboveground biomass per area and the burning efficiency (i.e. the share of the aboveground biomass that gets burned). For the average aboveground biomass of forests a value of 61.2 t/ha, taken from the Ecological and Forest Inventory of Catalonia (CREAF, 2004), was applied. The average aboveground biomass of shrublands was estimated at 22.3 t/ha (mean of all values from the sources that were also used for the estimation of NPP_{act}). Aboveground biomass of grasslands was allocated a value of 2.5 t/ha (Saugier et al., 2001). Burning efficiencies were estimated on the basis of Michel et al. (2005), IPCC (2006) and Seiler and Crutzen (1980) as 25% for forest, 70% for shrubland, and 90% for grassland.

Other harvest includes harvest on built-up land and harvest of Esparto. Harvest on built-up land takes place through gardening, park and infrastructure maintenance, etc. and is estimated to be 50% of NPP_{act} (Haberl et al., 2007). Data on the harvest of Esparto (*Stipa tenacissima L.*) leaves for fibre production and paper making were taken from Barciela et al. (2005) and Spanish agricultural statistics and were converted to dry matter assuming a water content of 10% (Scharnow, 2007).

I consider all unrecovered crop residues and felling losses, as well as livestock feces dropped on the grazing site as backflows to nature. The latter are calculated based on the assumptions that cattle excrete 35% and all other grazers 25% of dry matter feed intake, and that two thirds of the excrements are dropped on the grazing site (Haberl et al., 2007).

Results

In the following section only the results derived by using the best guess for NPP_{act} are presented and discussed in detail. The results of calculations using the low and high estimates of NPP_{act} are presented in Table 4.

According to the calculations of Haberl et al. (2007) aboveground productivity of the potential vegetation in Spain is 277.1 Mt/yr (Erb 2007 pers. comm.), which equals an average value of 5.6 t/ha/yr. NPP_0 shows high spatial differences. A gradient from the highly productive Atlantic coastal regions in the north and north-west to the semiarid regions with little productivity in the south-east can be observed. Whereas productivity values for the Balearic Islands lie well in the middle of this range of NPP_0, they are lower for the Canary Islands.

Human appropriation of NPP decreased from 67% to 61% within the observed period (Figure 2, Table 4). The main pathways, through which NPP was appropriated, have changed significantly. Whereas in 1955 NPP was mainly appropriated through productivity losses due to human-induced land conversions (63% of total HANPP), appropriation through biomass harvest has steadily gained importance and made up 63% of total HANPP in 2003. Apparently, as a result of a rise in productivity, it was possible to strongly increase societal biomass harvest without reducing the amount of NPP remaining in ecosystems.

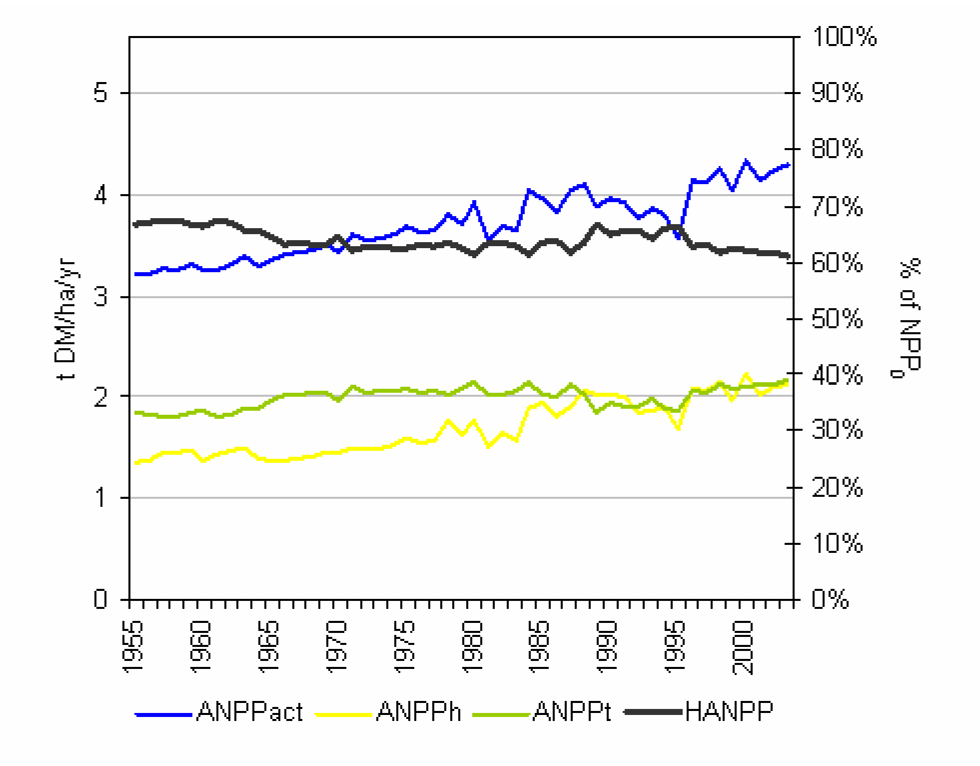

Figure 2: Development of HANPP, NPP of the actual vegetation, harvested NPP, and NPP remaining in ecosystems.
Sources: own calculations, see text.

Table 4: Development of HANPP, NPP_{act}, NPP_h and ΔNPP_{LC}.

	HANPP *	HANPP/cap *	NPP_{act} *	NPP_h	NPP_h/cap	ΔNPP_{LC} *
Unit	[% of NPP_0]	[t DM/cap/yr]	[Mt DM/yr]	[Mt DM/yr]	[t DM/cap/yr]	[% of NPP_0]
1955	67% ± 9%	6.4 ± 0.8	160 ± 24	68	2.3	42% ± 9%
1960	67% ± 9%	6.1 ± 0.8	164 ± 24	72	2.4	41% ± 9%
1965	65% ± 9%	5.6 ± 0.8	169 ± 24	70	2.2	39% ± 9%
1970	63% ± 9%	5.2 ± 0.7	175 ± 24	73	2.2	37% ± 9%
1975	63% ± 9%	4.9 ± 0.7	181 ± 25	78	2.2	35% ± 9%
1980	63% ± 9%	4.6 ± 0.7	186 ± 25	84	2.2	33% ± 9%
1985	63% ± 9%	4.5 ± 0.6	195 ± 24	91	2.4	30% ± 9%
1990	65% ± 9%	4.7 ± 0.6	196 ± 24	100	2.6	29% ± 9%
1995	64% ± 9%	4.5 ± 0.6	195 ± 25	96	2.4	30% ± 9%
2000	62% ± 9%	4.3 ± 0.6	210 ± 26	104	2.6	24% ± 9%
2003	61% ± 9%	4.1 ± 0.6	214 ± 26	106	2.5	23% ± 9%

* Values obtained by using the "best guess" of NPP_{act} ± variations when using the high respectively low estimates of NPP_{act}
All values except for 1955 and 2003 are given as 5-year-averages.
Sources: own calculations, see text.

Aboveground productivity increased almost steadily throughout the time series, with periods of lower productivity due to droughts in the early 1980s and 1990s. Productivity increased by 33%, from 160 Mt/yr in 1955 to 214 Mt/yr in 2003. This means that whereas in 1955, due to human influence, aboveground primary production reached only 58% of that of the potential vegetation, by 2003 this value had increased to 77%. NPP_{act} per unit of land area increased from 3.2 to 4.3 t/ha/yr. The yearly amount of harvested biomass increased by 56%, from 68 Mt/yr (1.4 t/ha/yr) in 1955 to 106 Mt/yr (2.1 t/ha/yr) in 2003. In drought periods, especially in those mentioned above, the lower productivity also resulted in smaller amounts of agricultural harvest, which makes up the main part of biomass harvest.

Per capita values of HANPP (Table 4) show a clear decreasing trend as a result of the population growth and the decrease in HANPP. The average yearly population growth rate was 1% during the period before 1980, and 0.5% for the following years. While in 1955 Spanish society appropriated 6.4 t/cap/yr, this value was at 4.5 t/cap/yr in 1980 and then stayed more or less constant until 1995 as a result of the lower population growth rate during this period. It then decreased again to reach a value of 4.1 t/cap/yr in 2003. HANPP per capita had therefore decreased by 36% between 1955 and 2003, with a decrease of 29% alone in the period from 1955 to 1980. Despite the strong rise in total biomass harvest, per capita harvest was only 9% higher in 2003 (2.5 t/cap/yr) than in 1955 (2.3 t/cap/yr), with a minimum value in 1981 (2.0 t/cap/yr), and a maximum in 2000 (2.8 t/cap/yr).

When looking at productivity changes by land use type it becomes apparent that NPP_{act} has increased on the areas of all land use types, but the rise of production on cropland is most pronounced. While in 1955 each ha of cropland produced on average 2.1 t DM biomass per year, this value has more than doubled, reaching 4.4 t/yr in 2003. As a result, cropland NPP_{act} increased by 83% despite the 15% decrease in area. This was possible through intensified production techniques on cropped areas, as well as through the abandonment of marginal lands, and a reduction of fallow areas. The area of fallow remained more or less constant up until the mid 1960s and decreased steadily thereafter. Up to 2003, fallow areas were reduced by half. Cropped areas even slightly increased by about 10% until the early 1990s, and decreased again afterwards to reach about the same size as at the beginning of the time series. When considering cropped areas only, productivity almost doubled, rising from 2.7 to 5.3 t/ha/yr. Relating to the area of annual crops it reached a maximum of 6.7 t/ha/yr in the year 2000, which is higher than the potential NPP on the areas currently covered by forests (6.4 t/ha/yr (Haberl et al. 2007, Erb pers. comm. 2007)). Grassland productivity increased by 10% during the observed period, which reflects the assumption that intensified production techniques (fertilizer input, irrigation, etc.) have raised productivity of meadows. Total grassland production increased by 13% from 29 to 33 Mt/yr, also reflecting the rise in grassland area. As a result of the expansion of forest area, forest production increased by 10 Mt/yr or 17%. Although productivity per unit area was considered to remain constant on shrubland, the changes in land area resulted in an increase of total annual production (1.8 Mt/yr or 9%). The increase of NPP_{act} on other land (1.6 Mt/yr or 23%) also took place due to the area extension (mainly of built-up land).

Biomass harvest increased by 56% in the observed period (Figure 3). The harvest of crops and crop residues accounted for 94% of this increase, and made up two thirds (64%) of total harvest at the end of the time series. Until about 1970 the increase in harvest of crops and crop residues was to some extent compensated mainly by the decrease in grazed biomass. The harvest of crops and crop residues had already more than doubled by the late 1980s (from 32 Mt/yr in 1955 to 68 Mt/yr in 1988), then decreased again due to the period of severe drought in the early 1990s, and stayed at similar levels as before the drought afterwards, even though harvest per area was still increasing. Harvest through livestock grazing made up 21 Mt/yr in 1955, a value that already had been reduced by half in the early 1970s due to an increased supply of market feed. In the late 1980s the amount of grazed biomass increased again and fluctuated between 18 and 23 Mt/yr thereafter. Note, however, that there are considerable uncertainties in feed supply statistics as well as in the estimates of feed demand. Therefore, the calculation of livestock grazing can give a reasonable estimate of the magnitude of yearly grazed biomass and its development over time, but should be interpreted with care. Wood fuel harvest increased from 8 Mt/yr in 1955 to 10 Mt/yr in 1962. It then decreased rapidly to between 1 and 3 Mt/yr from the mid 70s onwards, as its importance as an energy source was diminishing. Roundwood harvest strongly increased from 2 Mt/yr in 1955 to 9 Mt/yr in 1978. After showing a slight decrease around 1980, it then stayed more or less constant at about 10 Mt/yr from 1985 onwards. Harvest of other forest products (cork and resin) is of little importance in quantitative terms, as it made up less than 2% of forestry harvest throughout the time series. Whereas in the 1950s nearly 40% of total forestry harvest took place on shrubland, this share has generally been below 10% since the mid 1970s, owing to the decrease in wood fuel harvest. Hay harvest on meadows ranges between 2 and 4 Mt/yr, with a period of slight increase until the mid 1980s and a period of slight decrease thereafter. The amount of biomass burned in human-induced fires shows high interannual variability. Whereas it lies below 2 Mt/yr for most of the years, it reached values of up to about 6 Mt/yr during years in which large areas were burned (e.g. 1978, 1985, 1989, and 1994). Harvest on built-up land increased by 43%, from 1.7 to 2.4 Mt/yr, as a result of the considerable rise in area. Harvest of Esparto was already marginal in 1955 (0.1 Mt/yr), and rapidly declined during the examined timeframe.

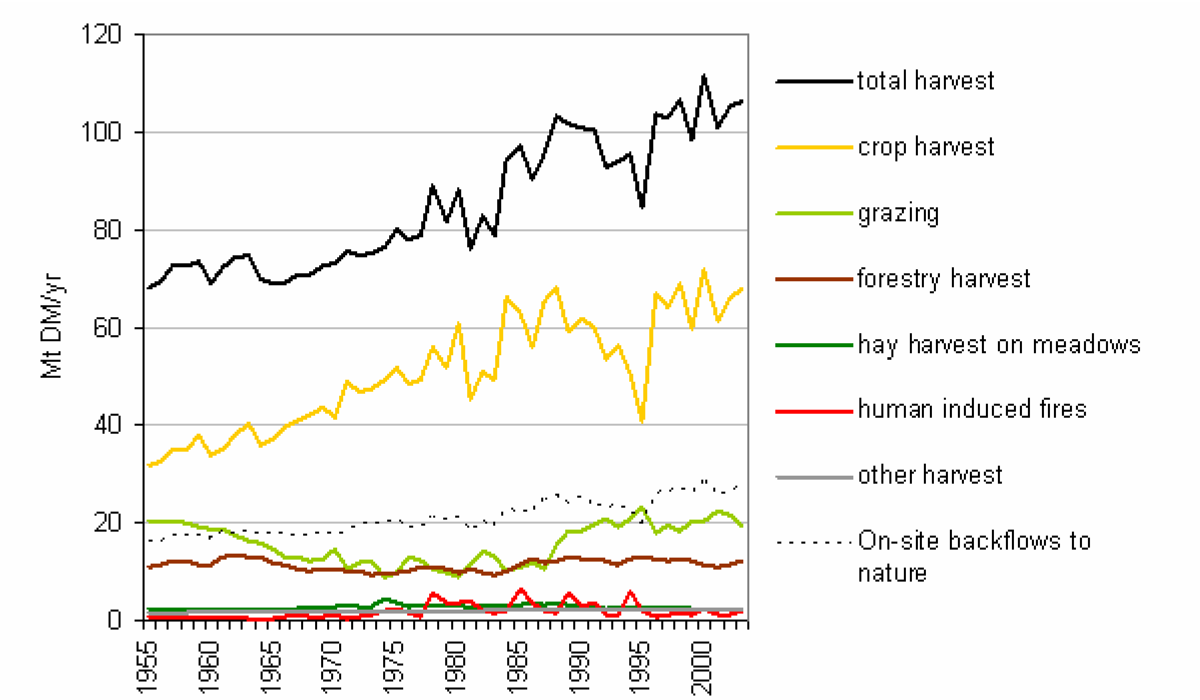

Figure 3: Development of biomass harvest for different harvest types, backflows to nature. Crop harvest includes crop residues. Forestry harvest includes felling losses.
Sources: own calculations, see text.

Throughout the time series, about 25% of NPP_h consists of biomass that immediately flowed back to ecosystems as unrecovered crop residues, felling losses or livestock feces dropped on the grazing site.

Discussion

Around the year 2000, human society appropriated about 62% of yearly potential aboveground biomass production in Spain. Even when using high estimates for the productivity of forests, shrublands and grasslands, HANPP still accounts for 53%. This means that less than half of the potentially produced biomass is left for other species. These values are remarkably high when compared to the results of Haberl et al. (2007), who have estimated global (aboveground) HANPP at 28.8%, and HANPP for Western Europe at 46.5% (Erb pers. comm. 2007). What is outstanding is the relatively high amount of HANPP resulting from productivity losses caused by human-induced land conversions (ΔNPP_{LC}) in Spain: 24% compared to a global value of 5.2%, -6% in Western Europe, 14% in Austria (Krausmann, 2001) or -7% in the United Kingdom (Musel, unpublished results, pers. comm. 2007). This is in line with the results of DeFries (2002), which also suggest a higher loss in productivity on the Iberian Peninsula compared to other European regions, where in some parts productivity even considerably exceeds that of the potential vegetation.

There is evidence that most of Spain was originally covered by (mainly deciduous) forest. Over centuries, large forest areas were cleared to give way to cropland and grazing land. Others were depleted by the massive extraction of forest resources (e.g. timber for ship building, wood fuel, overgrazing). By the middle of the 20th century, the forest area had been reduced to about 20% of the country area (or about 30% if shrublands were included). The reduction in cropland area, the partial or complete abandonment of traditional uses (e.g. extensive grazing, firewood collection), and the afforestation programmes since the 1940s have led to a steady increase in forest area during the second half of the century. This has contributed to a rise in productivity of the actual vegetation (although less strongly than the development of cropland productivity). Nonetheless, the relatively short period of forest area increase could not compensate for all the productivity losses through century-long deforestation. Note, however, that the data from the National Forest Inventories would suggest higher rates of forest area increase than the data used in this study. Land degradation has not only occurred through deforestation, but also through overgrazing, soil erosion[2] (especially on cropland and abandoned land in dry areas), fire, salinization (mainly through irrigation), etc. In this study, changes in productivity resulting from land degradation could only be accounted for insofar as they were reflected in land use changes or in agricultural yields.

Despite a remarkable increase in biomass harvest, HANPP in Spain slightly declined over the observed time period. The reason for this is that the productivity of the actual vegetation increased at the same time. Both, the increase in productivity and the increase in harvest, mainly took place on cropland. The increase in biomass harvest would not have been possible with pre-industrial cultivation practices. If cropland productivity and the relation of cropped area to fallow had not changed over the observed time period, the crop production at the end of the time series would have required a hypothetical cropland area the size of the whole country (or still over 80% of the country area, if changes in harvest indices were taken into account). The rise in productivity could only be achieved through massive, mainly fossil-fuel derived, external inputs. The consumption of fertilizer increased fivefold from 1955 to 2000. The input of fuel and electricity increased from 6 PJ in 1950/51 to 163 PJ in 1999/2000[3]. Energy efficiency (i.e. energy output per unit of energy input) of the Spanish agriculture decreased rapidly from 6.1 in 1950/51 to 1.22 in 1977/78, then slightly increased to 1.39 in 1993/94, and declined again to 1.27 in 1999/2000 (Naredo and Campos, 1980; Simón Fernández, 1999; Carpintero and Naredo, 2006). Draft animals, still in use in the mid 1950s, were replaced by a growing stock of heavy agricultural machinery. The area of irrigated cropland has more than doubled since 1955, while the area of cropland lying fallow was halved. Important changes also took place in the livestock sector, which turned more and more into an intensive production system of meat (especially pig meat) and milk. This also influenced developments on cropland, as the increasing feed demand led to a rise in the area planted with crops used as feed (32% increase from 1955 to 2000 (Carpintero, 2005); additionally a large amount of feed, especially maize and soya, is imported). Table 5 shows the development of some indicators of agricultural intensification within the observed time period.

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[2] According to the soil degradation assessment of the FAO AGL (2005), 37.2% of the country area is affected by severe or very severe soil degradation, 39% are affected by moderate degradation and 20.4% by light degradation.

[3] Fuel input has increased from 3.8 PJ in 1950/51 to 110.6 PJ in 1977/78 (Naredo and Campos, 1980). Although it then declined again to 83.6 PJ in 1993/94, this decrease was more than compensated by the increase in Electricity input (from 10.2 PJ to 52.8 PJ) (Simón Fernández, 1999). Up to 1999/2000 both, fuel (94.0 PJ) and electricity (69.1 PJ) inputs had increased again (Carpintero and Naredo, 2005)

Table 5: Agricultural intensification in Spain 1955-2000: some indicators.

	Consumption of fertilizer	Power of agricultural machinery	Number of mules, horses and asses	Cropland under irrigation	Share of cropland lying fallow	Meat production	Average yield of cereals
Unit	[Mt]	[GW]	[10^6 heads]	[%]	[%]	[Mt]	[t DM/ha/yr]
1955	0.5	0.6	2.4	8%	31%	0.4	0.9
1960	0.6	1.6	2.4	9%	31%	0.6	0.9
1965	0.8	4.9	1.6	10%	31%	0.9	1.1
1970	1.2	10.4	1.2	11%	28%	1.5	1.2
1975	1.5	17.1	0.9	13%	24%	1.9	1.7
1980	1.8	25.1	0.6	14%	24%	2.6	2.1
1985	1.7	30.8	0.5	15%	22%	2.9	2.4
1990	2.0	37.1	0.5	16%	21%	3.5	2.1
1995	1.8	41.0	0.5	17%	20%	4.0	1.5
2000	2.3	47.1	0.5	19%	18%	4.9	3.1

Sources: Spanish Agricultural Statistical Yearbooks; Barciela et al. (2005); FAO (2006); Ministerio de Agricultura (1963-1973); own calculations.

Increases in cropland productivity through agricultural intensification allow for equal increases in harvest. Therefore there is no significant change in the amount of NPP remaining in the ecosystem per unit area, which means that HANPP per unit area on cropped areas is scarcely affected by increases in productivity (c.f. Krausmann, 2001). Effects on Spain's aggregate HANPP can however be observed as a result of changes in land use patterns, as the agricultural intensification process has resulted in a reduction in cropland area. Since cropland generally has a very high HANPP per area, changes in cropland area are highly relevant for the overall HANPP trend.

HANPP values rose a bit from 1989 to 1995. This was due to an increase in biomass harvested through livestock grazing. Spain was affected by severe droughts during these years, which resulted in a decrease of feed supply, whereas feed demand was still increasing. With respect to the uncertainties in the calculation of grazed biomass (which might be even higher in an exceptional period like a long lasting drought), the increased HANPP during this period should however be interpreted with care. Although the values obtained for grazed biomass are still relatively high for the years after the drought period, HANPP clearly decreases as a result of the considerable rise of NPP_{act} in these years.

It might be surprising that per capita biomass harvest increased only slightly. This is due to the fact that only the biomass harvested within the study area, i.e. on Spain's territory, is relevant in terms of HANPP. To complete the picture regarding biomass consumption, useful information can be drawn from international trade statistics. When looking at the Spanish biomass trade in physical terms, an increasing trade deficit can be observed. Whereas biomass imports exceeded exports by about two million tons dry matter in the early 60s, this value rose almost tenfold until the year 2000 (FAO, 2006; own calculations). Things look different when measured in monetary terms, where exports have even slightly exceeded imports since the mid 1990s. The growing net imports of biomass could be interpreted as an "outsourcing" of biomass harvest.

The results of the Material Flow Analysis and the Ecological Footprint calculation of Carpintero (2005), which cover essentially the same time period, show the rapidly increasing requirement of materials and (hypothetical) area by the Spanish economy. This is however not contradictory to the observed decreasing trend in HANPP, as each of the indicators aims to measure different aspects of society-nature-interaction. Flows of materials other than biomass are not relevant in terms of HANPP, unless they are reflected in productivity changes (e.g. through soil sealing). The concept of HANPP considers biomass extraction in a defined territory, not biomass consumption of a defined socioeconomic system, and consequently biomass imports are not reflected in accounts of HANPP. Whereas the massive rise in fossil fuel consumption plays a decisive role in the growth of the Ecological Footprint, it leads to a decrease in HANPP through productivity increases and the substitution of fossil fuels for biomass as a source of energy.

While HANPP decreased, the Spanish economy grew considerably over the observed time period. Total GDP increased by a factor of 8.4 (GGDC 2007). The amount of appropriated NPP per unit of GDP decreased by nearly 90%, and had already been halved by the mid 1960s. The amount of harvested biomass per unit of GDP decreased similarly by over 80%. Therefore, other than in the case of material flows (Carpintero, 2005), HANPP in Spain is decoupled from economic growth. This reflects the declining relative importance of biomass extraction for the economic system in the last decades. It is however a debateable point, whether this decoupling could still prevail if for example biomass was to be extracted on a grand scale for energy purposes.

