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Environmental consequences of the palm oil industry in Malaysia

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Cover picture: Erosion from an oil palm plantation in Malaysian Borneo.
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PREFACE

There is a growing debate about how the increasing use of palm oil affects ecosystems in the tropics. Environmentalists claim that the industry is harmful while others have argued it is sustainable. I have been interested in this subject for a long time and it has been very interesting to learn more about the environmental issues related to the palm oil industry.

This is a bachelor's thesis in physical geography and ecosystems analysis carried out at Lund University in the spring of 2011.

Acknowledgements

First and foremost I wish to thank Jonathan Seaquist, my supervisor, for valuable feedback, advice and encouragement. I would also like to thank friends and my family for support.

ABSTRACT

There is a growing global demand for palm oil – a vegetable oil used in various products such as margarine and biofuel. Since 1961 the Malaysian palm oil production has experienced a 185-fold increase and currently Malaysia produces about 40 % of the world's palm oil. Malaysia also has one of the world's richest flora and fauna. The palm oil industry has gained much negative attention in recent years because of the many environmental problems associated with oil palm expansion and palm oil production. This thesis aims at identifying and describing the multiple environmental consequences of palm oil production in Malaysia with particular focus placed on land use change over the last few decades. The approach uses the DPSIR framework to systematically address the environmental aspects. Drawn conclusions are that the growth of the palm oil industry is driven by various synergistic factors such as population growth, governmental policies and changed consumption patterns; and that the main environmental issue related to the palm oil industry is the land use conversion from forest to oil palm. Because of this conversion the palm oil industry contributes to biodiversity loss, soil degradation, water pollution and GHG emissions. Most emissions to the air are related to forest fires that emerge during the clearing of land before establishing a plantation. Measures have been taken to prevent further loss of forests and to reduce pollution. These measures are, however, insufficient. Disagreement concerning what is to be considered areas of high (ecological) conservation value and what is to be classified as forest and non-forest aggravates a sustainable palm oil development. There seems to be an urgent need for comprehensive land use cover maps that detect areas of ecological importance.

Keywords: physical geography · palm oil · land use conversion · biodiversity · pollution

Miljökonsekvenser av palmoljeindustrin i Malaysia

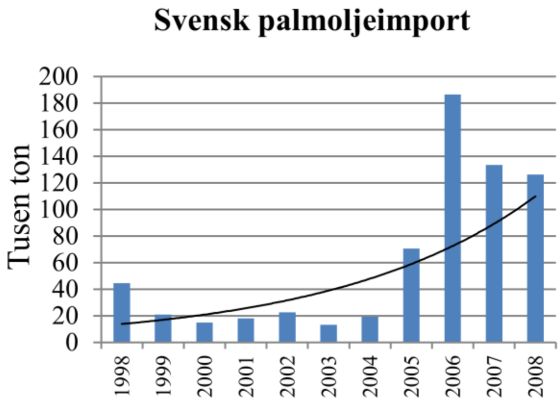
SAMMANFATTNING

Palmolja finns numer i en rad olika produkter, från margarin till biobränsle, och den globala efterfrågan på palmolja ökar år för år. I Malaysia har produktionen av palmolja ökat mer än 185 gånger sedan år 1961 och idag producerar landet omkring 40 % av världens palmolja. Den enorma tillväxten drivs av bland annat populationsökning, förändrade konsumtionsvanor samt policys som syftar till att öka Malaysias ekonomiska självständighet och minska fattigdom. Det hävdas ofta att palmoljeindustrin har skadliga effekter på ekosystem i tropikerna. Syftet med denna uppsats är att redogöra för palmoljeproduktionens miljörelaterade konsekvenser. Konvertering av regnskog till oljepalmsplantager medför en förlust av värdefulla habitat, i synnerhet i Malaysia där biodiversiteten är hög. Dessutom medför utbredandet av oljepalmsplantager ökad erosion vilket leder till sedimentation och övergödning i närliggande vatten. Den tropiska regnskogen utgör en enorm kolsänka, eftersom oljepalmplantager lagrar mindre kol per hektar orsakar markomvandling från skog till oljepalm en nettoförlust av bundet kol; och alltså mer koldioxid till atmosfären. I samband med inrättandet av nya oljepalmsplantager bränns ofta marken, i de fall då elden sprider sig ökar koldioxidutsläppen ännu mer. För att förhindra de palmoljerelaterade negativa miljökonsekvenserna har vissa områden skyddats från avskogning och utsläpp av vissa giftiga ämnen har förbjudits. Dessvärre råder det delade meningar om vilka områden som bör skyddas och därför fortsätter vissa skyddsvärda områden att omvandlas till palmolja. Den statistik som rör markomvandlingen är ofta bristfällig och det tycks finnas ett stort behov av mer aktuell data för att i framtiden kunna planera för ett hållbart marknyttjande.