The main processes determining the decreasing trend of HANPP can be summarized as follows: The process of industrialization has led to changes in land use patterns, the most important being the reduction of the cropland area and the rise in forest area, i.e. the reduction of a land use type with extremely high HANPP per unit area and the extension of a land use type with comparably low HANPP per unit area. Also both the increase in shrubland and grassland area in combination with the productivity increase on grassland and the diminishing biomass extraction from shrubland (as wood fuel harvest decreased rapidly) contributed to the decreasing trend of HANPP, whereas other land use changes, like the expansion of built-up land (with an area increase of over 40%) were of minor importance. The strong rise in biomass harvest mainly took place on cropland where it was fully compensated by the increase in productivity.

Discussing the decrease in HANPP, the “costs” of this development should not remain unmentioned. Agricultural intensification has undoubtedly caused considerable environmental problems like increasing soil erosion, salinization, soil, water and air pollution and an exhaustion of water resources, just to mention some of the most important ones. The environmental problems caused by the massive use of fossil fuels, which is per se unsustainable as it implies the depletion of non-renewable resources, are widely known and have received considerable attention in recent years.

Although the steep increase in cropland productivity per area has allowed for a strong rise in biomass harvest within the last decades, the possibility to increase productivity is not unlimited (due to physiological limits to HI improvement, fertilization saturation effects, limited water resources for irrigation, etc. (c.f. Krausmann, 2001)). In this context it is questionable whether biomass harvest could be increased much further, without this having significant impacts on fundamental ecosystem functions. There are however no signs of a decrease in the demand for biomass. On the contrary, demand might increase even more if for example biomass was to be further promoted as a substitute for fossil fuels. Yet, on the country level, trade might still offer options to satisfy a growing demand for biomass without a proportionate increase in biomass harvest. In the long run it will be indispensable to improve the efficiency of biomass use. For example the reasonability of devoting huge amounts of plant biomass to the production of meat, strongly promoted in Spain within the last decades, will have to be raised to question. With regards to future productivity, great efforts will have to be made in order to face the severe problems of soil degradation. This becomes even more evident, when considering the high level of HANPP in Spain at present, as well as the still considerable proportion of NPP foregone due to human-induced land conversions when compared to other industrialized countries.

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Annex A – Materials and Methods

The HANPP concept

The aim of this study is to analyse human influence on the availability of biomass for trophic energy flows in ecosystems in Spain from 1955-2003. For this analysis the indicator "Human Appropriation of Net Primary Production" (HANPP), first introduced by Vitousek et al. (1986), is used, generally following the definitions of HANPP used in Haberl et al. (2007). Humans appropriate Net Primary Production (NPP) through two pathways: through changes in productivity of ecosystems, caused by human-induced land conversions (such as land use change, land cover change, soil degradation), and through the harvest of biomass.
HANPP can thus be calculated by using the following formulas

$$HANPP = \Delta NPP_{LC} + NPP_h$$
$$\Delta NPP_{LC} = NPP_0 - NPP_{act}$$

with NPP_h being the NPP appropriation through harvest, and ΔNPP_{LC} being the change of NPP through human-induced land conversions. ΔNPP_{LC} is defined as the difference between the NPP of the potential (NPP_0), and the actual (NPP_{act}) vegetation. HANPP can therefore defined as the difference between the NPP_0 and the NPP remaining in ecosystems after harvest (NPP_t)

$$HANPP = NPP_0 - NPP_t$$
$$NPP_t = NPP_{act} - NPP_h$$

For further details on the HANPP concept see Vitousek et al. (1986), Haberl (1997), Schandl et al. (2002), Haberl et al. (2004), Haberl et al. (2007).

Due to limited availability and reliability of data on belowground NPP, my calculations are restricted to aboveground NPP flows. The unit used is tons dry matter per year (t DM/yr).

Land use data

Data availability

To study HANPP in a historical context, it is crucial to be able to understand and quantify changes in land use patterns that occurred throughout the time period observed. For this reason, I generated a land use data set on the basis of several data sources and model assumptions that are discussed in detail below. Unfortunately there are substantial discrepancies between the different data sources used. Apart from matters of data quality, this is mainly caused by strongly differing classifications. For this reason, and because of rather imprecise definitions of categories in some cases, the different data sets are hardly comparable. The main reasons for the discrepancies in both land cover and land use classifications in Spain are the tremendous diversity of ecosystems (between and within ecoregions), the coexistence of heterogeneous vegetation types, the variety of successional vegetation stages (especially through the abandonment of traditional land uses within the last decades) and the commonness of multifunctional uses (e.g. silvopastoralism (i.e. a combination of uses through forestry and livestock grazing)).

Yearly data on the distribution of different land uses relating to the total country area are documented within the Spanish Agricultural and Food Statistics Year Book (MAPA, 1999-2006) and its predecessors (Ministerio de Agricultura, 1929-1972 and 1974-1980; MAPA 1981-1997) as from 1955. I denominate data from this data set as "MAPA land use data". Between 1955 and 1973 classifications of land use categories were changed repeatedly. Since 1973 consistent classifications have been used. Unfortunately, there are no definitions of the categories available for the older classification schemes, and even nowadays definitions are rather unsatisfactory, at least for some categories (e.g. fallow or extensively grazed abandoned land). Thus, MAPA land use data leave a rather wide scope of interpretation, and the relation of many of the categories used nowadays to those used before 1973 remains unclear. For a better understanding of land use changes in the 20th century a detailed revision of the different sources would be urgently needed. This is especially true for forest, shrubland, and grassland. In the Agricultural and Food Statistics Yearbook data on up to four different classifications of forest land (which is a very encompassing term in these classifications) are presented. The different data refer to the national forest inventories IFN1 1966-1975 *(*ICONA, 1979 and 1980*)* and IFN2 1986-1996 *(*Ministerio de Medio Ambiente, 1998*)*), the Survey on the forest structure in 1986 *("Encuesta de Estructura Forestal (Diciembre 1986)")*, and the general MAPA land use data set, which is presented annually. It is noted in the yearbook that *"As a consequence of utilizing different sources, the numbers that are offered on forest areas can differ noticeably, because of the different methodologies used"*. It is also noted that some of the used terms/categories within the data sets are difficult to distinguish from each other. Data on forest areas relating to the years 1946 to 1971 are presented in the Spanish Forestry Statistics Year Book (Ministerio de Agricultura, 1947-1971). The huge fluctuations in the forest area data from this source are mainly due to revisions in the estimations and classifications, and not due to real changes in the forest area (which is pointed out explicitly in the Forestry Statistics Year Book of 1970). For this reason I did not use these data in my study. The two existing National Forest Inventories (IFN1, IFN2, The complete results of the IFN3 are supposed to be published soon) are the most frequently cited sources for the forest area of Spain, as well as for its change over time. Although data quality of the inventories might be good, they are of limited use for this study. One problem is again that classifications of the forest areas differ between these inventories (for example, the minimum tree crown cover was reduced from 10% to 5%), making it difficult to use them as a source for historical forest area change. For the purpose of this study the data given in the MAPA land use data set have the advantage of temporal and spatial consistency, at least from 1973 onwards. They were therefore also taken as reference for the area of forest and shrubland, although the forest inventory data are a more widely accepted source for these areas. A further source for land use data are the land use maps of 1960 and 1985, compiled by the Ministry of Agriculture. There have been changes in classification and survey methodology, but the accompanying text of the 1985 map (MAPA, 1989) includes a suggestion on how the tabular data taken from the two land use maps can be compared. The same is done for a comparison of the data delivered from the land use map of 1985 and the corresponding data from the MAPA land use data set. Although these comparisons are rather problematic for some of the categories, they are a useful source for general land use trends within the period 1960-1985. It should be mentioned that a few estimates of land use distribution exist also for some points in time before 1955, but with a nearly exclusive focus on the area of cropland (Grupo de Estudios de Historia Rural, 1983; cited by Barciela et al., 2005).

Compiled land use data set

The land use data set compiled for this study consists of 13 land use categories, aggregated to 5 land use types, and is presented in Figures 1 and A1. The following description of the categories is based on the definitions given in the Agricultural Statistical Yearbooks (for the categories used from 1973 onwards).

Cropland

Cropland consists of areas cultivated with annual crops or permanent crops and of fallow areas. All cropland areas were taken from the MAPA land use data set. For the area of annual crops an adjustment was made for the period 1955-1970. In the original data the land use area of annual crops for these years is remarkably smaller than in the following years (7% change from 1970 to 1971), a trend that cannot be observed in the data on the area harvested of annual crops. In 1971, the classifications of the land use data were changed, and it seems plausible that the change in the area of annual crops is rather a change in statistics than a real change in area. I adjusted the land use area in this period by assuming the same ratio of land use area to area harvested as in 1971. This assumption is supported by the data on total cropland given in the land use maps of 1960 and 1985.

Forest, shrubland, grassland

Closed forest refers to forests with a minimum tree crown cover of 20%. Its main economic use is roundwood production. According to the MAPA definitions these areas are hardly used for livestock grazing. Yet, San Miguel Ayanz (2001) estimates that at least two thirds of these areas are also used for grazing. Open forest is defined by a tree crown cover of 5 to 20%. It is mainly used for grazing. Areas dominated by stunted trees (particularly of the genus *Quercus*) with vegetative reproduction through sprouts from stumps or roots are not included in the forest area but in the area of shrublands. This probably explains the big differences compared to the data on forest areas provided by the IFN. Open forests in Spain are mainly managed as part of the so called dehesa systems. Dehesas are traditional agrosilvopastoral systems that are used for grazing of livestock, production of wood (and eventually cork) and for agriculture simultaneously.

Shrubland consists of areas dominated by stunted trees or shrubs (covering more than 20% of the area), and is mainly used for livestock grazing and wood fuel production.

Grassland consists of meadows, dry pastures, Esparto grasslands and extensively grazed abandoned land. Meadows are unsown perennial grasslands, requiring a certain degree of humidity, be it through natural climatic conditions or irrigation. They are managed by mowing and/or grazing, with mowing being principally possible. They may also contain trees and shrubs, but with a crown cover smaller than 5 and 20%, respectively. Meadows can mainly be found in the northern part of Spain, where there is sufficient rainfall. In the classifications of the MAPA data set they are misleadingly described as “natural”. It is common in Spain to distinguish between “natural” and “artificial” grasslands, with “natural” being unsown and “artificial” being sown grasslands. Meadows are undoubtedly man-made ecosystems in areas originally covered by forests (Ferrer et al., 1997). Dry pastures differ from meadows by being situated in drier climates, and by not being susceptible to mowing. Esparto grasslands are areas dominated by the perennial grass *Stipa tenacissima L.* (Esparto), of which the leaves have traditionally been used for the production of fibre and paper. The area of Esparto grassland is marginal and declining, and is nearly exclusively situated in the southeast of mainland Spain and some areas on the Canary Islands. Extensively grazed abandoned land refers to abandoned agricultural areas with spontaneous vegetation. These areas can be used as pastures, but only with very low stocking intensity. There is no clear definition of how long the areas in this category have been abandoned.

For the period 1973-2003 all the land use data for these categories were taken from the MAPA land use data set. For the period 1955-1972 data were only given for meadows and Esparto grassland. The area of all other grassland, shrubland and forest was calculated as the difference between total land area and the area of all other land uses. This area was then divided up between the categories by assuming that the trend of the proportions within this area was the same from the mid 50s to the mid 70s as from the mid 70s to the mid 90s.

Other land

Built-up land includes settlement and infrastructure areas (buildings, roads, railways, parks, gardens, etc.). To estimate this area, I used a model developed by Haberl et al. (2007) by means of which the urban area is calculated based on information on population density and development status. Population Data were taken from Nicolau (2005) for the period 1955-1990, and from Instituto Nacional de Estadística (2006) for 1991-2003. For Spain the model yields an estimate of 0.05 ha built-up land per capita for the whole time series. The category "Superficie no agrícola" in the MAPA data set (introduced in 1973) according to its definition is very similar to the category of built-up land used in my data set. The data reported are well in line with the results of the model, following the same trend over time, which I take as a validation of the model assumptions. The area of inland water contains all areas normally covered by inland waters, even if they are dried out over parts of the year. The area is given in the MAPA data set from 1973 onwards. For 1955-72 I use the value of 1973. The category other areas contains areas that are not used by society, be it because they are unproductive, remote, inaccessible, or because of other reasons. It includes deserts, gorges, rocks, etc. For 1973-2003 the area is calculated as the difference between total area and the area of all other land use categories. For 1955-72 I use the value of 1973.

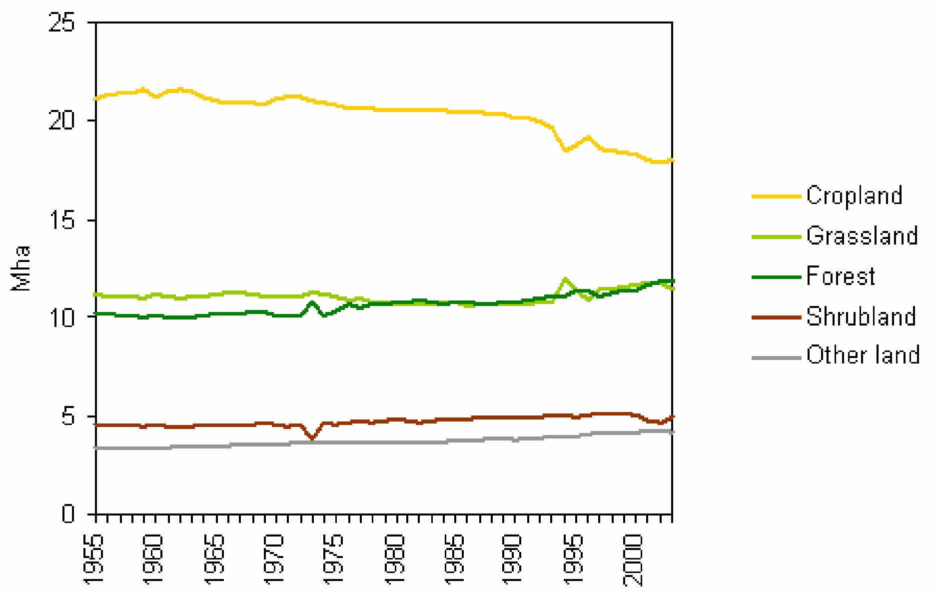

Figure A1: Development of land use; land use categories aggregated to 5 main land use types. Sources: see text.

NPP of the potential vegetation (NPP_0)

NPP_0 data were taken from the work of Haberl et al. (2007) (Erb pers. comm., 2007), who used the Lund-Potsdam-Jena (LPJ) Dynamic Global Vegetation Model (Sitch et al., 2003) with an improved representation of hydrology (Gerten et al., 2004) for their calculations. Data on NPP_0 were only available for the year 2000 (respectively the average of 1998-2002), and were for this reason kept constant throughout the time series. It has to be mentioned however that NPP_0 can vary significantly within individual years. Especially the high interannual variance of climatic conditions (particularly in precipitation) in the studied area would suggest fluctuations in NPP_0. Also the effect of changes in atmospheric carbon dioxide concentration on NPP_0 has been neglected in this study.

NPP of the actual vegetation (NPP_{act})

Spain has a huge diversity of vegetation types, climatic and topographic conditions. There is a wide range of aboveground productivity, with areas of highly productive forests in the north and semi-deserts in the southeast of mainland Spain. Studies on NPP in Spain are scarce, especially for non-forest areas. Using additional NPP studies from other regions with comparable climatic conditions provides a useful basis for assessing NPP_{act} of different vegetation types. As literature values are of a high range, low and high estimates of NPP_{act} for forest, shrubland, the main grassland categories and fallow were derived, which should give a plausible range for the average NPP_{act} of these areas. The average value of the high and low estimates is used as a “best guess” for NPP_{act}.

NPP_{act} on cropland

NPP_{act} on annual and permanent cropland (in production) consists of harvested NPP, NPP of weeds and NPP losses before harvesting (e.g. through herbivory). The calculation of harvested NPP is described in detail below. NPP losses and NPP of weeds are not accounted for in agricultural statistics. On the basis of Oerke (1994) and in accordance with Haberl et al. (2007) I estimate this part of NPP_{act} as 23% of NPP_h in 1955 and as 14% from 1980 onwards, assuming a linear development of this percentage between 1955 and 1980.

The area of permanent cultures not yet producing is calculated as the difference between the land use area of permanent crops and the area of permanent crops harvested. I assume the NPP_{act} on these areas to equal the average NPP_{act} of permanent cultures already in production.

Fallow areas are in most cases unsown, covered only with some spontaneous vegetation, or sowed with mostly grasses or legumes. The productivity of fallow areas is therefore highly variable, depending - apart from other factors- on the type of fallow, and on the length of the fallow period. Fallow rotations are most common in the semi-arid parts of Spain. In dry farming fallowing is practiced mainly to capture and store rainfall, and spontaneous vegetation is mostly destroyed through grazing, tillage or, more recently, the use of pesticides to reduce evapotranspiration. Le Houerou (1977) gives estimates on the productivity of fallow in Mediterranean areas for different climatic conditions. For the semi-arid zone, with an annual precipitation of 400-600 mm, he gives a range of 0.4-0.8 tons per ha and year. Given the distribution of annual rainfall in Spain, and the fact, that fallow is mostly practised in areas with comparatively low rainfall, I consider theses values as the most representative ones, and therefore estimate NPP_{act} on Fallow as 0.4 t/ha/yr (low estimate) respectively 0.8 t/ha/yr (high estimate).

NPP_{act} on forest

In the absence of reliable data on the effects of forest management on forest productivity (Haberl et al., 2001), I assume NPP_{act} per unit area and year on land covered by closed forest to equal its NPP_0, i.e. the NPP_0 of the potential vegetation currently covered by forest. The respective value is taken from the work of Haberl et al. (2007), who have combined the NPP_0

data with a land use map, and calculated NPP_0 values for each land use category, referring to the distribution of land uses in the year 2000. For details on model inputs and assumptions see Haberl et al. (2007). According to their results (Erb pers. comm., 2007), the NPP_0 of the area currently covered by forests in Spain is 6.4 t/ha/yr. This value is remarkably higher than that for the total country area (5.5 t/ha/yr), which is due to the fact, that the share of forest area is higher in the more productive northern parts of Spain.

Open forests in Spain are mainly part of the dehesa systems. They are man-made ecosystems, characterised by a savannah-like physiognomy (Joffre et al., 1999). The studies on productivity of dehesas I have reviewed all deal with pasture productivity only, and neglect the NPP of the tree layer. It can be argued that productivity loss might have occurred due to the opening of the crown cover, changes in the water regime, changes in the leaf area index, etc. However Simioni et al. (2003) suggest that for savannah ecosystems total NPP does hardly change with changing tree density. Note however, that even if the total NPP does not change with changing tree density, aboveground NPP would probably change, as the ratio of aboveground NPP to total NPP is higher for trees than for grasses (Saugier et al. 2001). My high estimate of NPP_{act} per unit area and year on land covered by open forest is the NPP_0 of areas currently covered by forests (as for closed forest). For the low estimate I use the average value of NPP_{act} per unit area of closed forest and grassland (using the low estimate; calculated as the weighted average of the low estimates for NPP_{act} per unit area of all grassland categories according to their share on total grassland area).

NPP_{act} on shrubland

Rambal (2001) gives an overview of the results of numerous studies on the productivity of Mediterranean-type shrublands and woodlands, in which the extreme range of productivity within these vegetation types is documented. I use the data on high and low shrublands given in this publication and additional data from Merino and Vicente (1981), Navarro (2004), Martínez Fernández et al. (1994) and Ibañez et al. (1999)[4], to estimate NPP_{act} of shrublands, with the average NPP of high shrublands as the high estimate, and that of low shrublands as the low estimate.

[4]This study refers to two study sites in Northeast Spain, Prades and Montsey. I used the data from the Prades study site only. Both sites are actually rather forests than shrublands, but the broad definition of shrublands used in this study includes areas dominated by stunted trees with vegetative reproduction through sprouts from stumps or roots, which is the case in Prades, but not in Montseny.

NPP_{act} on grassland

The definition of meadows is rather vague, and probably contains a noticeable variety of land uses, from intensively used, irrigated and fertilized meadows, to extensively used semi-natural mountain grasslands. According to their definition, they are situated in regions with higher humidity than dry pastures and can be mowed. It is reasonable to assume that on the intensively used areas productivity has increased due to the use of fertilizer and irrigation, as it has been the case on cropland. I assume productivity of irrigated meadows to be the same as for the sum of areas sown with grasses and legumes for fodder. On non-irrigated meadows (which certainly also include fertilized areas) productivity is estimated as the average productivity of irrigated meadows and dry pastures (using the low respectively high estimate of $ANPP_{act}$ of dry pastures). For the years 1955-60 the share of the irrigated area on the total area of meadows was assumed to be the same as in 1961.

Estimates of the productivity of dry pastures were derived on the basis of literature values (for study sites in Spain and other countries around the Mediterranean basin). Note that in many cases the exact allocation of these literature values to a certain land use category is ambiguous.[5] Apart from that, most of the literature available deals with fodder production rather than with primary production, which is often not clearly stated. Olea et al. (1991) give an average value for the fodder production of semiarid pastures in south-western Spain of 1.4 t/ha/yr. Gomez Gutierrez et al. (1980) have studied grassland NPP of different types of pastures in the province of Salamanca (western Spain) over 5 consecutive years. They distinguished 7 pasture types of which at least the three most productive ones can be considered as meadows (because they are susceptible to mowing). The mean values of NPP for the dry pasture types range from 2.1 to 3.8 t/ha/yr. The authors explicitly state that there are also pastures on poor soils that are less productive (<0.5 t/ha/yr), and that have not been considered in the study. Papanastasis (1981) (cited by Biddiscombe, 1987) reports an NPP of 2.6 t/ha/yr for grasslands in the lowlands of northern Greece, with 480 mm annual rainfall. Gutman (1978) (cited by Biddiscombe, 1987) gives a range of 2.5 to 3.8 t/ha/yr for the NPP of herbaceous pastures studied in northern Israel with an average annual rainfall around 600 mm (litterfall and non-domestic herbivory were not accounted for in this study). Le Houerou and Hoste (1977) compiled data from eight countries around the Mediterranean Basin and studied the relationship between annual rainfall and NPP. According to their findings (using

[5] Dry pastures differ from meadows by being situated in drier climates, and by not being susceptible to mowing. Regarding the climatic conditions there is no clear threshold (e.g. annual amount of rainfall), and the susceptibility to mowing is not explicitly mentioned in most productivity studies.

their linear regression) NPP under annual rainfall of 400 mm would be about 1.5 t/ha/yr, which I use as the low estimate for NPP_{act} of dry pastures in my calculations. I use the highest of the above mentioned values, 3.8 t/ha/yr, as the high estimate for NPP_{act}.[6]

NPP_{act} of Esparto Grassland was taken as 3.1 t/ha/yr, which is the average of a four year record of the productivity of Esparto stands in Rambla Honda (south-east Spain), presented by Puigdefábregas et al. (1997) (cited by Puigdefábregas and Mendizabal, 1998).

Extensively grazed abandoned land can be considered less productive than dry pastures, as it can only maintain livestock at very low stocking intensity (according to its definition). The main cause for the lower productivity is the relatively high proportion of bare soil in the first years of abandonment (Ferrer et al., 1997). I estimate NPP_{act} of extensively grazed abandoned land as the average of NPP_{act} of fallow and dry pastures (low estimate: 1.0 t/ha/yr, high estimate: 2.3 t/ha/yr)

NPP_{act} on other land

The calculation of NPP_{act} on built-up land is based on the assumption that two thirds of this area is sealed, whilst one third is carrying vegetation. NPP_{act} of the vegetated area is calculated as the average of NPP_0 and NPP derived through an LPJ run with unlimited water supply. (Haberl et al., 2007). I assign no productivity to inland waters, as this study considers terrestrial productivity only. The category “Terrenos improductivos” in the MAPA data set from 1973 onwards is, according to its definition, very similar to the category “other areas” used in my data set. These areas are mainly classified as shrublands in the land use map of 1985 (MAPA, 1989). I assume 50% of the category “other areas” to be unproductive, and 50% to have the productivity of shrubland (using the best guess for shrubland NPP_{act}).

Harvested NPP (NPP_h)

Harvest of crops and crop residues

NPP_h on annual and permanent cropland consists of primary crop harvest and of harvested, grazed and unrecovered residues. The rationale of including unrecovered residues in the definition of NPP_h is that they are usually either ploughed in or burned on site, and that they

[6] This would correspond to an annual rainfall of more than 900mm according to Le Houerou and Hoste 1977. However, they have mainly used data from areas with annual rainfall below 400mm, which means that their calculations might be less accurate for higher annual amounts of rainfall.

are therefore not available for consumer food webs. Data on primary crop harvest were taken from the Spanish Agricultural Year Books, and were converted to dry matter using crop specific data on water content from the cited literature (Table A1). For reasons of consistency with former studies (Haberl, 1997; Haberl et al., 2001; Krausmann, 2001) I also accounted for crop harvest of roots and tubers.

Table A1: Values on water content (W.c.) of primary crops.

Primary crop	W.c.	Primary crop	W.c.
Wheat	14%	Broad Beans, Green	80%
Rice, Paddy	14%	Carrots	88%
Barley	14%	Mushrooms	90%
Maize	14%	Chicory Roots	90%
Rye	14%	Carobs	70%
Oats	14%	Vegetables Fresh nes	95%
Millet	12%	Bananas	75%
Sorghum	11%	Oranges	86%
Triticale	14%	Tang.Mand.Clement.Satsma	87%
Canary Seed	10%	Lemons and Limes	87%
Cereals nes	14%	Grapefruit and Pomelos	88%
Potatoes	78%	Citrus Fruit nes	86%
Sweet Potatoes	70%	Apples	85%
Roots and Tubers nes	75%	Pears	83%
Sugar Cane	83%	Quinces	84%
Sugar Beets	77%	Apricots	85%
Beans, Dry	10%	Sour Cherries and Cherries	80%
Broad Beans, Dry	10%	Peaches and Nectarines	89%
Peas, Dry	11%	Plums	81%
Chick-Peas	11%	Strawberries	90%
Lentils	11%	Grapes	81%
Vetches	10%	Watermelons	93%
Lupins	15%	Cantaloupes&oth Melons	90%
Pulses nes	10%	Figs	77%
Chestnuts	8%	Avocados	74%
Almonds	4%	Dates	22%
Walnuts	4%	Kiwi Fruit	90%
Hazelnuts (Filberts)	6%	Fruit Fresh nes	80%
Soybeans	10%	Maize for Forage+Silage	80%
Groundnuts in Shell	6%	Sorghum for Forage+Silag	80%
Olives	60%	Rye Grass,Forage+Silage	84%
Sunflower Seed	7%	Grasses nes,Forage+Silag	80%
Rapeseed	12%	Clover for Forage+Silage	80%
Safflower Seed	5%	Alfalfa for Forage+Silag	80%
Seed Cotton	10%	Leguminous nes,For+Sil	80%
Cabbages	92%	Pumpkins for Fodder	91%
Artichokes	85%	Cabbage for Fodder	92%
Asparagus	92%	Turnips for Fodder	88%
Lettuce	95%	Beets for Fodder	88%
Spinach	90%	Carrots for Fodder	89%
Tomatoes	94%	Roots and Tubers for Fodder	80%
Cauliflower	91%	Forage Products nes	80%
Pumpkins, Squash, Gourds	91%	Coffee, Green	10%
Cucumbers and Gherkins	95%	Hops	80%

Eggplants	92%	Pimento, Allspice	80%
Chillies&Peppers, Green	80%	Spices nes	5%
Onions+Shallots, Green	89%	Peppermint	80%
Onions, Dry	89%	Fibre, Tow, Seed of Flax and Hemp	10%
Garlic	61%	Tobacco Leaves	10%
Leeks and Oth.Alliac.Veg	85%	Industrial crops nes	29%
Beans, Green	80%	Permanent crops nes	40%
Peas, Green	78%		

Sources: based on Souci et al. (2000), Purdue University Center for New Crops and Plant Products (2006), Löhr (1990), Watt et al. (1975)
nes = not elsewhere specified

As data on the amount of total residues are not given in agricultural statistics, I calculated these using crop-specific or crop-aggregate-specific harvest indices (HI) taken from the cited literature. The harvest index is the ratio of crop harvest to the total aboveground biomass of this crop (Evans, 1993). In the case of permanent crops, I understand HI as the ratio of crop harvest to the total annual aboveground increment of this crop. Harvest indices used in this study are presented in Table A2 for selected years.

For those annual crops, where no information on HIs was available, harvest (primary crops + total residues) per area was assumed to be the mean value of all other annual crops, or 125% of primary crop harvest, as HIs were assumed not to exceed 0.8 (Smil, 2000). On areas of permanent cultures not yet producing I assume that, apart from NPP of weeds and NPP losses before harvest, 50% of NPP_{act} remain in the ecosystem (as growing stock) and 50% are harvested through cultivation practices (e.g. pruning).

Table A2: Harvest indices for selected years.
HI = primary crop harvest / (primary crop harvest + residues)

Primary crop	1955	1980	2003	Source
Wheat	0.37	0.48	0.55	A
Barley	0.34	0.49	0.53	A
Rye	0.36	0.44	0.51	A
Oats	0.36	0.44	0.51	A
Cereals nes	0.36	0.46	0.52	A
Potatoes	0.60	0.76	0.82	A
Sweet Potatoes	0.71	0.71	0.71	B
Roots and Tubers nes	0.71	0.71	0.71	B
Sugar Cane	0.60	0.60	0.60	C
Sugar Beets	0.62	0.69	0.73	A
Pulses	0.30	0.30	0.30	D
Chestnuts	0.33	0.33	0.33	B
Almonds	0.33	0.33	0.33	B
Walnuts	0.33	0.33	0.33	B
Hazelnuts (Filberts)	0.33	0.33	0.33	B
Soybeans	0.32	0.32	0.32	B
Groundnuts in Shell	0.32	0.32	0.32	B

Olives	0.50	0.50	0.50	E
Sunflower Seed	0.31	0.32	0.33	A
Rapeseed	0.32	0.34	0.36	A
Safflower Seed	0.42	0.42	0.42	B
Seed Cotton	0.32	0.32	0.32	B
Cabbages	0.67	0.67	0.67	B
Artichokes	0.67	0.67	0.67	B
Asparagus	0.67	0.67	0.67	B
Lettuce	0.67	0.67	0.67	B
Spinach	0.67	0.67	0.67	B
Tomatoes	0.50	0.50	0.50	B
Cauliflower	0.67	0.67	0.67	B
Pumpkins, Squash, Gourds	0.67	0.67	0.67	B
Cucumbers and Gherkins	0.67	0.67	0.67	B
Eggplants	0.67	0.67	0.67	B
Chillies&Peppers, Green	0.67	0.67	0.67	B
Onions+Shallots, Green	0.67	0.67	0.67	B
Onions, Dry	0.67	0.67	0.67	B
Garlic	0.67	0.67	0.67	B
Leeks and Oth.Alliac.Veg	0.67	0.67	0.67	B
Peas, Green	0.67	0.67	0.67	B
Carrots	0.67	0.67	0.67	B
Mushrooms	0.67	0.67	0.67	B
Carobs	0.50	0.50	0.50	B
Vegetables Fresh nes	0.67	0.67	0.67	B
Bananas	0.33	0.33	0.33	B
Oranges	0.33	0.33	0.33	B
Tang.Mand.Clement.Satsma	0.50	0.50	0.50	B
Lemons and Limes	0.50	0.50	0.50	B
Grapefruit and Pomelos	0.33	0.33	0.33	B
Citrus Fruit nes	0.33	0.33	0.33	B
Apples	0.33	0.33	0.33	B
Pears	0.50	0.50	0.50	B
Quinces	0.50	0.50	0.50	B
Apricots	0.50	0.50	0.50	B
Sour Cherries and Cherries	0.50	0.50	0.50	B
Peaches and Nectarines	0.33	0.33	0.33	B
Plums	0.50	0.50	0.50	B
Strawberries	0.50	0.50	0.50	B
Grapes	0.33	0.33	0.33	B
Cantaloupes&oth Melons	0.67	0.67	0.67	B
Figs	0.50	0.50	0.50	B
Avocados	0.50	0.50	0.50	B
Dates	0.50	0.50	0.50	B
Kiwi Fruit	0.50	0.50	0.50	B
Fruit Fresh nes	0.50	0.50	0.50	B
Grasses and Legumes for Fodder (excl. Maize)	0.75	0.75	0.75	F
Permanent crops nes	0.42	0.42	0.42	G

Sources: A) Krausmann (2001), Weisz et al. (1999), Krausmann pers. comm. (2006); B) Jölli and Giljum (2005); C) Wirsenius (2000); D) Goudriaan et al. (2001); E) Villalobos et al. (2005); F) Haberl et al. (2007); G) Mean of HIs of permanent crops
nes = not elsewhere specified

I distinguish between harvested, grazed and unrecovered residues, with unrecovered residues being those, which have no further use in the socioeconomic system. Data on the harvest of straw of cereals and pulses were taken from Spanish agricultural statistics. For the few years with missing data for some cereals I assumed the ratio of harvested straw to grain to be the same as in the nearest preceding respectively following year for which data was available. Other harvested residues were calculated by multiplying the amount of residues with specific recovery rates, which are shown in Table A3. The calculation of grazed residues is described below. Grazed residues are assigned to the harvest category "harvest through livestock grazing".

Table A3: Recovery rates of crop residues: used values and main sources

Primary crop	Recovery rate	Main Sources
Olives	0.30	Di Blasi et al. (1996)
Sunflower Seed	0.50	Wirsenius (2000)
Groundnuts in Shell	0.90	Wirsenius (2000)
Soybeans	0.70	Wirsenius (2000)
Oil Crops nes	0.10	Jölli and Giljum (2005)
Seed Cotton	0.10	Jölli and Giljum (2005)
Vegetables	0.10	Jölli and Giljum (2005)
Fruits	0.10	Jölli and Giljum (2005)
Roots and Tubers	0.10	Jölli and Giljum (2005)
Sugar Cane	0.90	Wirsenius (2000)
Sugar Beets	0.15	Di Blasi et al. (1996)
Treenuts	0.10	Jölli and Giljum (2005)
Other Permanent Crops	0.33	Haberl et al. (2007), Krausmann pers. comm. (2007)

Harvest through livestock grazing

The amount of annually grazed biomass was calculated as the difference of feed demand and feed supply. Feed demand was calculated separately for 9 livestock species. Feed demand of sheep, goats, horses, asses, mules and rabbits was calculated with estimates on average dry matter feed intake per head and day. The respective values were taken from Haberl et al. (2007) and are presented in Table A5. In the case of pigs and poultry efficiency factors, that is required feed intake per unit of product output, were used (Haberl et al., 2007; Table A4). The factors of Haberl et al. (2007) were used for the year 2003, as they refer to industrialized livestock production (Krausmann pers. comm., 2007). To consider improvements in feed efficiency, I assume that in 1955 feed intake per unit of product output was 50% higher, and that feed efficiency has increased linearly.

Table A4: Efficiency factors used for the calculation of feed demand of pigs and poultry. Efficiency factor = Feed intake / Product output [kg DM/kg fresh weight]

	1955	2003
Pork	6	4
Poultry	4.5	3
Eggs	4.2	2.8

Source: Haberl et al. (2007); own calculations, see text.

Feed demand of cattle was calculated on a yearly basis as a function of the average carcass weight, using the following formula (Haberl et al., 2007):

$$\text{Feed intake [kgDM/head/day]} = 0.036361 * \text{carcass weight [kg/animal]} + 1.702006$$

Table A5 gives values of feed demand per head and day, resulting from the calculations described above, for selected years of the studied time period.

Table A5: Species specific feed demand [kg DM/head/day] for selected years.

	1955	1965	1975	1985	1995	2003
Cattle	6.0	7.4	9.8	9.7	11.0	11.0
Sheep	1.5	1.5	1.5	1.5	1.5	1.5
Goats	1.5	1.5	1.5	1.5	1.5	1.5
Pigs	0.5	1.0	1.1	1.6	1.3	1.5
Poultry	0.10	0.16	0.13	0.12	0.11	0.12
Horses	10.0	10.0	10.0	10.0	10.0	10.0
Asses	6.0	6.0	6.0	6.0	6.0	6.0
Mules	6.0	6.0	6.0	6.0	6.0	6.0
Rabbits	0.1	0.1	0.1	0.1	0.1	0.1

Source: Haberl et al. (2007); own calculations, see text.

Data on animal stocks and production from 1961 onwards were taken from FAO (2006). For the years 1955-1960 I used the data from Ministerio de Agricultura (1963-1973) and Barciela et al. (2005).

Feed supply (apart from grazing) consists of market feed and non-market feed. Market feed consists of feed from primary crops and processed feedstuff, and was taken from FAO (2006) and converted to dry matter (using the values on water content given in Table A6). For 1955-60 the average yearly increase of the market feed components (crops primary equivalent and livestock and fish primary equivalent) was assumed to be the same as in the period 1961-70.

Table A6: Values on water content (W.c.) used for FAO Market Feed.

Feed item	W.c.	Feed item	W.c.	Feed item	W.c.
Barley	14%	Copra Cake	10%	Tomatoes	94%
Maize	14%	Cottonseed Cake	10%	Vegetables, Other	95%
Wheat	14%	Groundnut Cake	10%	Molasses	33%
Millet	12%	Palmkernel Cake	10%	Sugar & Sweeteners	1%
Oats	14%	Rape and Mustard Cake	10%		
Rice (Paddy Equiv)	14%	Sesameseed Cake	10%	Animal Fats	0%
Rye	14%	Soyabean Cake	10%	Eggs	73%
Sorghum	11%	Sunflowerseed Cake	10%	Fish, Seafood	50%
Cereals, Other	14%	Oilseed Cakes, Other	10%	Fish Meal	10%
Roots&Tuber Dry Equiv	0%	Apples	85%	Meat	50%
Sunflowerseed	7%	Fruits, Other	85%	Meat Meal	10%
Cottonseed	10%	Beans	80%	Milk – excl. Butter	87%
Soyabeans	10%	Peas	78%	Whey	93%
Oilcrops, Other	10%	Pulses, Other	10%		

Sources: based on Souci et al. (2000), Purdue University Center for New Crops and Plant Products (2006), Löhr (1990), Watt et al. (1975)

Non-market feed consists of fodder crops (not included in FAO market feed), crop residues and hay (harvested on meadows). Data on fodder crops are given by Spanish agricultural statistics. Wirsenius (2000) estimates that in industrial regions 5-10% of total crop residues are used as feed, whereas in non-industrial regions the number is around 30% (with estimates of recovered residues being around 70%, respectively 80-90% of total crop residues). Haberl et al. (2007) estimate (for the year 2000) that in Western Europe 10% of total recovered crop residues are used for feed. According to Orskov (1992) the share of crop by-products used as feed is higher in the Mediterranean regions than in many northern and western European countries. Based on this information I estimate that 15% of all recovered crop residues are used as feed. To consider the state of industrialization this value is set at 25% at the beginning of the time series, when the Spanish agriculture can still be considered pre-industrial (Naredo, 2004), and is interpolated linearly between 1955 and 1980, from where on the value of 15% is applied. Hay harvest on meadows is reported in Spanish agricultural statistics. Data before 1973 are about 5 times higher than afterwards. I assume that data are reported in fresh weight until 1973 and as air-dry hay thereafter (although there is no note on this in the year books). I converted the data on hay harvest to dry matter using values on water content of 83% and 15% respectively (Löhr, 1990).

The total harvest through grazing was assigned to different land use categories using the following assumptions: 20% of NPP_{act} on Fallow were supposed to be consumed through livestock grazing, as well as 10% of the NPP remaining on the field after harvest on the areas of cereals, pulses, and grasses and legumes for fodder. On meadows, total harvest (hay harvest and grazing) was assumed to account for ⅔ of NPP_{act}. The remaining part of harvest through livestock grazing was assigned to other grassland, shrubland and forest categories in the same proportions as the total weight of grazing animals per year was distributed amongst them. Estimates on this are given in the Spanish agricultural statistics. Before 1973 proportions of the different amounts of grazed biomass per unit area and year between these land use categories were assumed to be constant at the ten-year-average from 1973 to 1982.

Harvest through forestry

Harvest through forestry includes industrial roundwood and wood fuel harvest, and harvest of other forest products (cork and resin). It should be mentioned that the harvest of wood and cork is the harvest of NPP accumulated over several years. This has been discussed as a problem in HANPP definitions (Haberl et al., 2004; Krausmann, 2001), as it could result in negative NPP_t values in the case of stock-depleting destructive forestry harvest. This is however not the case for Spain within the observed time period, where the forest area has steadily increased, and large areas have been subject to afforestation since 1940.

Roundwood harvest consists of removals of roundwood and of felling losses. Data on roundwood removals were taken from the Spanish Forestry Statistics Year Books and the Spanish agricultural statistics. Data are given in cubic metres fresh weight (overbark) and were converted to tons dry matter using wood density values of 41% for coniferous and 58% for non-coniferous wood (derived from Penman et al. 2003). Felling losses consist of all aboveground components of felled trees that are not removed from the felling site (including silvicultural and pre-commercial thinnings and cleanings). Total fellings are calculated by dividing removals by the recovery rate (the recovery rate being the ratio of removals to total fellings). Based on the country-specific estimates of felling residues presented by Karjalainen et al. (2004), I used a recovery rate of 71% for my calculations. As roundwood harvest mainly takes place in closed forest, 95% of the fellings were assigned to this land use category and the remaining 5% to open forest.

Data on removals of wood fuel were taken from the same sources as roundwood removals. Before 1956 firewood statistics did not account for gorse *(Ulex europaeus L.)*, which makes up a considerable part of wood fuel harvest. Therefore I estimated wood fuel harvest in 1955 by using the per capita wood fuel harvest of 1956. Up to 1972 statistics include wood fuel used for livestock bedding. From 1961-73 official data include an estimate of wood fuel considered as “unclassified or from outside the forest”. As there is no further information on the origin of this wood fuel, I can not rule out that this category includes agricultural residues. To eliminate the possibility of double-counting I do not account for wood fuel from this category. Data are given in stacked cubic metres. Factors for the conversion to solid cubic metres usually range from about 0.65 to 0.75. In this study I used a factor of 0.7 (FAO 1986, ÖSTAT 1992). For the conversion to tons dry matter and for the accounting of felling losses the same factors (wood densities and recovery rate) as for roundwood were applied. 50% of the wood fuel harvest was assigned to shrubland, 25% to closed forest and 25% to open forest.

Other forestry harvest includes the harvest of cork and resin. Production data were taken from Spanish agricultural statistics and Barciela et al. (2005) and converted to dry matter with values on water content taken from Scharnow (2007). For these products the difference between total harvest and removed harvest was considered marginal and was not accounted for. Cork harvest was assigned to open forest, and harvest of resin to closed forest.

Harvest through human-induced fires

I consider the amount of aboveground biomass burned in human-induced fires as harvest of NPP. To avoid double-counting, I do not account unburnt parts of trees killed in human-induced fires as appropriated, since most of the burned trees are harvested after the fire, and are therefore already included in wood harvest (Prieto (1990) estimates that 90% of the wood is harvested). I consider all fires except those caused by lightning as human-induced (Prieto, 1990).

The amount of biomass burned in human-induced fires was calculated separately for forest areas, non-forest areas with predominately woody vegetation cover (interpreted as shrublands), and non forest areas with predominately herbaceous vegetation cover (interpreted as grasslands), using the following formula:

$$BB = A * B * \beta$$

BB = burned biomass [t DM/yr]
A = burned area [ha /yr]
B = total aboveground biomass before fire [t DM/ha]
Β = burning efficiency (% of total aboveground biomass burned)

Calculations were made on a yearly basis. Data on burned areas were taken from Ministerio de Medio Ambiente (2006). Based on the data for the period 1995-2005, given in Ministerio de Medio Ambiente (2006), I assume that 92% of burned forest areas, and 95% of burned non forest areas are burned due to human activities[7], and that 84% of the non forest areas burned in human-induced fires are shrublands, and 16% grasslands. As an estimate for the average aboveground biomass of forest ecosystems in Spain, I used the average value of aboveground Biomass of Catalonian forests, taken from the Ecological and Forest Inventory of Catalonia (CREAF, 2004). For the estimation of aboveground biomass of shrublands I use the same sources as for the estimation of NPP_{act} of shrublands, using the average of all values given in these sources. Aboveground biomass of grasslands was estimated at 2.5 t/ha (Saugier et al., 2001). Values for burning efficiencies were estimated on the basis of Michel et al. (2005), IPCC (2006) and Seiler and Crutzen (1980). Table A7 gives the values on aboveground biomass and burning efficiency used in this study.

Table A7: Values of aboveground biomass and burning efficiency used.

	Forest	Shrubland	Grassland
Aboveground biomass before fire [t DM/ha]	61.2	22.3	2.5
Burning efficiency (% of aboveground biomass burned)	25%	70%	90%

Sources: see text

Other harvest

This category consists of harvest on built-up land and on Esparto grassland. Harvest on built-up land takes place through gardening, park and infrastructure maintenance, etc. and is estimated to be 50% of NPP_{act} (Haberl et al., 2007). Data on the harvest of Esparto (*Stipa tenacissima L.*) leaves for fibre production and paper making were taken from Barciela et al. (2005) and from Spanish agricultural statistics and were converted to dry matter assuming a water content of 10% (Scharnow, 2007).

Backflows to nature

Following definitions given by Haberl el al (2007) I consider unrecovered crop residues, felling losses, and livestock feces dropped on the grazing site as backflows to nature. Livestock feces dropped on the grazing site are calculated based on the assumptions that cattle excrete 35% and all other grazers 25% of dry matter feed intake, and that two thirds of the excrements are dropped on the grazing site (Haberl et al., 2007).

[7] Although only approximately 4% of the fires are caused by lightning (Prieto, 1990), it is frequent that relatively large areas are burned in these fires (FAO 2001).

Annex B - Results: Additional Figures and Tables

This Annex is meant to give more detailed information on the results of the study. Some of the results are broken down to main land use types. For some harvest categories (e.g. harvest through livestock grazing, harvest of wood fuel) the allocation to certain land use types is rather problematic. For this reason the results on NPP_h and NPP_t are probably more reliable for the total area than when broken down to land use types (especially in the case of shrubland, grassland and forest).

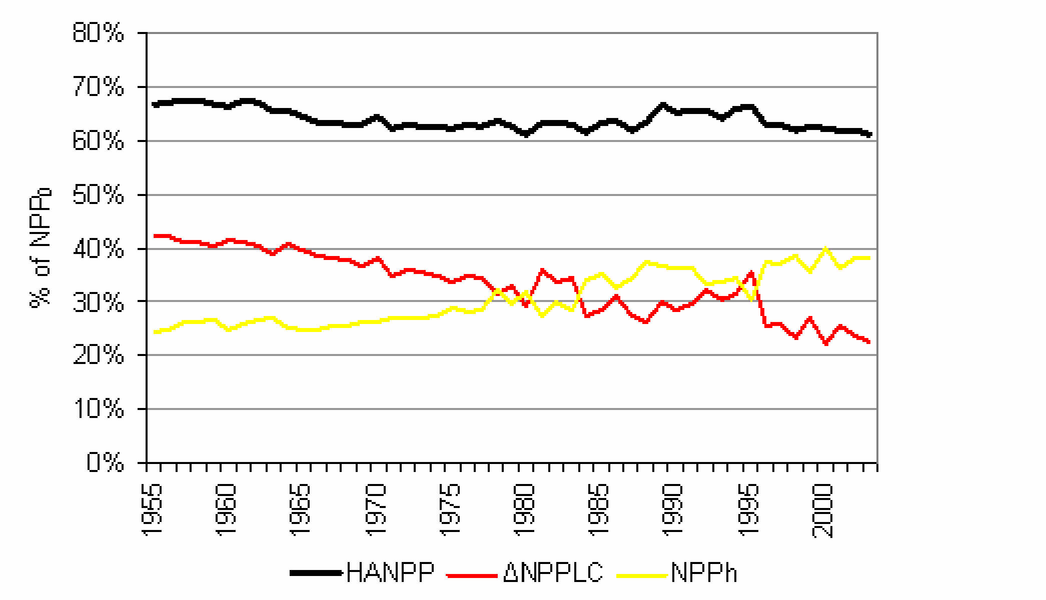

Figure B1: Development of HANPP, ΔNPP_{LC} and NPP_h as % of the potential NPP.
Sources: own calculations, see text.

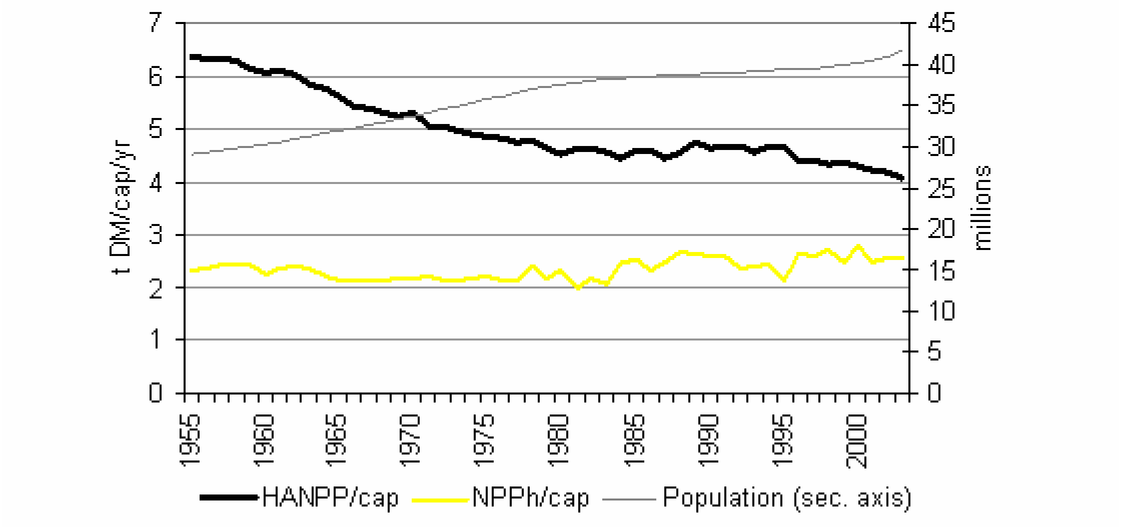

Figure B2: Development of HANPP and NPP_h per capita, and population development.
Sources: Population: Nicolau (2005), Instituto Nacional de Estadística (2006); HANPP and NPP_h: own calculations, see text.

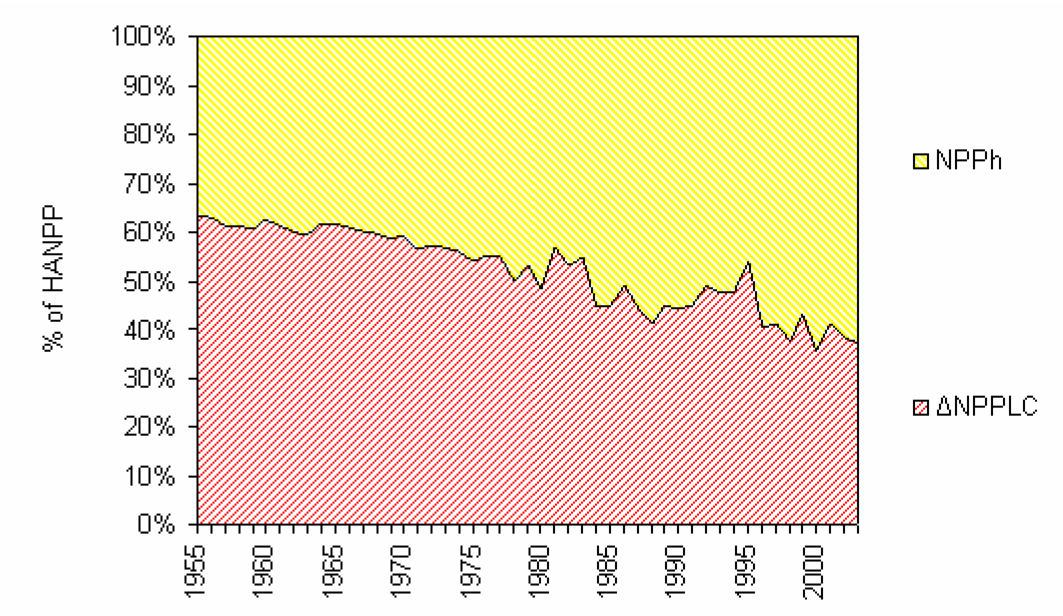

Figure B3: Development of the pathways of NPP appropriation: NPP_h and ΔNPP_{LC} as % of HANPP. Sources: own calculations, see text.

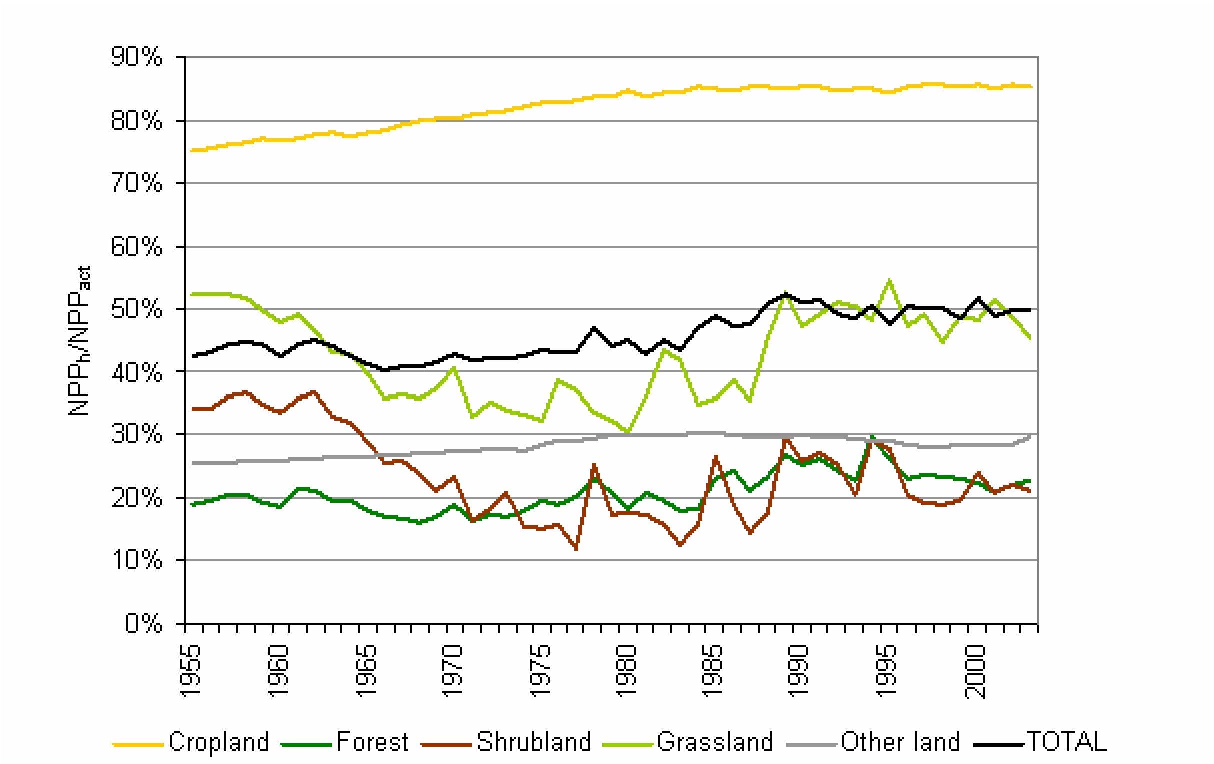

Figure B4: Development of the share of NPP_h on NPP_{act}, broken down to main land use types. Sources: own calculations, see text.

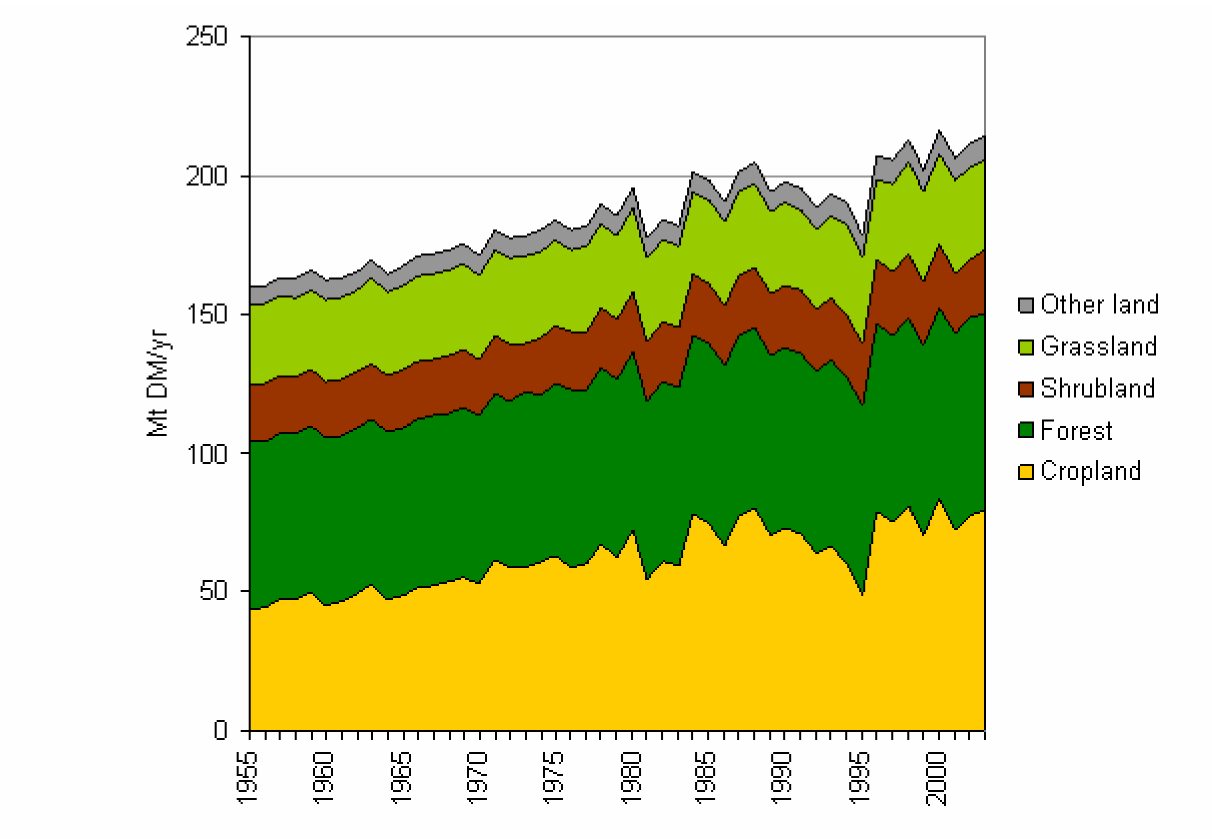

Figure B5: Development of NPP_{act}, broken down to main land use types.
(stacked area chart)
Sources: own calculations, see text.

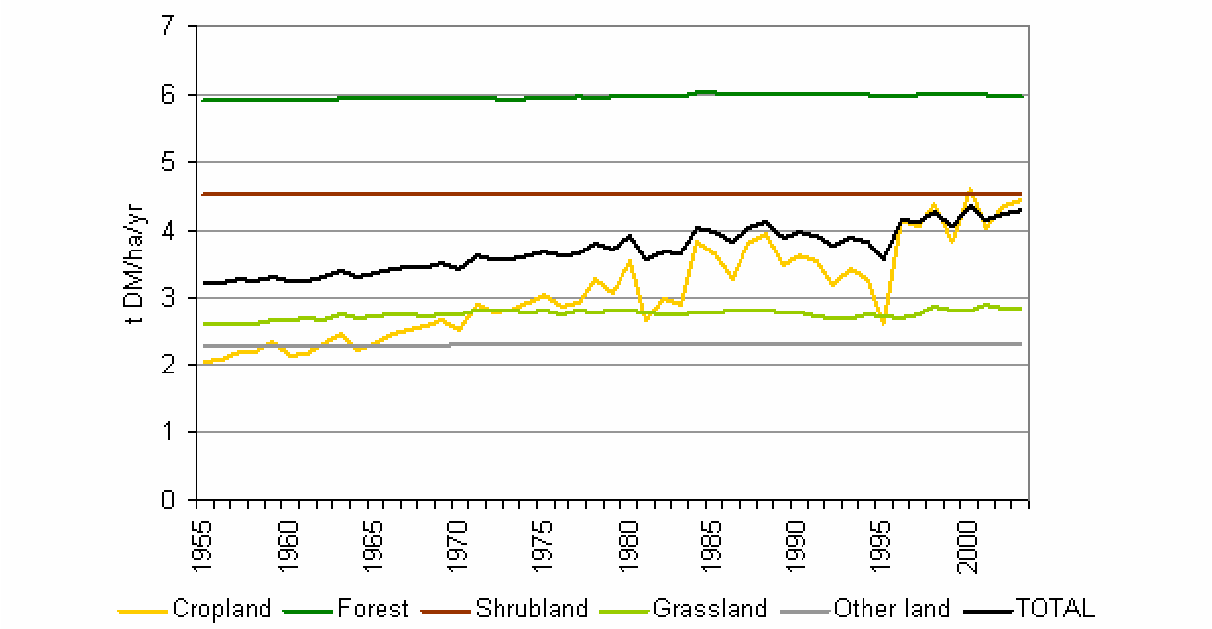

Figure B6: Development of NPP_{act} per area, broken down to main land use types.
Sources: own calculations, see text.

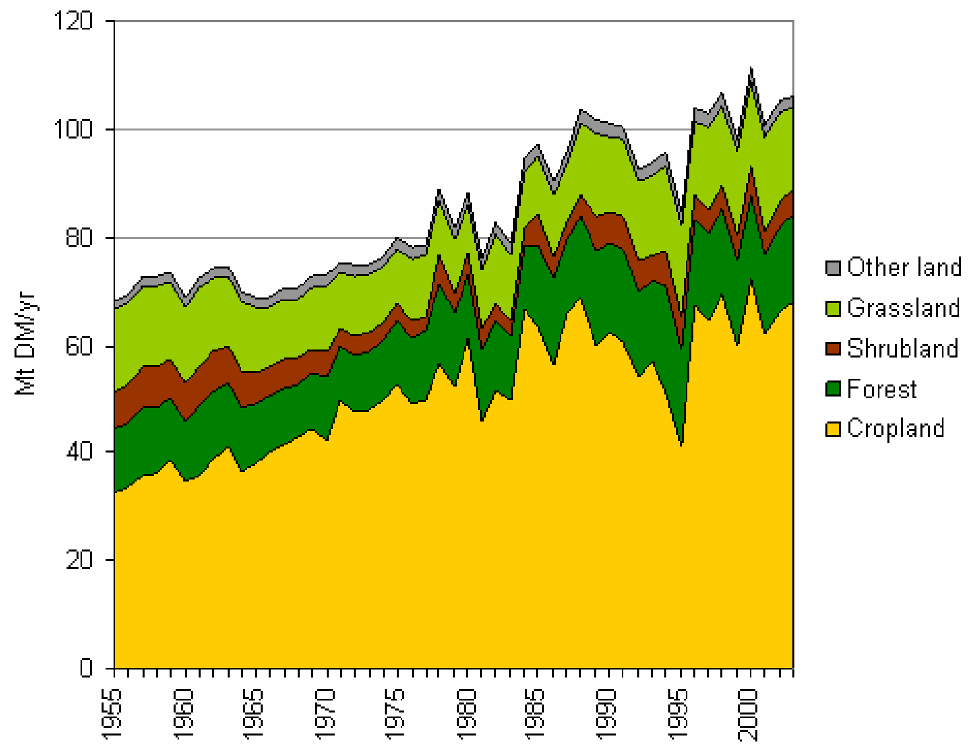

Figure B7: Development of NPP_h, broken down to main land use types.
(stacked area chart)
Sources: own calculations, see text.

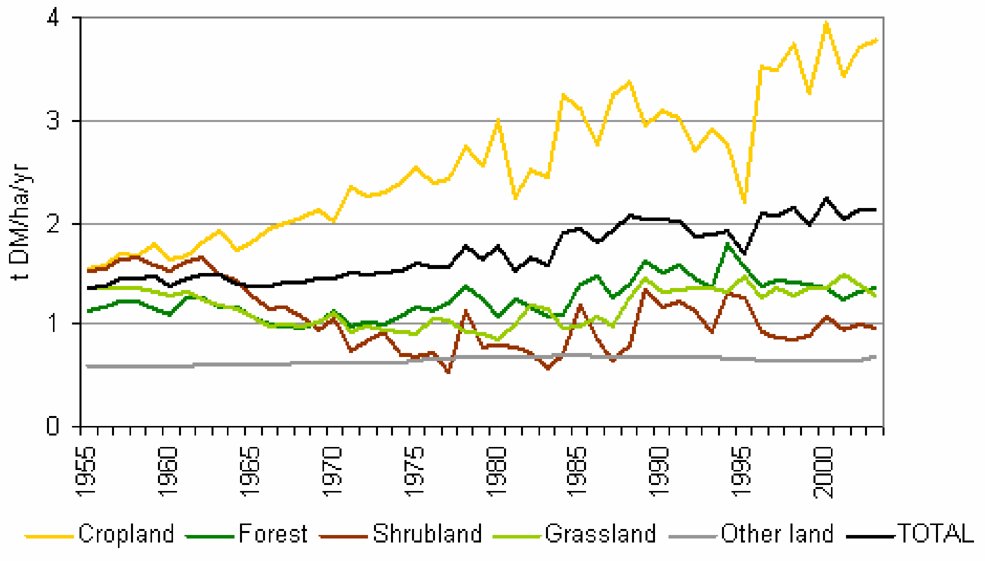

Figure B8: Development of NPP_h per area, broken down to main land use types.
Sources: own calculations, see text.

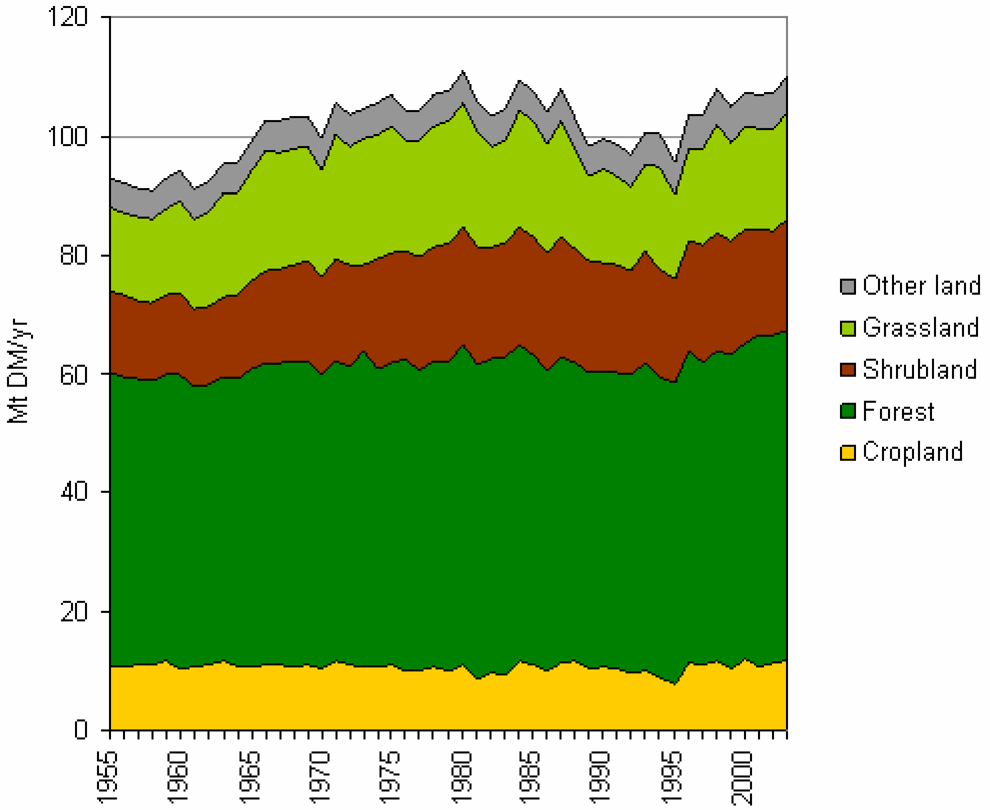

Figure B9: Development of NPP_t, broken down to main land use types.
(stacked area chart)
Sources: own calculations, see text.

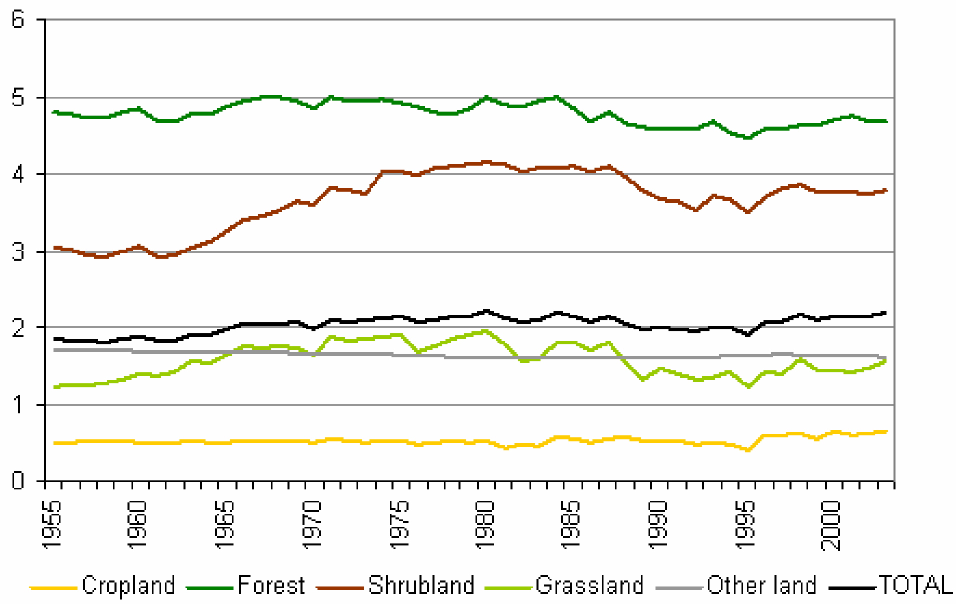

Figure B10: Development of NPP_t per area, broken down to main land use types.
Sources: own calculations, see text.

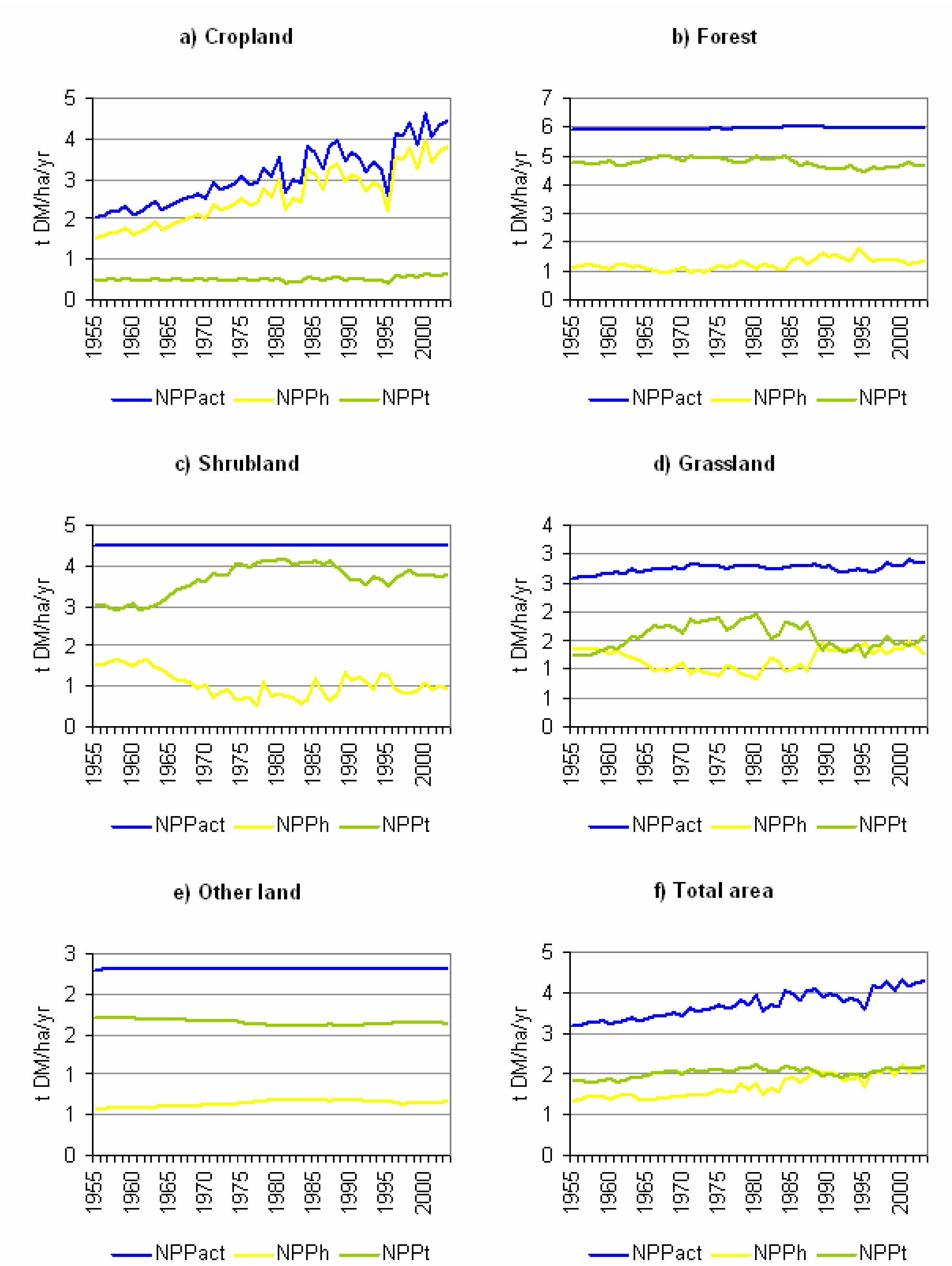

Figure B11: Development of NPPact, NPPh and NPPt per area for the main land use types (a-e) and for the total area (f).
Sources: own calculations, see text.

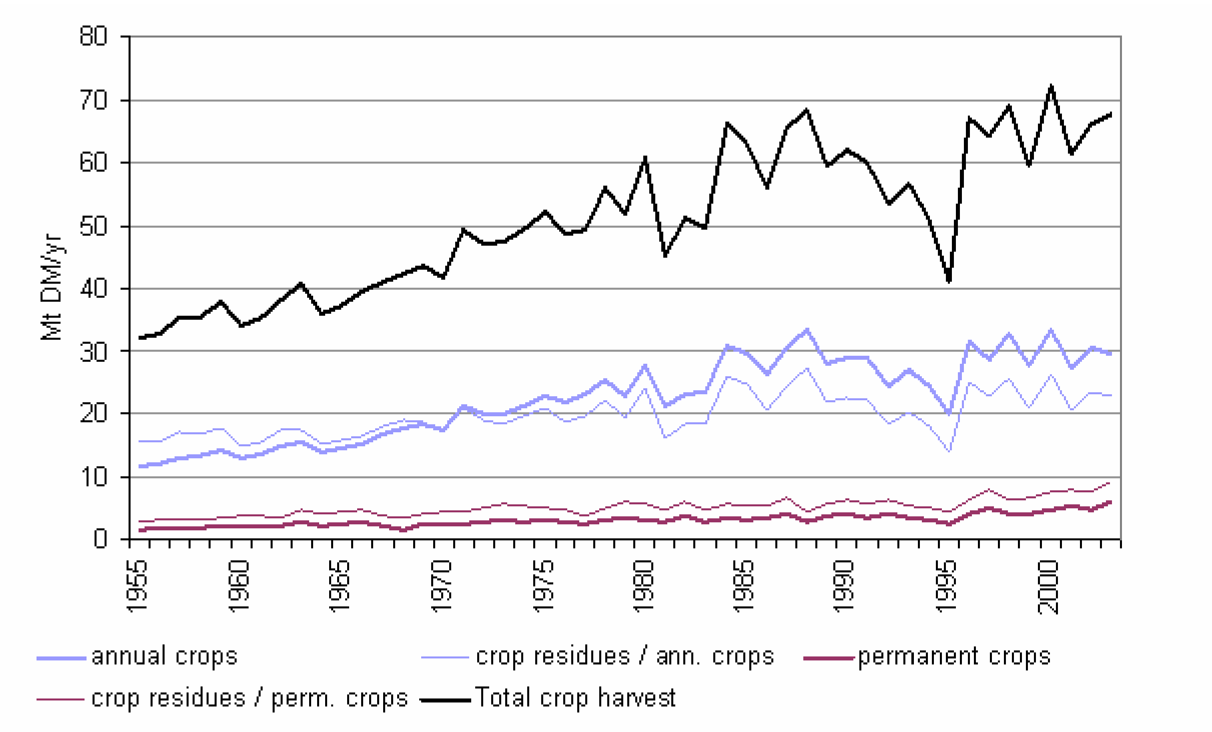

Figure B12: Development of crop harvest (primary crops and crop residues).
Crop residues include grazed residues.
Sources: Spanish Agricultural Statistical Yearbooks; own calculations, see text.

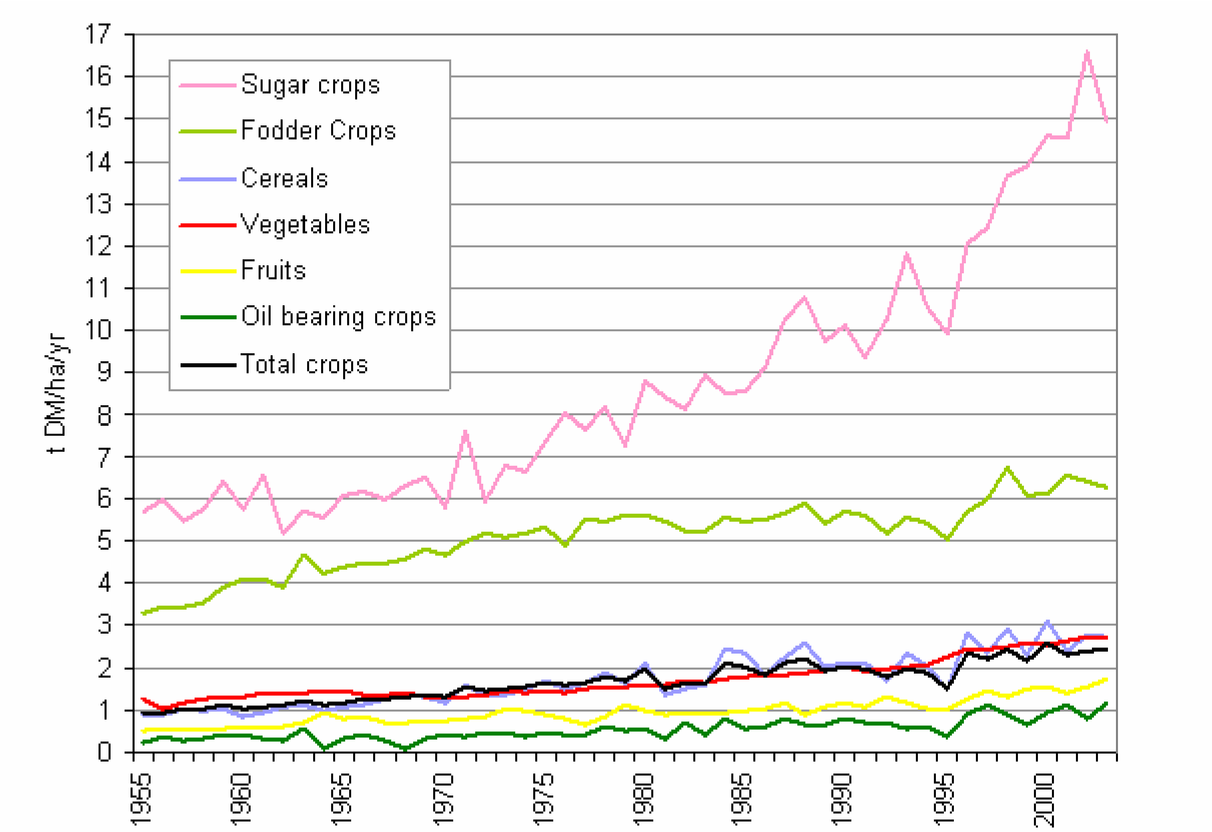

Figure B13: Development of average primary crop yields, broken down to various crop aggregates.
Sources: Spanish Agricultural Statistical Yearbooks; own calculations, see text.

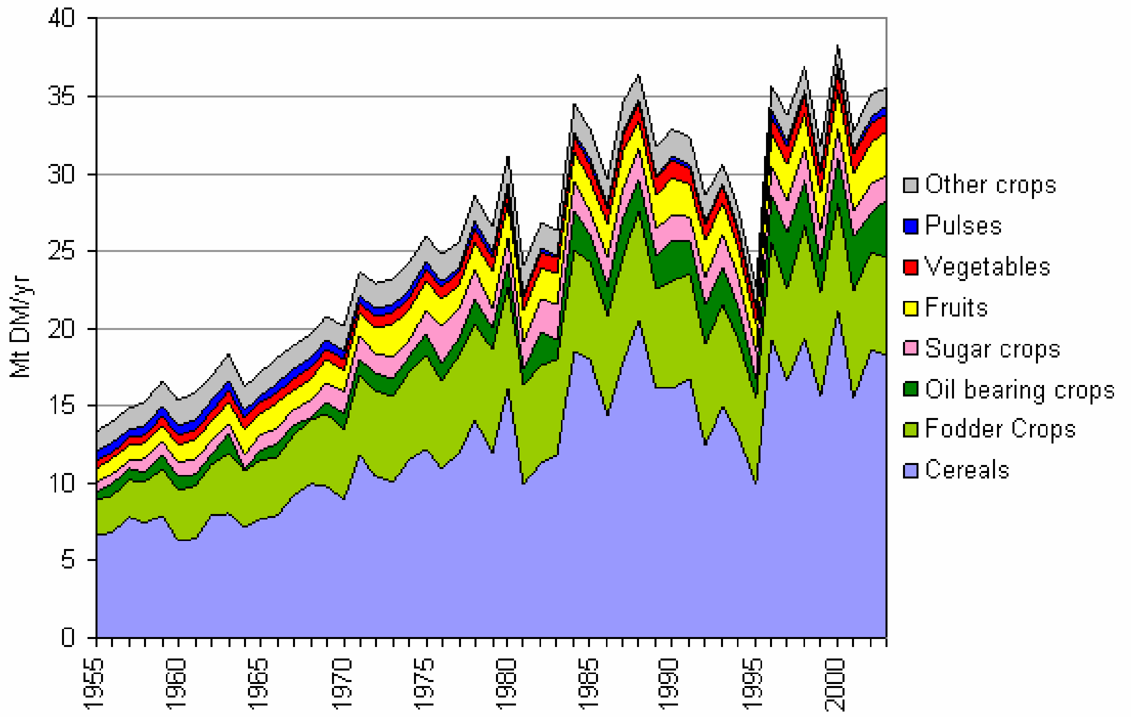

Figure B14: Development of primary crop harvest, broken down to various crop aggregates. (stacked area chart)
Sources: Spanish Agricultural Statistical Yearbooks, own calculations, see text.

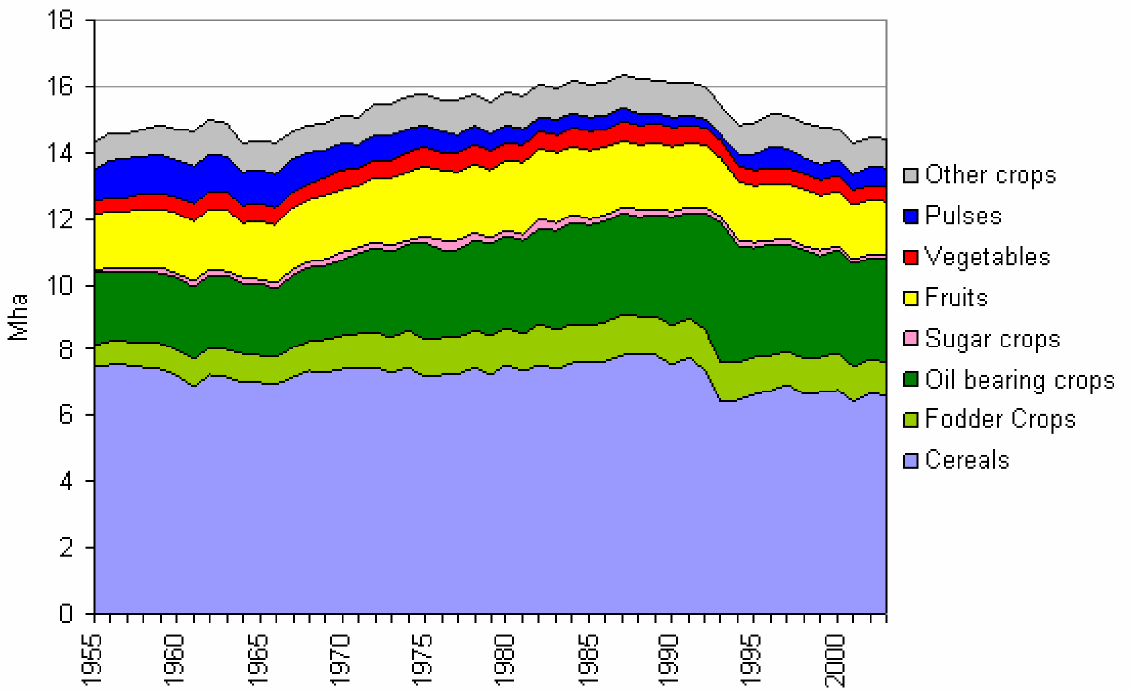

Figure B15: Development of harvested areas on cropland, broken down to various crop aggregates. (stacked area chart)
Sources: Spanish Agricultural Statistical Yearbooks, own calculations, see text.

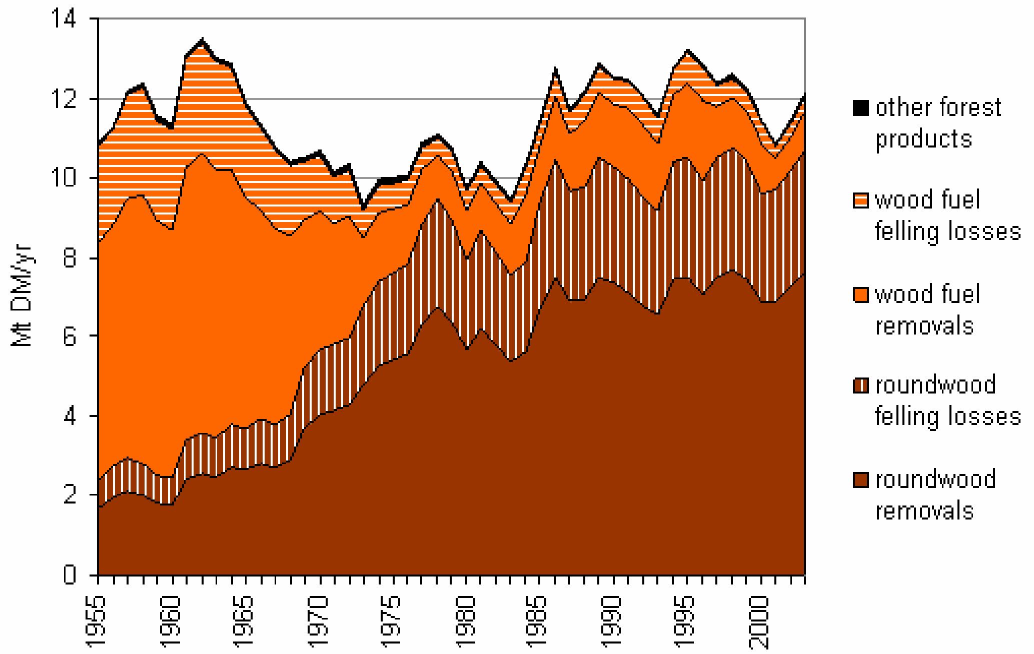

Figure B16: Development of forestry harvest (wood removals, felling losses and other forest products).
(stacked area chart)
Sources: Spanish Forestry Statistics Yearbook; Spanish Agriculatural Statistical Yearbook; Barciela et al., 2005; own calculations, see text.

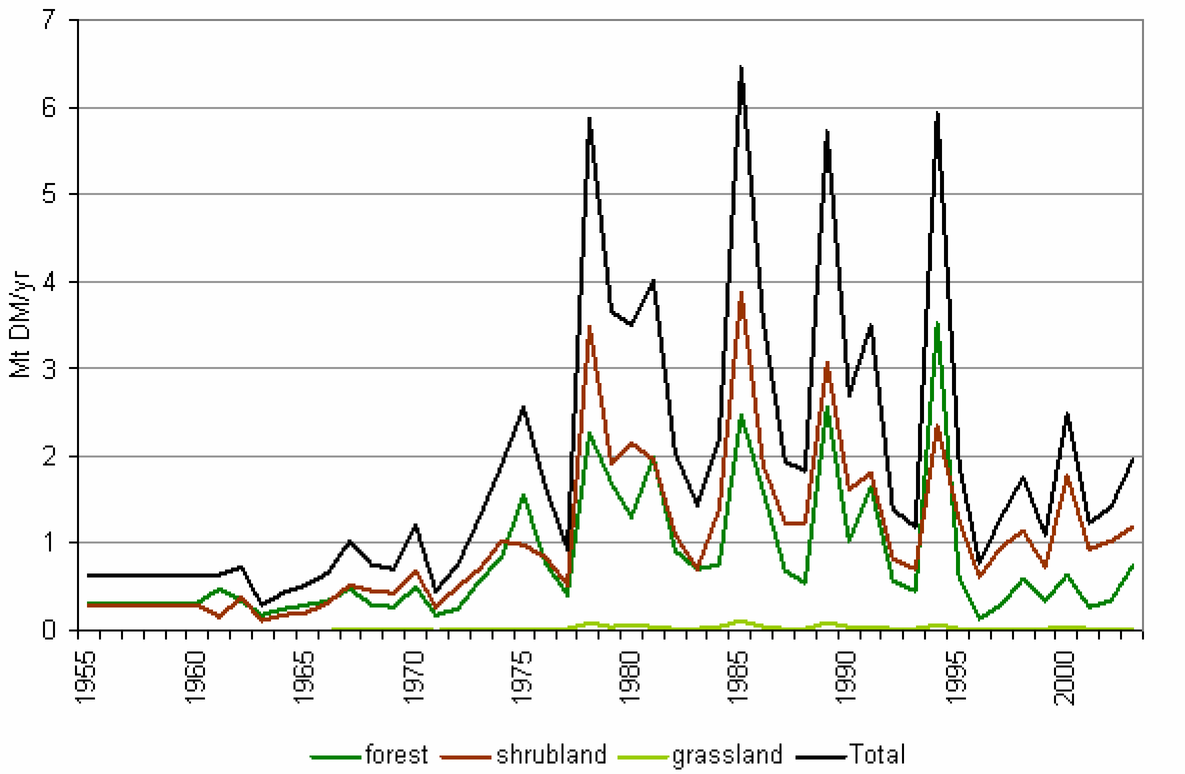

Figure B17: Development of biomass burned in human-induced fires, broken down to main land use types.
Sources: own calculations, see text.

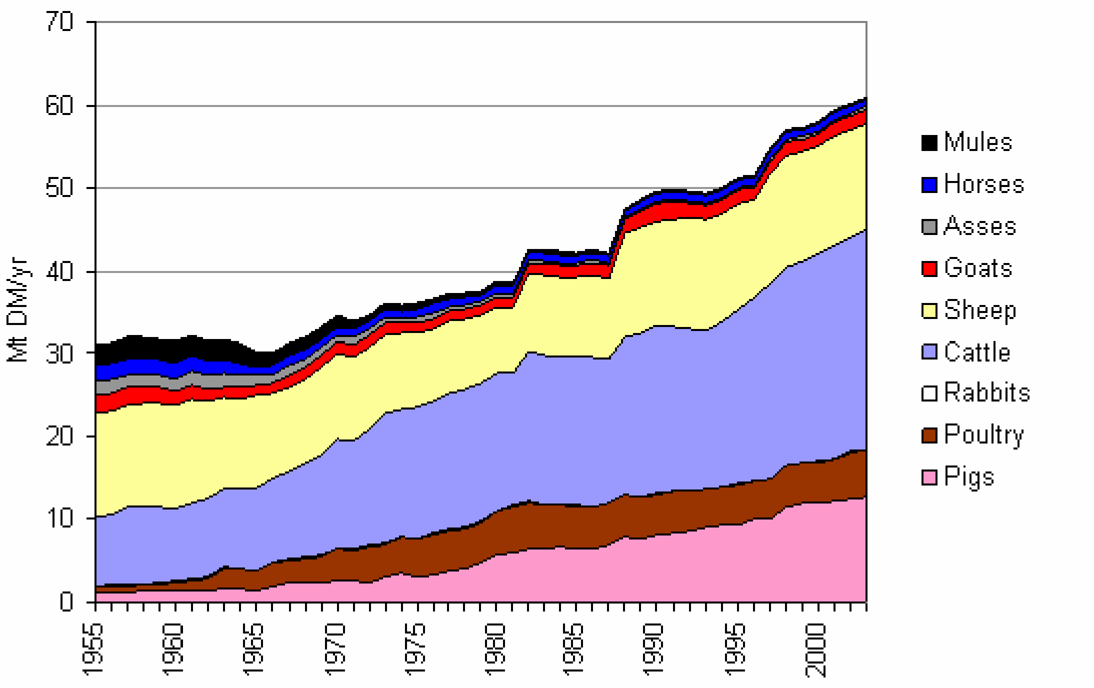

Figure B18: Development of feed demand for different livestock species
(stacked area chart)
Sources: own calculations, see text.

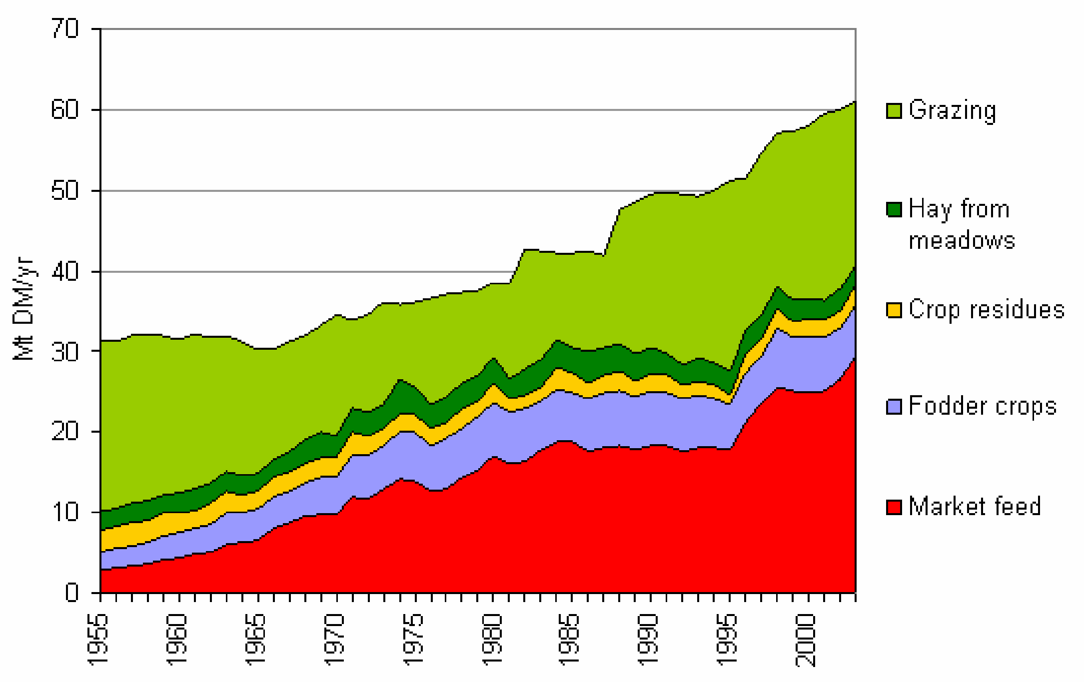

Figure B19: Development of feed supply and grazing.
(stacked area chart)
Sources: FAO, 2006 (Market Feed); own calculations, see text.

Table B1: Development of HANPP and its main components (NPP_{act}, NPP_h, ΔNPP_{LC}); yearly data.

	HANPP % *	HANPP/cap *	NPP_{act} *	NPP_h	NPP_h/cap	ΔNPP_{LC} *
Unit	%	Mt cap^{-1} a^{-1}	Mt a^{-1}	Mt a^{-1}	Mt cap^{-1} a^{-1}	%
1955	67% ± 9%	6.4 ± 0.8	160 ± 24	68	2.3	42% ± 9%
1956	67% ± 9%	6.3 ± 0.8	161 ± 24	69	2.4	42% ± 9%
1957	67% ± 9%	6.3 ± 0.8	163 ± 24	73	2.5	41% ± 9%
1958	67% ± 9%	6.3 ± 0.8	163 ± 24	73	2.4	41% ± 9%
1959	67% ± 9%	6.2 ± 0.8	166 ± 24	74	2.4	40% ± 9%
1960	66% ± 9%	6.1 ± 0.8	162 ± 24	69	2.3	41% ± 9%
1961	67% ± 9%	6.1 ± 0.8	163 ± 24	72	2.4	41% ± 9%
1962	67% ± 9%	6.0 ± 0.8	165 ± 24	74	2.4	40% ± 9%
1963	66% ± 9%	5.8 ± 0.8	170 ± 25	75	2.4	39% ± 9%
1964	66% ± 9%	5.8 ± 0.8	165 ± 24	70	2.2	41% ± 9%
1965	64% ± 9%	5.6 ± 0.8	167 ± 24	69	2.2	40% ± 9%
1966	63% ± 9%	5.4 ± 0.8	171 ± 25	69	2.1	38% ± 9%
1967	63% ± 9%	5.4 ± 0.8	172 ± 24	70	2.2	38% ± 9%
1968	63% ± 9%	5.3 ± 0.7	173 ± 24	70	2.1	38% ± 9%
1969	63% ± 9%	5.2 ± 0.7	175 ± 25	73	2.2	37% ± 9%
1970	65% ± 9%	5.3 ± 0.7	171 ± 24	73	2.2	38% ± 9%
1971	62% ± 9%	5.0 ± 0.7	180 ± 24	75	2.2	35% ± 9%
1972	63% ± 9%	5.0 ± 0.7	178 ± 24	75	2.2	36% ± 9%
1973	63% ± 9%	5.0 ± 0.7	178 ± 24	75	2.1	36% ± 9%
1974	63% ± 9%	4.9 ± 0.7	180 ± 25	76	2.2	35% ± 9%
1975	62% ± 9%	4.8 ± 0.7	184 ± 25	80	2.2	34% ± 9%
1976	63% ± 9%	4.8 ± 0.7	181 ± 24	78	2.2	35% ± 9%
1977	63% ± 9%	4.7 ± 0.7	182 ± 25	79	2.2	34% ± 9%
1978	64% ± 9%	4.8 ± 0.7	190 ± 25	89	2.4	32% ± 9%
1979	63% ± 9%	4.6 ± 0.7	186 ± 25	82	2.2	33% ± 9%
1980	61% ± 9%	4.5 ± 0.7	196 ± 25	88	2.4	29% ± 9%
1981	63% ± 9%	4.6 ± 0.7	178 ± 25	76	2.0	36% ± 9%
1982	64% ± 9%	4.6 ± 0.6	184 ± 24	83	2.2	34% ± 9%
1983	63% ± 9%	4.6 ± 0.6	182 ± 24	79	2.1	34% ± 9%
1984	61% ± 9%	4.4 ± 0.6	202 ± 24	94	2.5	27% ± 9%
1985	63% ± 9%	4.6 ± 0.6	198 ± 24	97	2.5	28% ± 9%
1986	64% ± 9%	4.6 ± 0.6	190 ± 24	90	2.3	31% ± 9%
1987	62% ± 9%	4.4 ± 0.6	201 ± 24	96	2.5	27% ± 9%
1988	63% ± 9%	4.5 ± 0.6	205 ± 24	103	2.7	26% ± 9%
1989	67% ± 9%	4.8 ± 0.6	194 ± 24	102	2.6	30% ± 9%
1990	65% ± 9%	4.6 ± 0.6	198 ± 25	101	2.6	29% ± 9%
1991	66% ± 9%	4.7 ± 0.6	195 ± 24	100	2.6	29% ± 9%
1992	66% ± 9%	4.7 ± 0.6	188 ± 24	92	2.4	32% ± 9%
1993	64% ± 9%	4.5 ± 0.6	193 ± 24	94	2.4	30% ± 9%
1994	66% ± 9%	4.7 ± 0.6	190 ± 25	96	2.4	31% ± 9%
1995	66% ± 9%	4.7 ± 0.6	178 ± 25	84	2.1	36% ± 9%
1996	63% ± 9%	4.4 ± 0.6	207 ± 25	104	2.6	25% ± 9%
1997	63% ± 9%	4.4 ± 0.7	205 ± 26	103	2.6	26% ± 9%
1998	62% ± 9%	4.3 ± 0.7	213 ± 26	107	2.7	23% ± 9%
1999	63% ± 9%	4.4 ± 0.6	202 ± 26	98	2.5	27% ± 9%
2000	62% ± 9%	4.3 ± 0.6	216 ± 26	111	2.8	22% ± 9%
2001	62% ± 9%	4.2 ± 0.6	207 ± 26	101	2.5	25% ± 9%
2002	62% ± 9%	4.2 ± 0.6	211 ± 26	105	2.6	24% ± 9%
2003	61% ± 9%	4.1 ± 0.6	214 ± 26	106	2.5	23% ± 9%

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B2: Development of land use [kha]: Cropland, Forest, Shrubland; yearly data.

	Annual crops	Permanent crops	Fallow	**Cropland**	Closed forest	Open forest	**Forest**	**Shrubland**
1955	10,002	4,500	6,586	**21,088**	6,015	4,244	10,259	**4,597**
1956	10,318	4,453	6,526	**21,296**	5,989	4,200	10,189	**4,565**
1957	10,288	4,255	6,821	**21,363**	5,974	4,165	10,139	**4,541**
1958	10,336	4,282	6,831	**21,449**	5,968	4,135	10,103	**4,524**
1959	10,406	4,340	6,879	**21,624**	5,945	4,094	10,039	**4,494**
1960	10,226	4,389	6,639	**21,254**	6,030	4,129	10,159	**4,546**
1961	10,105	4,484	6,912	**21,501**	5,979	4,069	10,048	**4,495**
1962	10,422	4,536	6,624	**21,581**	5,971	4,039	10,009	**4,477**
1963	10,276	4,632	6,627	**21,535**	5,981	4,021	10,003	**4,473**
1964	9,959	4,634	6,654	**21,246**	6,073	4,059	10,132	**4,529**
1965	9,922	4,628	6,456	**21,006**	6,156	4,089	10,245	**4,579**
1966	9,943	4,647	6,308	**20,898**	6,173	4,076	10,249	**4,579**
1967	10,173	4,699	6,045	**20,917**	6,188	4,061	10,249	**4,578**
1968	10,295	4,749	5,913	**20,956**	6,215	4,055	10,270	**4,586**
1969	10,290	4,745	5,812	**20,847**	6,284	4,075	10,359	**4,625**
1970	10,470	4,829	5,858	**21,157**	6,180	3,983	10,164	**4,536**
1971	10,552	4,845	5,793	**21,189**	6,164	3,949	10,113	**4,513**
1972	10,667	4,880	5,621	**21,169**	6,198	3,947	10,145	**4,525**
1973	10,608	4,925	5,446	**20,979**	6,172	4,578	10,750	**3,840**
1974	10,790	4,967	5,128	**20,885**	6,240	3,835	10,075	**4,640**
1975	10,785	5,012	5,036	**20,834**	6,396	3,948	10,344	**4,600**
1976	10,572	5,002	5,086	**20,659**	6,511	4,193	10,703	**4,630**
1977	10,342	4,974	5,289	**20,604**	6,604	3,918	10,522	**4,721**
1978	10,576	4,938	5,064	**20,578**	6,629	4,076	10,705	**4,697**
1979	10,396	4,950	5,181	**20,527**	6,673	4,068	10,741	**4,765**
1980	10,668	4,941	4,891	**20,499**	6,741	4,033	10,774	**4,824**
1981	10,582	4,919	4,986	**20,487**	6,745	4,032	10,777	**4,804**
1982	10,844	4,922	4,759	**20,524**	6,807	4,044	10,852	**4,711**
1983	10,848	4,916	4,744	**20,508**	6,812	4,025	10,838	**4,729**
1984	11,078	4,861	4,573	**20,512**	7,216	3,470	10,686	**4,857**
1985	10,991	4,852	4,573	**20,415**	7,252	3,500	10,752	**4,863**
1986	11,038	4,855	4,527	**20,420**	7,183	3,601	10,784	**4,891**
1987	11,266	4,806	4,319	**20,390**	7,188	3,552	10,740	**4,921**
1988	11,275	4,791	4,302	**20,368**	7,179	3,560	10,740	**4,916**
1989	11,178	4,812	4,334	**20,324**	7,183	3,593	10,776	**4,917**
1990	11,173	4,837	4,162	**20,172**	7,189	3,636	10,825	**4,981**
1991	11,203	4,831	4,055	**20,089**	7,253	3,599	10,852	**5,006**
1992	11,165	4,746	4,036	**19,947**	7,255	3,696	10,951	**4,965**
1993	10,740	4,675	4,241	**19,657**	7,368	3,739	11,107	**5,030**
1994	10,263	4,690	3,501	**18,454**	7,365	3,750	11,114	**5,031**
1995	10,275	4,708	3,771	**18,753**	7,216	4,211	11,427	**4,964**
1996	10,590	4,694	3,861	**19,144**	7,241	4,130	11,371	**5,042**
1997	10,552	4,774	3,296	**18,623**	7,255	3,866	11,121	**5,177**
1998	10,270	4,832	3,412	**18,515**	7,422	3,868	11,289	**5,122**
1999	10,219	4,858	3,262	**18,338**	7,539	3,858	11,397	**5,125**
2000	10,178	4,904	3,222	**18,304**	7,460	3,893	11,353	**5,055**
2001	9,554	4,980	3,510	**18,044**	7,662	4,046	11,708	**4,752**
2002	9,772	4,977	3,195	**17,944**	7,557	4,297	11,854	**4,638**
2003	9,664	4,964	3,353	**17,981**	7,614	4,246	11,860	**5,007**

Sources: see text

Table B3: Development of land use [kha]: Grassland, Other land; yearly data.

	Dry pastures	Esparto grassland	Meadows	Ext. grazed abandoned land	**Grassland**	Built-up land	Other areas	Inland water	**Other land**
1955	6,133	652	1,258	3,175	**11,218**	1,453	1,442	480	**3,375**
1956	6,064	610	1,261	3,165	**11,100**	1,465	1,442	480	**3,387**
1957	6,008	627	1,298	3,160	**11,093**	1,477	1,442	480	**3,400**
1958	5,960	629	1,301	3,160	**11,049**	1,490	1,442	480	**3,412**
1959	5,896	626	1,282	3,151	**10,955**	1,502	1,442	480	**3,425**
1960	5,940	698	1,303	3,199	**11,140**	1,515	1,442	480	**3,437**
1961	5,849	702	1,315	3,175	**11,041**	1,530	1,442	480	**3,452**
1962	5,800	703	1,325	3,174	**11,002**	1,546	1,442	480	**3,468**
1963	5,770	695	1,395	3,183	**11,042**	1,562	1,442	480	**3,485**
1964	5,818	692	1,382	3,235	**11,128**	1,579	1,442	480	**3,501**
1965	5,856	680	1,372	3,282	**11,190**	1,596	1,442	480	**3,518**
1966	5,832	713	1,437	3,294	**11,276**	1,613	1,442	480	**3,535**
1967	5,806	684	1,446	3,305	**11,241**	1,630	1,442	480	**3,552**
1968	5,791	640	1,401	3,323	**11,155**	1,647	1,442	480	**3,569**
1969	5,815	494	1,448	3,363	**11,119**	1,665	1,442	480	**3,587**
1970	5,679	606	1,481	3,310	**11,075**	1,682	1,442	480	**3,605**
1971	5,624	561	1,600	3,304	**11,089**	1,711	1,442	480	**3,633**
1972	5,616	548	1,558	3,326	**11,047**	1,729	1,442	480	**3,651**
1973	6,118	481	1,530	3,171	**11,300**	1,746	1,442	480	**3,668**
1974	5,844	453	1,513	3,383	**11,193**	1,764	1,477	503	**3,744**
1975	5,719	438	1,506	3,412	**11,076**	1,784	1,385	515	**3,684**
1976	5,419	435	1,497	3,506	**10,857**	1,806	1,362	521	**3,688**
1977	5,505	437	1,479	3,565	**10,986**	1,828	1,353	524	**3,705**
1978	5,413	434	1,441	3,557	**10,845**	1,849	1,339	525	**3,712**
1979	5,315	438	1,448	3,627	**10,827**	1,864	1,288	524	**3,677**
1980	5,257	425	1,449	3,607	**10,738**	1,876	1,295	531	**3,702**
1981	5,223	423	1,464	3,638	**10,748**	1,887	1,301	532	**3,721**
1982	5,203	420	1,457	3,635	**10,714**	1,897	1,304	535	**3,736**
1983	5,193	421	1,452	3,661	**10,727**	1,906	1,295	535	**3,736**
1984	5,206	457	1,440	3,651	**10,754**	1,914	1,280	534	**3,728**
1985	5,271	458	1,457	3,568	**10,755**	1,921	1,301	531	**3,753**
1986	5,192	450	1,460	3,539	**10,641**	1,927	1,338	536	**3,801**
1987	5,247	442	1,438	3,527	**10,654**	1,932	1,369	533	**3,833**
1988	5,341	392	1,429	3,507	**10,669**	1,936	1,359	549	**3,844**
1989	5,319	389	1,430	3,535	**10,671**	1,940	1,359	550	**3,849**
1990	5,368	446	1,390	3,542	**10,746**	1,943	1,320	550	**3,812**
1991	5,107	425	1,330	3,845	**10,708**	1,944	1,362	577	**3,882**
1992	5,151	423	1,321	3,860	**10,755**	1,952	1,389	580	**3,920**
1993	5,188	417	1,307	3,882	**10,794**	1,957	1,412	581	**3,950**
1994	6,098	409	1,473	3,945	**11,925**	1,962	1,469	581	**4,012**
1995	5,507	407	1,500	3,960	**11,373**	1,967	1,471	581	**4,019**
1996	5,204	385	1,271	4,028	**10,888**	1,972	1,537	583	**4,092**
1997	5,596	329	1,440	4,078	**11,443**	1,976	1,609	587	**4,172**
1998	5,628	330	1,486	3,998	**11,441**	1,982	1,585	602	**4,170**
1999	5,701	310	1,491	4,027	**11,529**	1,990	1,552	606	**4,148**
2000	5,493	312	1,540	4,300	**11,645**	2,002	1,567	610	**4,180**
2001	5,547	309	1,663	4,265	**11,785**	2,024	1,575	650	**4,249**
2002	5,659	332	1,579	4,237	**11,807**	2,048	1,617	628	**4,293**
2003	5,548	341	1,546	4,079	**11,513**	2,083	1,476	616	**4,175**

Sources: see text

Table B4: Development of NPP_{act} [Mt DM/yr], broken down to main land use types; yearly data.

	Cropland *	Forest *	Shrubland *	Grassland *	Other land	Total land area *
1955	43.5 ± 1.3	60.5 ± 5.0	20.7 ± 7.8	29.0 ± 9.9	6.6	160.4 ± 24.0
1956	44.4 ± 1.3	60.1 ± 4.9	20.5 ± 7.8	28.9 ± 9.9	6.7	160.6 ± 23.9
1957	47.2 ± 1.4	59.9 ± 4.9	20.4 ± 7.7	28.9 ± 9.9	6.7	163.2 ± 23.9
1958	47.2 ± 1.4	59.7 ± 4.8	20.4 ± 7.7	28.9 ± 9.9	6.7	162.8 ± 23.8
1959	50.4 ± 1.4	59.3 ± 4.8	20.2 ± 7.6	29.0 ± 10.2	6.8	165.7 ± 24.0
1960	45.2 ± 1.3	60.0 ± 4.8	20.5 ± 7.7	29.7 ± 10.5	6.8	162.3 ± 24.3
1961	46.7 ± 1.4	59.4 ± 4.7	20.2 ± 7.6	29.6 ± 10.4	6.8	162.8 ± 24.1
1962	49.9 ± 1.3	59.2 ± 4.7	20.1 ± 7.6	29.3 ± 10.2	6.9	165.4 ± 23.8
1963	53.0 ± 1.3	59.2 ± 4.6	20.1 ± 7.6	30.4 ± 10.9	6.9	169.6 ± 24.5
1964	47.4 ± 1.3	60.0 ± 4.7	20.4 ± 7.7	30.0 ± 10.4	6.9	164.7 ± 24.2
1965	48.7 ± 1.3	60.7 ± 4.7	20.6 ± 7.8	30.4 ± 10.7	7.0	167.4 ± 24.5
1966	51.4 ± 1.3	60.7 ± 4.7	20.6 ± 7.8	31.0 ± 10.9	7.0	170.7 ± 24.6
1967	52.6 ± 1.2	60.7 ± 4.7	20.6 ± 7.8	30.8 ± 10.8	7.1	171.9 ± 24.5
1968	53.7 ± 1.2	60.9 ± 4.7	20.6 ± 7.8	30.5 ± 10.8	7.1	172.8 ± 24.4
1969	55.2 ± 1.2	61.4 ± 4.7	20.8 ± 7.9	30.6 ± 11.0	7.1	175.2 ± 24.8
1970	53.0 ± 1.2	60.3 ± 4.6	20.4 ± 7.7	30.4 ± 10.7	7.2	171.3 ± 24.2
1971	61.6 ± 1.2	60.0 ± 4.5	20.3 ± 7.7	31.2 ± 11.1	7.3	180.3 ± 24.4
1972	58.6 ± 1.1	60.2 ± 4.5	20.4 ± 7.7	31.1 ± 11.2	7.3	177.6 ± 24.5
1973	58.7 ± 1.1	63.3 ± 5.3	17.3 ± 6.5	31.7 ± 11.5	7.3	178.3 ± 24.4
1974	60.8 ± 1.0	59.9 ± 4.4	20.9 ± 7.9	31.2 ± 11.4	7.5	180.2 ± 24.7
1975	63.5 ± 1.0	61.5 ± 4.5	20.7 ± 7.8	31.1 ± 11.4	7.3	184.1 ± 24.8
1976	59.3 ± 1.0	63.5 ± 4.8	20.8 ± 7.9	29.8 ± 10.7	7.3	180.7 ± 24.4
1977	60.1 ± 1.1	62.6 ± 4.5	21.2 ± 8.0	30.8 ± 11.3	7.3	182.0 ± 24.9
1978	67.4 ± 1.0	63.6 ± 4.7	21.1 ± 8.0	30.2 ± 11.1	7.3	189.7 ± 24.8
1979	62.7 ± 1.0	63.9 ± 4.7	21.4 ± 8.1	30.3 ± 11.2	7.3	185.5 ± 25.0
1980	72.4 ± 1.0	64.1 ± 4.7	21.7 ± 8.2	30.0 ± 11.0	7.3	195.6 ± 24.9
1981	54.6 ± 1.0	64.1 ± 4.7	21.6 ± 8.2	29.9 ± 10.9	7.3	177.6 ± 24.7
1982	61.4 ± 1.0	64.6 ± 4.7	21.2 ± 8.0	29.5 ± 10.7	7.4	184.0 ± 24.3
1983	59.3 ± 0.9	64.5 ± 4.7	21.3 ± 8.0	29.4 ± 10.6	7.4	181.9 ± 24.3
1984	78.2 ± 0.9	64.2 ± 4.0	21.9 ± 8.3	29.9 ± 10.9	7.4	201.5 ± 24.1
1985	74.5 ± 0.9	64.6 ± 4.0	21.9 ± 8.3	29.9 ± 10.9	7.4	198.3 ± 24.1
1986	66.6 ± 0.9	64.7 ± 4.1	22.0 ± 8.3	29.7 ± 10.8	7.5	190.5 ± 24.2
1987	77.5 ± 0.9	64.5 ± 4.1	22.1 ± 8.4	29.8 ± 10.9	7.6	201.5 ± 24.2
1988	80.4 ± 0.9	64.4 ± 4.1	22.1 ± 8.4	30.1 ± 11.2	7.6	204.6 ± 24.5
1989	70.3 ± 0.9	64.6 ± 4.2	22.1 ± 8.4	29.6 ± 10.8	7.6	194.2 ± 24.2
1990	73.2 ± 0.8	64.9 ± 4.2	22.4 ± 8.5	29.9 ± 11.0	7.5	197.9 ± 24.5
1991	71.0 ± 0.8	65.1 ± 4.2	22.5 ± 8.5	29.2 ± 10.7	7.6	195.4 ± 24.2
1992	63.6 ± 0.8	65.6 ± 4.3	22.3 ± 8.4	28.8 ± 10.4	7.7	188.0 ± 24.0
1993	67.0 ± 0.8	66.5 ± 4.4	22.6 ± 8.6	29.1 ± 10.7	7.8	193.1 ± 24.4
1994	60.2 ± 0.7	66.6 ± 4.3	22.6 ± 8.6	32.7 ± 11.7	7.9	190.0 ± 25.2
1995	49.0 ± 0.8	68.1 ± 4.9	22.3 ± 8.4	30.8 ± 10.7	7.9	178.1 ± 24.8
1996	78.9 ± 0.8	67.7 ± 4.8	22.7 ± 8.6	29.2 ± 10.9	8.1	206.6 ± 25.1
1997	75.7 ± 0.7	66.5 ± 4.5	23.3 ± 8.8	31.5 ± 11.9	8.3	205.2 ± 25.9
1998	81.1 ± 0.7	67.6 ± 4.4	23.1 ± 8.7	32.7 ± 12.3	8.2	212.7 ± 26.2
1999	70.2 ± 0.7	68.3 ± 4.5	23.1 ± 8.7	32.3 ± 12.0	8.2	201.9 ± 25.8
2000	84.4 ± 0.6	68.0 ± 4.5	22.7 ± 8.6	32.7 ± 12.0	8.2	216.0 ± 25.7
2001	72.7 ± 0.7	70.1 ± 4.6	21.4 ± 8.1	34.1 ± 12.6	8.3	206.5 ± 26.0
2002	77.6 ± 0.6	70.7 ± 4.9	20.9 ± 7.9	33.6 ± 12.5	8.4	211.3 ± 26.0
2003	79.7 ± 0.7	70.8 ± 4.9	22.5 ± 8.5	32.8 ± 12.2	8.2	214.0 ± 26.3

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B5: Development of NPP_{act} per area [t DM/ha/yr], broken down to main land use types; yearly data.

	Cropland *	Forest *	Shrubland *	Grassland *	Other land	Total land area*
1955	2.1 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.6 ± 0.9	2.3	3.2 ± 0.5
1956	2.1 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.6 ± 0.9	2.3	3.2 ± 0.5
1957	2.2 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.6 ± 0.9	2.3	3.3 ± 0.5
1958	2.2 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.6 ± 0.9	2.3	3.3 ± 0.5
1959	2.3 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 0.9	2.3	3.3 ± 0.5
1960	2.1 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 0.9	2.3	3.2 ± 0.5
1961	2.2 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 0.9	2.3	3.3 ± 0.5
1962	2.3 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 0.9	2.3	3.3 ± 0.5
1963	2.5 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.8 ± 1.0	2.3	3.4 ± 0.5
1964	2.2 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 0.9	2.3	3.3 ± 0.5
1965	2.3 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.3 ± 0.5
1966	2.5 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.4 ± 0.5
1967	2.5 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.4 ± 0.5
1968	2.6 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.5 ± 0.5
1969	2.6 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.8 ± 1.0	2.3	3.5 ± 0.5
1970	2.5 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.4 ± 0.5
1971	2.9 ± 0.1	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.6 ± 0.5
1972	2.8 ± 0.1	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.5 ± 0.5
1973	2.8 ± 0.1	5.9 ± 0.5	4.5 ± 1.7	2.8 ± 1.0	2.3	3.6 ± 0.5
1974	2.9 ± 0.0	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.6 ± 0.5
1975	3.1 ± 0.0	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.7 ± 0.5
1976	2.9 ± 0.0	5.9 ± 0.5	4.5 ± 1.7	2.7 ± 1.0	2.3	3.6 ± 0.5
1977	2.9 ± 0.1	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.6 ± 0.5
1978	3.3 ± 0.0	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.8 ± 0.5
1979	3.1 ± 0.1	5.9 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.7 ± 0.5
1980	3.5 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.9 ± 0.5
1981	2.7 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.6 ± 0.5
1982	3.0 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.7 ± 0.5
1983	2.9 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	3.6 ± 0.5
1984	3.8 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.0 ± 0.5
1985	3.6 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.0 ± 0.5
1986	3.3 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.8 ± 0.5
1987	3.8 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.0 ± 0.5
1988	3.9 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.1 ± 0.5
1989	3.5 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	3.9 ± 0.5
1990	3.6 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.0 ± 0.5
1991	3.5 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	3.9 ± 0.5
1992	3.2 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	3.8 ± 0.5
1993	3.4 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	3.9 ± 0.5
1994	3.3 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	3.8 ± 0.5
1995	2.6 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 0.9	2.3	3.6 ± 0.5
1996	4.1 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.7 ± 1.0	2.3	4.1 ± 0.5
1997	4.1 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.1 ± 0.5
1998	4.4 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.9 ± 1.1	2.3	4.3 ± 0.5
1999	3.8 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.0 ± 0.5
2000	4.6 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.0	2.3	4.3 ± 0.5
2001	4.0 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.9 ± 1.1	2.3	4.1 ± 0.5
2002	4.3 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.1	2.3	4.2 ± 0.5
2003	4.4 ± 0.0	6.0 ± 0.4	4.5 ± 1.7	2.8 ± 1.1	2.3	4.3 ± 0.5

* Values obtained by using the “best guess” of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area for certain land use categories.
Sources: own calculations, see text.

Table B6: Development of NPP_{act} [Mt DM/yr]: Cropland, Forest, Shrubland; broken down to land use categories; yearly data.

	Annual crops	Permanent crops	Fallow *			Closed forest	Open forest *			Shrubland *		
1955	33.5	6.1	4.0	±	1.3	38.4	22.1	±	5.0	20.7	±	7.8
1956	34.0	6.5	3.9	±	1.3	38.2	21.9	±	4.9	20.5	±	7.8
1957	36.8	6.3	4.1	±	1.4	38.1	21.7	±	4.9	20.4	±	7.7
1958	36.6	6.5	4.1	±	1.4	38.1	21.6	±	4.8	20.4	±	7.7
1959	39.3	7.0	4.1	±	1.4	37.9	21.4	±	4.8	20.2	±	7.6
1960	33.7	7.5	4.0	±	1.3	38.5	21.5	±	4.8	20.5	±	7.7
1961	35.1	7.5	4.1	±	1.4	38.2	21.2	±	4.7	20.2	±	7.6
1962	39.0	6.9	4.0	±	1.3	38.1	21.1	±	4.7	20.1	±	7.6
1963	39.7	9.3	4.0	±	1.3	38.2	21.0	±	4.6	20.1	±	7.6
1964	35.3	8.1	4.0	±	1.3	38.8	21.2	±	4.7	20.4	±	7.7
1965	36.4	8.4	3.9	±	1.3	39.3	21.4	±	4.7	20.6	±	7.8
1966	38.0	9.6	3.8	±	1.3	39.4	21.3	±	4.7	20.6	±	7.8
1967	41.4	7.6	3.6	±	1.2	39.5	21.2	±	4.7	20.6	±	7.8
1968	43.7	6.4	3.5	±	1.2	39.7	21.2	±	4.7	20.6	±	7.8
1969	43.6	8.1	3.5	±	1.2	40.1	21.3	±	4.7	20.8	±	7.9
1970	40.9	8.6	3.5	±	1.2	39.4	20.8	±	4.6	20.4	±	7.7
1971	49.6	8.5	3.5	±	1.2	39.3	20.7	±	4.5	20.3	±	7.7
1972	45.6	9.6	3.4	±	1.1	39.6	20.7	±	4.5	20.4	±	7.7
1973	44.5	10.9	3.3	±	1.1	39.4	24.0	±	5.3	17.3	±	6.5
1974	47.5	10.1	3.1	±	1.0	39.8	20.1	±	4.4	20.9	±	7.9
1975	50.6	9.9	3.0	±	1.0	40.8	20.7	±	4.5	20.7	±	7.8
1976	47.1	9.1	3.1	±	1.0	41.6	21.9	±	4.8	20.8	±	7.9
1977	49.3	7.5	3.2	±	1.1	42.2	20.5	±	4.5	21.2	±	8.0
1978	54.4	10.0	3.0	±	1.0	42.3	21.3	±	4.7	21.1	±	8.0
1979	48.3	11.3	3.1	±	1.0	42.6	21.3	±	4.7	21.4	±	8.1
1980	59.1	10.4	2.9	±	1.0	43.0	21.1	±	4.7	21.7	±	8.2
1981	42.6	9.0	3.0	±	1.0	43.0	21.1	±	4.7	21.6	±	8.2
1982	47.3	11.2	2.9	±	1.0	43.4	21.1	±	4.7	21.2	±	8.0
1983	47.8	8.7	2.8	±	0.9	43.5	21.0	±	4.7	21.3	±	8.0
1984	64.7	10.7	2.7	±	0.9	46.1	18.1	±	4.0	21.9	±	8.3
1985	61.9	9.8	2.7	±	0.9	46.3	18.3	±	4.0	21.9	±	8.3
1986	53.5	10.3	2.7	±	0.9	45.8	18.8	±	4.1	22.0	±	8.3
1987	62.4	12.4	2.6	±	0.9	45.9	18.6	±	4.1	22.1	±	8.4
1988	69.2	8.6	2.6	±	0.9	45.8	18.6	±	4.1	22.1	±	8.4
1989	56.7	11.0	2.6	±	0.9	45.8	18.8	±	4.2	22.1	±	8.4
1990	58.7	12.0	2.5	±	0.8	45.9	19.0	±	4.2	22.4	±	8.5
1991	58.0	10.6	2.4	±	0.8	46.3	18.8	±	4.2	22.5	±	8.5
1992	49.0	12.2	2.4	±	0.8	46.3	19.3	±	4.3	22.3	±	8.4
1993	54.1	10.4	2.5	±	0.8	47.0	19.5	±	4.4	22.6	±	8.6
1994	48.5	9.6	2.1	±	0.7	47.0	19.6	±	4.3	22.6	±	8.6
1995	38.6	8.1	2.3	±	0.8	46.1	22.0	±	4.9	22.3	±	8.4
1996	64.3	12.3	2.3	±	0.8	46.2	21.5	±	4.8	22.7	±	8.6
1997	58.4	15.3	2.0	±	0.7	46.3	20.2	±	4.5	23.3	±	8.8
1998	66.6	12.4	2.0	±	0.7	47.4	20.2	±	4.4	23.1	±	8.7
1999	55.4	12.8	2.0	±	0.7	48.1	20.2	±	4.5	23.1	±	8.7
2000	67.9	14.5	1.9	±	0.6	47.6	20.4	±	4.5	22.7	±	8.6
2001	54.6	16.0	2.1	±	0.7	48.9	21.2	±	4.6	21.4	±	8.1
2002	61.3	14.5	1.9	±	0.6	48.2	22.5	±	4.9	20.9	±	7.9
2003	59.7	18.0	2.0	±	0.7	48.6	22.2	±	4.9	22.5	±	8.5

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B7: Development of NPP_{act} [Mt DM/yr]: Grassland, Other land; broken down to land use categories; yearly data.

	Dry pastures *			Esparto grassland	Meadows *			Ext. grazed abandoned land *			Built-up land	Other areas
1955	16.3	±	7.1	2.0	5.6	±	0.7	5.2	±	2.1	3.4	3.2
1956	16.1	±	7.0	1.9	5.7	±	0.8	5.1	±	2.1	3.4	3.2
1957	15.9	±	6.9	1.9	5.9	±	0.9	5.1	±	2.1	3.5	3.2
1958	15.8	±	6.9	1.9	6.0	±	1.0	5.1	±	2.1	3.5	3.2
1959	15.6	±	6.8	1.9	6.4	±	1.3	5.1	±	2.1	3.5	3.2
1960	15.7	±	6.8	2.2	6.6	±	1.5	5.2	±	2.2	3.5	3.2
1961	15.5	±	6.7	2.2	6.7	±	1.5	5.2	±	2.1	3.6	3.2
1962	15.4	±	6.7	2.2	6.6	±	1.3	5.2	±	2.1	3.6	3.2
1963	15.3	±	6.6	2.2	7.8	±	2.1	5.2	±	2.1	3.7	3.2
1964	15.4	±	6.7	2.1	7.2	±	1.6	5.3	±	2.2	3.7	3.2
1965	15.5	±	6.7	2.1	7.4	±	1.7	5.3	±	2.2	3.7	3.2
1966	15.5	±	6.7	2.2	7.9	±	1.9	5.4	±	2.2	3.8	3.2
1967	15.4	±	6.7	2.1	8.0	±	1.9	5.4	±	2.2	3.8	3.2
1968	15.3	±	6.7	2.0	7.7	±	1.8	5.4	±	2.2	3.9	3.2
1969	15.4	±	6.7	1.5	8.2	±	2.1	5.5	±	2.3	3.9	3.2
1970	15.0	±	6.5	1.9	8.1	±	1.9	5.4	±	2.2	3.9	3.2
1971	14.9	±	6.5	1.7	9.2	±	2.4	5.4	±	2.2	4.0	3.2
1972	14.9	±	6.5	1.7	9.1	±	2.5	5.4	±	2.2	4.0	3.2
1973	16.2	±	7.0	1.5	8.8	±	2.3	5.2	±	2.1	4.1	3.2
1974	15.5	±	6.7	1.4	8.8	±	2.4	5.5	±	2.3	4.1	3.3
1975	15.2	±	6.6	1.4	9.0	±	2.5	5.5	±	2.3	4.2	3.1
1976	14.4	±	6.2	1.3	8.4	±	2.1	5.7	±	2.4	4.2	3.1
1977	14.6	±	6.3	1.4	9.0	±	2.6	5.8	±	2.4	4.3	3.0
1978	14.3	±	6.2	1.3	8.8	±	2.5	5.8	±	2.4	4.3	3.0
1979	14.1	±	6.1	1.4	8.9	±	2.6	5.9	±	2.4	4.4	2.9
1980	13.9	±	6.0	1.3	8.9	±	2.6	5.9	±	2.4	4.4	2.9
1981	13.8	±	6.0	1.3	8.8	±	2.5	5.9	±	2.5	4.4	2.9
1982	13.8	±	6.0	1.3	8.5	±	2.2	5.9	±	2.5	4.4	2.9
1983	13.8	±	6.0	1.3	8.4	±	2.2	5.9	±	2.5	4.5	2.9
1984	13.8	±	6.0	1.4	8.7	±	2.4	5.9	±	2.5	4.5	2.9
1985	14.0	±	6.1	1.4	8.7	±	2.4	5.8	±	2.4	4.5	2.9
1986	13.8	±	6.0	1.4	8.8	±	2.4	5.8	±	2.4	4.5	3.0
1987	13.9	±	6.0	1.4	8.8	±	2.5	5.7	±	2.4	4.5	3.1
1988	14.2	±	6.1	1.2	9.0	±	2.7	5.7	±	2.4	4.5	3.1
1989	14.1	±	6.1	1.2	8.5	±	2.3	5.7	±	2.4	4.5	3.1
1990	14.2	±	6.2	1.4	8.6	±	2.4	5.8	±	2.4	4.6	3.0
1991	13.5	±	5.9	1.3	8.1	±	2.3	6.2	±	2.6	4.6	3.1
1992	13.7	±	5.9	1.3	7.5	±	1.9	6.3	±	2.6	4.6	3.1
1993	13.7	±	6.0	1.3	7.8	±	2.1	6.3	±	2.6	4.6	3.2
1994	16.2	±	7.0	1.3	8.9	±	2.0	6.4	±	2.7	4.6	3.3
1995	14.6	±	6.3	1.3	8.5	±	1.7	6.4	±	2.7	4.6	3.3
1996	13.8	±	6.0	1.2	7.7	±	2.2	6.5	±	2.7	4.6	3.5
1997	14.8	±	6.4	1.0	9.0	±	2.7	6.6	±	2.8	4.6	3.6
1998	14.9	±	6.5	1.0	10.3	±	3.2	6.5	±	2.7	4.6	3.6
1999	15.1	±	6.6	1.0	9.7	±	2.7	6.5	±	2.7	4.7	3.5
2000	14.6	±	6.3	1.0	10.2	±	2.8	7.0	±	2.9	4.7	3.5
2001	14.7	±	6.4	1.0	11.5	±	3.4	6.9	±	2.9	4.7	3.5
2002	15.0	±	6.5	1.0	10.7	±	3.1	6.9	±	2.9	4.8	3.6
2003	14.7	±	6.4	1.1	10.4	±	3.1	6.6	±	2.8	4.9	3.3

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B8: Development of NPP_{act} per area [t DM/ha/yr] for selected land use categories; yearly data.

	Annual crops	Permanent crops	Open forest *			Meadows *		
1955	3.4	1.3	5.2	±	1.2	4.5	±	0.6
1956	3.3	1.5	5.2	±	1.2	4.6	±	0.7
1957	3.6	1.5	5.2	±	1.2	4.6	±	0.7
1958	3.5	1.5	5.2	±	1.2	4.6	±	0.7
1959	3.8	1.6	5.2	±	1.2	5.0	±	1.0
1960	3.3	1.7	5.2	±	1.2	5.1	±	1.1
1961	3.5	1.7	5.2	±	1.2	5.1	±	1.2
1962	3.7	1.5	5.2	±	1.2	5.0	±	1.0
1963	3.9	2.0	5.2	±	1.2	5.6	±	1.5
1964	3.5	1.8	5.2	±	1.2	5.2	±	1.1
1965	3.7	1.8	5.2	±	1.2	5.4	±	1.3
1966	3.8	2.1	5.2	±	1.1	5.5	±	1.3
1967	4.1	1.6	5.2	±	1.2	5.5	±	1.3
1968	4.2	1.4	5.2	±	1.2	5.5	±	1.3
1969	4.2	1.7	5.2	±	1.2	5.7	±	1.4
1970	3.9	1.8	5.2	±	1.2	5.5	±	1.3
1971	4.7	1.8	5.2	±	1.1	5.7	±	1.5
1972	4.3	2.0	5.2	±	1.1	5.9	±	1.6
1973	4.2	2.2	5.2	±	1.1	5.8	±	1.5
1974	4.4	2.0	5.2	±	1.2	5.8	±	1.6
1975	4.7	2.0	5.2	±	1.2	6.0	±	1.7
1976	4.5	1.8	5.2	±	1.2	5.6	±	1.4
1977	4.8	1.5	5.2	±	1.2	6.1	±	1.7
1978	5.1	2.0	5.2	±	1.2	6.1	±	1.7
1979	4.6	2.3	5.2	±	1.2	6.2	±	1.8
1980	5.5	2.1	5.2	±	1.2	6.2	±	1.8
1981	4.0	1.8	5.2	±	1.2	6.0	±	1.7
1982	4.4	2.3	5.2	±	1.2	5.8	±	1.5
1983	4.4	1.8	5.2	±	1.2	5.8	±	1.5
1984	5.8	2.2	5.2	±	1.2	6.1	±	1.7
1985	5.6	2.0	5.2	±	1.2	6.0	±	1.6
1986	4.8	2.1	5.2	±	1.2	6.0	±	1.7
1987	5.5	2.6	5.2	±	1.2	6.1	±	1.7
1988	6.1	1.8	5.2	±	1.2	6.3	±	1.9
1989	5.1	2.3	5.2	±	1.2	6.0	±	1.6
1990	5.3	2.5	5.2	±	1.2	6.2	±	1.8
1991	5.2	2.2	5.2	±	1.2	6.1	±	1.7
1992	4.4	2.6	5.2	±	1.2	5.7	±	1.4
1993	5.0	2.2	5.2	±	1.2	6.0	±	1.6
1994	4.7	2.0	5.2	±	1.2	6.0	±	1.3
1995	3.8	1.7	5.2	±	1.2	5.7	±	1.2
1996	6.1	2.6	5.2	±	1.2	6.1	±	1.7
1997	5.5	3.2	5.2	±	1.2	6.3	±	1.9
1998	6.5	2.6	5.2	±	1.1	6.9	±	2.1
1999	5.4	2.6	5.2	±	1.2	6.5	±	1.8
2000	6.7	3.0	5.2	±	1.2	6.6	±	1.8
2001	5.7	3.2	5.2	±	1.1	6.9	±	2.0
2002	6.3	2.9	5.2	±	1.1	6.8	±	2.0
2003	6.2	3.6	5.2	±	1.1	6.7	±	2.0

* "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B9: Development of NPP_h [Mt DM/yr], broken down to harvest types; yearly data.

	Primary crops	Crop byproducts	**Total crop harvest**	**Grazing**	**Hay harvest**	Roundwood removals	Wood fuel removals	Felling losses	Other forest products	**Total forestry harvest**	**Human-induced fires**	**Other harvest**	**Total harvest**	**Backflows to nature**
1955	13.4	18.6	**31.9**	20.5	2.4	1.7	6.0	3.1	0.1	**10.9**	**0.6**	**1.8**	**68.2**	**16.2**
1956	13.9	18.8	**32.7**	20.4	2.4	2.0	6.0	3.2	0.1	**11.3**	**0.6**	**1.8**	**69.3**	**16.3**
1957	14.9	20.3	**35.2**	20.3	2.4	2.1	6.5	3.5	0.1	**12.2**	**0.6**	**1.8**	**72.6**	**17.4**
1958	15.2	20.1	**35.2**	20.0	2.4	2.0	6.8	3.5	0.1	**12.4**	**0.6**	**1.8**	**72.6**	**17.5**
1959	16.6	21.3	**37.9**	19.1	2.4	1.8	6.4	3.3	0.1	**11.6**	**0.6**	**1.8**	**73.5**	**17.7**
1960	15.3	18.6	**33.9**	18.7	2.5	1.8	6.2	3.2	0.1	**11.3**	**0.6**	**1.8**	**68.8**	**16.9**
1961	15.9	19.2	**35.1**	19.0	2.6	2.4	6.8	3.7	0.1	**13.1**	**0.6**	**1.9**	**72.3**	**18.2**
1962	16.9	21.1	**38.0**	17.6	2.5	2.6	7.0	3.8	0.1	**13.5**	**0.7**	**1.9**	**74.2**	**17.9**
1963	18.4	22.2	**40.6**	16.2	2.6	2.5	6.7	3.7	0.1	**13.0**	**0.3**	**1.9**	**74.6**	**18.3**
1964	16.2	19.6	**35.9**	16.1	2.6	2.7	6.4	3.6	0.1	**12.9**	**0.4**	**1.9**	**69.7**	**17.5**
1965	17.1	20.1	**37.2**	14.9	2.3	2.6	5.8	3.4	0.1	**11.9**	**0.5**	**1.9**	**68.8**	**17.8**
1966	18.1	21.4	**39.5**	13.2	2.3	2.8	5.2	3.2	0.1	**11.3**	**0.7**	**1.9**	**68.9**	**17.8**
1967	18.9	22.0	**41.0**	13.2	2.5	2.7	4.9	3.1	0.1	**10.8**	**1.0**	**1.9**	**70.4**	**17.4**
1968	19.6	22.5	**42.1**	12.3	2.9	2.9	4.5	2.9	0.1	**10.4**	**0.8**	**1.9**	**70.5**	**17.7**
1969	20.7	22.8	**43.6**	12.9	3.0	3.7	3.7	3.0	0.1	**10.5**	**0.7**	**2.0**	**72.6**	**18.4**
1970	20.1	21.6	**41.7**	14.7	2.7	4.0	3.5	3.0	0.1	**10.7**	**1.2**	**2.0**	**73.0**	**17.4**
1971	23.7	25.5	**49.1**	10.5	3.1	4.1	3.0	2.9	0.1	**10.1**	**0.5**	**2.0**	**75.3**	**18.4**
1972	22.9	23.9	**46.9**	11.8	2.9	4.3	3.0	2.9	0.1	**10.4**	**0.8**	**2.0**	**74.8**	**19.6**
1973	23.2	24.0	**47.2**	12.3	2.8	4.8	1.7	2.6	0.2	**9.3**	**1.3**	**2.1**	**75.0**	**19.9**
1974	24.2	25.1	**49.3**	8.8	4.3	5.3	1.7	2.8	0.2	**10.0**	**1.9**	**2.1**	**76.4**	**20.0**
1975	25.9	26.0	**52.0**	9.8	3.5	5.4	1.6	2.8	0.1	**10.0**	**2.6**	**2.1**	**79.9**	**20.8**
1976	24.8	23.6	**48.4**	12.9	2.9	5.6	1.5	2.8	0.1	**10.1**	**1.7**	**2.1**	**78.1**	**19.1**
1977	25.6	23.7	**49.2**	12.2	3.2	6.3	1.4	3.1	0.1	**10.9**	**0.9**	**2.2**	**78.6**	**19.0**
1978	28.5	27.3	**55.9**	10.6	3.2	6.8	1.1	3.1	0.1	**11.1**	**5.9**	**2.2**	**88.8**	**21.1**
1979	26.5	25.3	**51.8**	10.0	3.2	6.4	1.2	3.0	0.1	**10.8**	**3.7**	**2.2**	**81.7**	**20.9**
1980	31.0	29.7	**60.8**	8.8	3.2	5.7	1.2	2.8	0.1	**9.7**	**3.5**	**2.2**	**88.3**	**21.3**
1981	24.0	21.2	**45.2**	11.6	2.6	6.2	1.2	3.0	0.1	**10.4**	**4.0**	**2.2**	**75.9**	**18.3**
1982	26.8	24.3	**51.1**	14.5	3.1	5.8	1.2	2.8	0.1	**9.9**	**2.0**	**2.2**	**82.9**	**20.5**
1983	26.2	23.1	**49.4**	13.2	3.2	5.4	1.3	2.7	0.1	**9.5**	**1.5**	**2.2**	**78.9**	**19.4**
1984	34.4	31.6	**66.0**	10.2	3.4	5.6	1.7	2.9	0.1	**10.4**	**2.2**	**2.3**	**94.5**	**23.0**
1985	32.8	30.0	**62.8**	11.0	3.2	6.7	1.4	3.2	0.1	**11.4**	**6.4**	**2.3**	**97.1**	**22.3**
1986	29.6	26.3	**55.9**	11.9	3.8	7.5	1.6	3.6	0.1	**12.8**	**3.5**	**2.3**	**90.2**	**22.4**
1987	34.6	31.0	**65.5**	10.7	3.4	6.9	1.4	3.3	0.1	**11.7**	**1.9**	**2.3**	**95.6**	**24.9**
1988	36.3	31.8	**68.1**	15.6	3.5	7.0	1.6	3.5	0.1	**12.2**	**1.8**	**2.3**	**103.5**	**25.8**
1989	31.6	27.6	**59.2**	18.3	3.3	7.5	1.6	3.7	0.1	**12.9**	**5.7**	**2.3**	**101.6**	**23.9**
1990	32.9	28.9	**61.8**	18.3	3.3	7.3	1.6	3.6	0.1	**12.5**	**2.7**	**2.3**	**100.9**	**25.3**
1991	32.3	27.7	**60.0**	19.4	2.7	7.1	1.7	3.6	0.1	**12.5**	**3.5**	**2.3**	**100.3**	**23.6**
1992	28.6	24.9	**53.4**	20.9	2.4	6.8	1.8	3.4	0.1	**12.1**	**1.4**	**2.3**	**92.5**	**23.3**
1993	30.6	25.8	**56.4**	19.4	3.0	6.6	1.6	3.3	0.1	**11.6**	**1.2**	**2.3**	**93.8**	**23.7**
1994	27.7	23.1	**50.8**	21.0	2.8	7.4	1.6	3.6	0.1	**12.8**	**5.9**	**2.3**	**95.6**	**22.7**
1995	22.7	18.2	**40.8**	23.3	2.9	7.5	1.9	3.8	0.1	**13.2**	**1.9**	**2.3**	**84.5**	**20.1**
1996	35.6	31.3	**66.9**	18.2	2.8	7.1	2.0	3.6	0.1	**12.8**	**0.8**	**2.3**	**103.8**	**26.1**
1997	33.7	30.6	**64.2**	19.5	3.0	7.5	1.3	3.5	0.1	**12.4**	**1.3**	**2.3**	**102.8**	**26.6**
1998	36.8	32.2	**69.0**	18.3	2.7	7.7	1.2	3.6	0.1	**12.6**	**1.8**	**2.3**	**106.7**	**27.2**
1999	31.8	27.7	**59.4**	20.5	2.6	7.4	1.3	3.5	0.1	**12.3**	**1.1**	**2.3**	**98.2**	**25.9**
2000	38.2	33.7	**71.9**	20.6	2.5	6.8	1.3	3.3	0.1	**11.4**	**2.5**	**2.3**	**111.2**	**28.4**
2001	32.7	28.7	**61.4**	22.5	2.5	6.9	0.8	3.1	0.1	**10.9**	**1.2**	**2.4**	**100.8**	**25.9**
2002	35.0	30.9	**65.9**	21.7	2.5	7.3	0.9	3.3	0.1	**11.5**	**1.4**	**2.4**	**105.4**	**26.7**
2003	35.5	32.1	**67.6**	19.5	2.6	7.6	1.0	3.5	0.1	**12.2**	**2.0**	**2.4**	**106.2**	**28.0**

Sources: own calculations, see text.

Table B10: Development of NPP_h [Mt DM/yr] and NPP_h per area [t DM/ha/yr], broken down to main land use types; yearly data.

	Cropland		Forest		Shrubland		Grassland		Other land		Total land area	
	[Mt DM/yr]	[t DM/ha/yr]	[Mt DM/yr]	[t DM/ha/yr]	[Mt DM/yr]	[t DM/ha/yr]	[Mt DM/yr]	[t DM/ha/yr]	[Mt DM/yr]	[t DM/ha/yr]	[Mt DM/yr]	[t DM/ha/yr]
1955	32.7	1.6	11.6	1.1	7.1	1.5	15.2	1.4	1.7	0.6	68.2	1.4
1956	33.5	1.6	11.9	1.2	7.1	1.5	15.1	1.4	1.7	0.6	69.3	1.4
1957	36.0	1.7	12.4	1.2	7.4	1.6	15.1	1.4	1.7	0.6	72.6	1.5
1958	36.0	1.7	12.3	1.2	7.5	1.7	14.9	1.4	1.7	0.6	72.6	1.4
1959	38.8	1.8	11.5	1.1	7.1	1.6	14.4	1.3	1.8	0.6	73.5	1.5
1960	34.7	1.6	11.2	1.1	6.9	1.5	14.2	1.3	1.8	0.6	68.8	1.4
1961	35.9	1.7	12.8	1.3	7.2	1.6	14.5	1.3	1.8	0.6	72.3	1.4
1962	38.8	1.8	12.6	1.3	7.4	1.6	13.6	1.2	1.8	0.6	74.2	1.5
1963	41.4	1.9	11.6	1.2	6.7	1.5	13.1	1.2	1.8	0.6	74.6	1.5
1964	36.7	1.7	11.9	1.2	6.5	1.4	12.8	1.2	1.8	0.6	69.7	1.4
1965	38.0	1.8	11.0	1.1	5.9	1.3	12.0	1.1	1.9	0.6	68.8	1.4
1966	40.3	1.9	10.4	1.0	5.3	1.2	11.1	1.0	1.9	0.6	68.9	1.4
1967	41.7	2.0	10.2	1.0	5.4	1.2	11.3	1.0	1.9	0.6	70.4	1.4
1968	42.8	2.0	9.9	1.0	4.9	1.1	10.9	1.0	1.9	0.6	70.5	1.4
1969	44.3	2.1	10.5	1.0	4.4	1.0	11.5	1.0	1.9	0.6	72.6	1.5
1970	42.4	2.0	11.5	1.1	4.8	1.1	12.3	1.1	2.0	0.6	73.0	1.5
1971	49.8	2.4	9.9	1.0	3.4	0.7	10.3	0.9	2.0	0.6	75.3	1.5
1972	47.5	2.2	10.4	1.0	3.8	0.8	11.0	1.0	2.0	0.6	74.8	1.5
1973	47.9	2.3	10.7	1.0	3.6	0.9	10.7	1.0	2.0	0.6	75.0	1.5
1974	49.9	2.4	10.8	1.1	3.3	0.7	10.3	0.9	2.1	0.6	76.4	1.5
1975	52.6	2.5	12.1	1.2	3.1	0.7	10.0	0.9	2.1	0.7	79.9	1.6
1976	49.1	2.4	12.1	1.1	3.3	0.7	11.5	1.1	2.1	0.7	78.1	1.6
1977	49.9	2.4	12.7	1.2	2.5	0.5	11.4	1.0	2.1	0.7	78.6	1.6
1978	56.5	2.7	14.7	1.4	5.3	1.1	10.1	0.9	2.2	0.7	88.8	1.8
1979	52.5	2.6	13.5	1.3	3.8	0.8	9.8	0.9	2.2	0.7	81.7	1.6
1980	61.3	3.0	11.7	1.1	3.9	0.8	9.2	0.9	2.2	0.7	88.3	1.8
1981	45.8	2.2	13.5	1.2	3.7	0.8	10.8	1.0	2.2	0.7	75.9	1.5
1982	51.7	2.5	12.8	1.2	3.4	0.7	12.8	1.2	2.2	0.7	82.9	1.7
1983	50.0	2.4	11.7	1.1	2.7	0.6	12.3	1.1	2.2	0.7	78.9	1.6
1984	66.6	3.2	11.7	1.1	3.5	0.7	10.4	1.0	2.2	0.7	94.5	1.9
1985	63.3	3.1	15.0	1.4	5.8	1.2	10.7	1.0	2.2	0.7	97.1	1.9
1986	56.4	2.8	15.8	1.5	4.2	0.9	11.5	1.1	2.3	0.7	90.2	1.8
1987	66.0	3.2	13.6	1.3	3.2	0.6	10.5	1.0	2.3	0.7	95.6	1.9
1988	68.6	3.4	15.0	1.4	4.0	0.8	13.6	1.3	2.3	0.7	103.5	2.1
1989	59.7	2.9	17.5	1.6	6.6	1.3	15.5	1.5	2.3	0.7	101.6	2.0
1990	62.3	3.1	16.4	1.5	5.8	1.2	14.2	1.3	2.3	0.7	100.9	2.0
1991	60.5	3.0	17.1	1.6	6.1	1.2	14.3	1.3	2.3	0.7	100.3	2.0
1992	53.9	2.7	15.9	1.5	5.7	1.1	14.7	1.4	2.3	0.7	92.5	1.9
1993	56.9	2.9	15.2	1.4	4.7	0.9	14.7	1.4	2.3	0.7	93.8	1.9
1994	51.2	2.8	19.8	1.8	6.6	1.3	15.7	1.3	2.3	0.7	95.6	1.9
1995	41.3	2.2	17.8	1.6	6.3	1.3	16.8	1.5	2.3	0.7	84.5	1.7
1996	67.4	3.5	15.7	1.4	4.7	0.9	13.8	1.3	2.3	0.7	103.8	2.1
1997	64.6	3.5	15.9	1.4	4.5	0.9	15.5	1.4	2.3	0.6	102.8	2.1
1998	69.4	3.7	15.9	1.4	4.4	0.9	14.7	1.3	2.3	0.7	106.7	2.1
1999	59.8	3.3	15.8	1.4	4.6	0.9	15.7	1.4	2.3	0.7	98.2	2.0
2000	72.3	3.9	15.4	1.4	5.5	1.1	15.7	1.4	2.3	0.7	111.2	2.2
2001	61.8	3.4	14.7	1.3	4.5	0.9	17.4	1.5	2.4	0.7	100.8	2.0
2002	66.3	3.7	15.7	1.3	4.6	1.0	16.4	1.4	2.4	0.7	105.4	2.1
2003	68.0	3.8	16.2	1.4	4.8	1.0	14.8	1.3	2.4	0.7	106.2	2.1

Sources: own calculations, see text.

Table B11: Development of NPP_t [Mt DM/yr], broken down to main land use types; yearly data.

	Cropland *			Forest *			Shrubland *			Grassland *			Other land	Total land area *		
1955	10.8	±	1.3	49.3	±	5.0	13.9	±	7.8	13.9	±	9.9	4.9	92.9	±	24.0
1956	10.9	±	1.3	48.5	±	4.9	13.8	±	7.8	13.8	±	9.9	5.0	91.9	±	23.9
1957	11.3	±	1.4	47.8	±	4.9	13.3	±	7.7	13.9	±	9.9	5.0	91.2	±	23.9
1958	11.1	±	1.4	47.6	±	4.8	13.2	±	7.7	14.0	±	9.9	5.0	90.9	±	23.8
1959	11.6	±	1.4	48.1	±	4.8	13.5	±	7.6	14.6	±	10.2	5.0	92.9	±	24.0
1960	10.5	±	1.3	49.1	±	4.8	13.9	±	7.7	15.5	±	10.5	5.0	94.1	±	24.3
1961	10.8	±	1.4	47.1	±	4.7	13.1	±	7.6	15.1	±	10.4	5.0	91.1	±	24.1
1962	11.1	±	1.3	46.9	±	4.7	13.2	±	7.6	15.7	±	10.2	5.1	91.9	±	23.8
1963	11.6	±	1.3	47.7	±	4.6	13.6	±	7.6	17.3	±	10.9	5.1	95.4	±	24.5
1964	10.8	±	1.3	48.4	±	4.7	14.0	±	7.7	17.1	±	10.4	5.1	95.4	±	24.2
1965	10.7	±	1.3	50.0	±	4.7	14.9	±	7.8	18.4	±	10.7	5.1	99.1	±	24.5
1966	11.1	±	1.3	50.7	±	4.7	15.6	±	7.8	19.9	±	10.9	5.1	102.5	±	24.6
1967	10.9	±	1.2	51.0	±	4.7	15.8	±	7.8	19.6	±	10.8	5.2	102.4	±	24.5
1968	10.9	±	1.2	51.3	±	4.7	16.2	±	7.8	19.6	±	10.8	5.2	103.1	±	24.4
1969	11.0	±	1.2	51.1	±	4.7	16.8	±	7.9	19.2	±	11.0	5.2	103.3	±	24.8
1970	10.6	±	1.2	49.3	±	4.6	16.3	±	7.7	18.1	±	10.7	5.2	99.5	±	24.2
1971	11.8	±	1.2	50.3	±	4.5	17.2	±	7.7	20.9	±	11.1	5.2	105.5	±	24.4
1972	11.0	±	1.1	50.1	±	4.5	17.1	±	7.7	20.1	±	11.2	5.3	103.6	±	24.5
1973	10.8	±	1.1	53.2	±	5.3	14.4	±	6.5	21.0	±	11.5	5.3	104.6	±	24.4
1974	10.8	±	1.0	49.9	±	4.4	18.7	±	7.9	20.9	±	11.4	5.4	105.7	±	24.7
1975	11.0	±	1.0	51.0	±	4.5	18.5	±	7.8	21.1	±	11.4	5.2	106.8	±	24.8
1976	10.2	±	1.0	52.2	±	4.8	18.4	±	7.9	18.3	±	10.7	5.2	104.2	±	24.4
1977	10.2	±	1.1	50.4	±	4.5	19.2	±	8.0	19.4	±	11.3	5.2	104.3	±	24.9
1978	10.9	±	1.0	51.2	±	4.7	19.3	±	8.0	20.2	±	11.1	5.2	106.8	±	24.8
1979	10.2	±	1.0	52.1	±	4.7	19.6	±	8.1	20.5	±	11.2	5.1	107.5	±	25.0
1980	11.1	±	1.0	53.7	±	4.7	20.0	±	8.2	20.9	±	11.0	5.1	110.8	±	24.9
1981	8.9	±	1.0	52.7	±	4.7	19.8	±	8.2	19.2	±	10.9	5.1	105.7	±	24.7
1982	9.7	±	1.0	52.7	±	4.7	18.9	±	8.0	16.7	±	10.7	5.2	103.2	±	24.3
1983	9.3	±	0.9	53.5	±	4.7	19.3	±	8.0	17.1	±	10.6	5.1	104.5	±	24.3
1984	11.6	±	0.9	53.2	±	4.0	19.8	±	8.3	19.5	±	10.9	5.1	109.2	±	24.1
1985	11.2	±	0.9	52.1	±	4.0	19.9	±	8.3	19.3	±	10.9	5.2	107.7	±	24.1
1986	10.2	±	0.9	50.4	±	4.1	19.7	±	8.3	18.2	±	10.8	5.3	103.9	±	24.2
1987	11.4	±	0.9	51.5	±	4.1	20.2	±	8.4	19.3	±	10.9	5.3	107.8	±	24.2
1988	11.8	±	0.9	50.0	±	4.1	19.4	±	8.4	16.5	±	11.2	5.3	103.0	±	24.5
1989	10.6	±	0.9	49.7	±	4.2	18.6	±	8.4	14.1	±	10.8	5.3	98.3	±	24.2
1990	10.9	±	0.8	49.5	±	4.2	18.2	±	8.5	15.8	±	11.0	5.2	99.7	±	24.5
1991	10.6	±	0.8	49.6	±	4.2	18.2	±	8.5	14.9	±	10.7	5.3	98.6	±	24.2
1992	9.7	±	0.8	50.2	±	4.3	17.5	±	8.4	14.1	±	10.4	5.4	96.9	±	24.0
1993	10.1	±	0.8	51.8	±	4.4	18.6	±	8.6	14.5	±	10.7	5.5	100.5	±	24.4
1994	9.0	±	0.7	50.3	±	4.3	18.4	±	8.6	17.0	±	11.7	5.6	100.4	±	25.2
1995	7.7	±	0.8	50.9	±	4.9	17.3	±	8.4	14.0	±	10.7	5.6	95.6	±	24.8
1996	11.6	±	0.8	52.2	±	4.8	18.6	±	8.6	15.5	±	10.9	5.8	103.6	±	25.1
1997	11.0	±	0.7	50.9	±	4.5	19.8	±	8.8	16.1	±	11.9	5.9	103.7	±	25.9
1998	11.7	±	0.7	52.3	±	4.4	19.8	±	8.7	18.1	±	12.3	5.9	107.8	±	26.2
1999	10.4	±	0.7	52.8	±	4.5	19.2	±	8.7	16.6	±	12.0	5.8	104.8	±	25.8
2000	12.1	±	0.6	53.2	±	4.5	19.1	±	8.6	17.0	±	12.0	5.9	107.2	±	25.7
2001	10.9	±	0.7	55.7	±	4.6	17.8	±	8.1	16.7	±	12.6	5.9	107.0	±	26.0
2002	11.3	±	0.6	55.4	±	4.9	17.3	±	7.9	17.3	±	12.5	6.0	107.3	±	26.0
2003	11.7	±	0.7	55.4	±	4.9	18.9	±	8.5	18.0	±	12.2	5.8	109.8	±	26.3

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

Table B12: Development of NPP_t per area [t DM/ha/yr], broken down to main land use types; yearly data.

	Cropland	Forest	Shrubland	Grassland	Other land	Total land area
1955	0.5 ± 0.1	4.8 ± 0.5	3.0 ± 1.7	1.2 ± 0.9	1.7	1.9 ± 0.5
1956	0.5 ± 0.1	4.8 ± 0.5	3.0 ± 1.7	1.2 ± 0.9	1.7	1.8 ± 0.5
1957	0.5 ± 0.1	4.7 ± 0.5	2.9 ± 1.7	1.2 ± 0.9	1.7	1.8 ± 0.5
1958	0.5 ± 0.1	4.7 ± 0.5	2.9 ± 1.7	1.3 ± 0.9	1.7	1.8 ± 0.5
1959	0.5 ± 0.1	4.8 ± 0.5	3.0 ± 1.7	1.3 ± 0.9	1.7	1.9 ± 0.5
1960	0.5 ± 0.1	4.8 ± 0.5	3.1 ± 1.7	1.4 ± 0.9	1.7	1.9 ± 0.5
1961	0.5 ± 0.1	4.7 ± 0.5	2.9 ± 1.7	1.4 ± 0.9	1.7	1.8 ± 0.5
1962	0.5 ± 0.1	4.7 ± 0.5	2.9 ± 1.7	1.4 ± 0.9	1.7	1.8 ± 0.5
1963	0.5 ± 0.1	4.8 ± 0.5	3.0 ± 1.7	1.6 ± 1.0	1.7	1.9 ± 0.5
1964	0.5 ± 0.1	4.8 ± 0.5	3.1 ± 1.7	1.5 ± 0.9	1.7	1.9 ± 0.5
1965	0.5 ± 0.1	4.9 ± 0.5	3.3 ± 1.7	1.6 ± 1.0	1.7	2.0 ± 0.5
1966	0.5 ± 0.1	4.9 ± 0.5	3.4 ± 1.7	1.8 ± 1.0	1.7	2.0 ± 0.5
1967	0.5 ± 0.1	5.0 ± 0.5	3.4 ± 1.7	1.7 ± 1.0	1.7	2.0 ± 0.5
1968	0.5 ± 0.1	5.0 ± 0.5	3.5 ± 1.7	1.8 ± 1.0	1.7	2.1 ± 0.5
1969	0.5 ± 0.1	4.9 ± 0.5	3.6 ± 1.7	1.7 ± 1.0	1.7	2.1 ± 0.5
1970	0.5 ± 0.1	4.8 ± 0.5	3.6 ± 1.7	1.6 ± 1.0	1.7	2.0 ± 0.5
1971	0.6 ± 0.1	5.0 ± 0.4	3.8 ± 1.7	1.9 ± 1.0	1.7	2.1 ± 0.5
1972	0.5 ± 0.1	4.9 ± 0.4	3.8 ± 1.7	1.8 ± 1.0	1.7	2.1 ± 0.5
1973	0.5 ± 0.1	4.9 ± 0.5	3.7 ± 1.7	1.9 ± 1.0	1.7	2.1 ± 0.5
1974	0.5 ± 0.0	5.0 ± 0.4	4.0 ± 1.7	1.9 ± 1.0	1.7	2.1 ± 0.5
1975	0.5 ± 0.0	4.9 ± 0.4	4.0 ± 1.7	1.9 ± 1.0	1.6	2.1 ± 0.5
1976	0.5 ± 0.0	4.9 ± 0.5	4.0 ± 1.7	1.7 ± 1.0	1.6	2.1 ± 0.5
1977	0.5 ± 0.1	4.8 ± 0.4	4.1 ± 1.7	1.8 ± 1.0	1.6	2.1 ± 0.5
1978	0.5 ± 0.0	4.8 ± 0.4	4.1 ± 1.7	1.9 ± 1.0	1.6	2.1 ± 0.5
1979	0.5 ± 0.1	4.8 ± 0.4	4.1 ± 1.7	1.9 ± 1.0	1.6	2.2 ± 0.5
1980	0.5 ± 0.0	5.0 ± 0.4	4.1 ± 1.7	2.0 ± 1.0	1.6	2.2 ± 0.5
1981	0.4 ± 0.0	4.9 ± 0.4	4.1 ± 1.7	1.8 ± 1.0	1.6	2.1 ± 0.5
1982	0.5 ± 0.0	4.9 ± 0.4	4.0 ± 1.7	1.6 ± 1.0	1.6	2.1 ± 0.5
1983	0.5 ± 0.0	4.9 ± 0.4	4.1 ± 1.7	1.6 ± 1.0	1.6	2.1 ± 0.5
1984	0.6 ± 0.0	5.0 ± 0.4	4.1 ± 1.7	1.8 ± 1.0	1.6	2.2 ± 0.5
1985	0.5 ± 0.0	4.8 ± 0.4	4.1 ± 1.7	1.8 ± 1.0	1.6	2.2 ± 0.5
1986	0.5 ± 0.0	4.7 ± 0.4	4.0 ± 1.7	1.7 ± 1.0	1.6	2.1 ± 0.5
1987	0.6 ± 0.0	4.8 ± 0.4	4.1 ± 1.7	1.8 ± 1.0	1.6	2.2 ± 0.5
1988	0.6 ± 0.0	4.7 ± 0.4	3.9 ± 1.7	1.5 ± 1.0	1.6	2.1 ± 0.5
1989	0.5 ± 0.0	4.6 ± 0.4	3.8 ± 1.7	1.3 ± 1.0	1.6	2.0 ± 0.5
1990	0.5 ± 0.0	4.6 ± 0.4	3.7 ± 1.7	1.5 ± 1.0	1.6	2.0 ± 0.5
1991	0.5 ± 0.0	4.6 ± 0.4	3.6 ± 1.7	1.4 ± 1.0	1.6	2.0 ± 0.5
1992	0.5 ± 0.0	4.6 ± 0.4	3.5 ± 1.7	1.3 ± 1.0	1.6	1.9 ± 0.5
1993	0.5 ± 0.0	4.7 ± 0.4	3.7 ± 1.7	1.3 ± 1.0	1.6	2.0 ± 0.5
1994	0.5 ± 0.0	4.5 ± 0.4	3.7 ± 1.7	1.4 ± 1.0	1.6	2.0 ± 0.5
1995	0.4 ± 0.0	4.5 ± 0.4	3.5 ± 1.7	1.2 ± 0.9	1.6	1.9 ± 0.5
1996	0.6 ± 0.0	4.6 ± 0.4	3.7 ± 1.7	1.4 ± 1.0	1.6	2.1 ± 0.5
1997	0.6 ± 0.0	4.6 ± 0.4	3.8 ± 1.7	1.4 ± 1.0	1.7	2.1 ± 0.5
1998	0.6 ± 0.0	4.6 ± 0.4	3.9 ± 1.7	1.6 ± 1.1	1.7	2.2 ± 0.5
1999	0.6 ± 0.0	4.6 ± 0.4	3.8 ± 1.7	1.4 ± 1.0	1.6	2.1 ± 0.5
2000	0.7 ± 0.0	4.7 ± 0.4	3.8 ± 1.7	1.5 ± 1.0	1.6	2.1 ± 0.5
2001	0.6 ± 0.0	4.8 ± 0.4	3.7 ± 1.7	1.4 ± 1.1	1.6	2.1 ± 0.5
2002	0.6 ± 0.0	4.7 ± 0.4	3.7 ± 1.7	1.5 ± 1.1	1.6	2.1 ± 0.5
2003	0.7 ± 0.0	4.7 ± 0.4	3.8 ± 1.7	1.6 ± 1.1	1.6	2.2 ± 0.5

* Values obtained by using the "best guess" of NPP_{act} per area ± variations when using the high respectively low estimates of NPP_{act} per area.
Sources: own calculations, see text.

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