Nyckelord: naturgeografi · palmolja · markomvandling · biodiversitet · föroreningar

Palmolja i Sverige

Bland svenska importvaror ligger palmolja på plats nummer nitton och år 2008 importerade vi 126 197 ton, till ett värde av US$ 141 497 (FAOSTAT 2011). Palmolja finns även i ett stort antal importerade produkter vilket gör det svårt att veta den exakta mängden som används. Hur mycket palmolja som importeras från år till år varierar kraftigt, men trenden verkar gå mot en ökad användning. Större delen av palmoljan används i livsmedel och resten används inom industrisektorn (Tegnäs & Svedén 2002). Av den totala mängden vegetabiliska oljor som används i Sverige utgörs omkring 30 procent av palmolja (Möllersten 2001). Karlshamns AB och Unilever Bestfoods AB står tillsammans för merparten av den svenska importen. Båda importerar palmolja från Malaysia, Karlshamns får hela sin import från Västmalaysia och Unilever Bestfoods importerar från både Indonesien och Malaysia (Möllersten 2008).



Figuren visar den svenska palmoljeimporten mellan 1998 och 2008. Källa: FAOSTAT 2011-03-20

LIST OF ABBREVATIONS

BOD	Biological Oxygen Demand
CPKO	Crude Palm Kernel Oil
CPO	Crude Palm Oil
DPSIR	Driving force – Pressure – State – Impact – Response
EEA	European Environment Agency
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
FELCRA	Federal land Consolidation and Rehabilitation
FELDA	Federal Land Development Authority
GHG	Greenhouse gas
GNP	Gross National Product
HCVF	High Conservation Value Forest
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MNS	Malaysian Nature Society
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council (formerly known as MPOPC)
MPOWCF	Malaysian Palm Oil Wildlife Conservation Fund
OECD	Organization for Economic Co-operation and Development
PAR	Photosynthetically Active Radiation
POME	Palm Oil Mill Effluent
PRF	Permanent Forest Reserve
PSR	Pressure – State – Response
RISDA	Rubber Industry Smallholders' Development Authority
RSPO	Roundtable on Sustainable Palm Oil
UNEP	United Nations Environment Programme
WWF	World Wide Fund for nature

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INTRODUCTION

Palm oil from the oil palm (*Elaeis guianensis*) has in recent years become the world's most important vegetable oil when it comes to production quantity (USDA 2011). Being used in various products, from margarine to biofuel, palm oil has found a role in the West as well as in the developing markets of China and India. The global demand for palm oil is constantly growing in step with global population and per capita income. Since the early 1980s the total global area of harvested oil palms has more than tripled reaching over 147 thousand km^2 in 2009, resulting in 41 million tonnes of produced palm oil (FAOSTAT 2011). Much of the area under oil palm cultivation is located in Malaysia and Indonesia[1] and together they produce 85 % of the world's palm oil. This thesis focuses on the Malaysian palm oil industry which has been world-leading from the 1960s until just recently when Indonesia reached the same production rate (see Appendix I).

The palm oil industry has offered wealth and development in many areas, but the expansion of oil palm cultivation is, however, not without conflicts. In recent years the palm oil industry has gained much negative criticism for its several harmful impacts on the environment. For example, it has been claimed that the industry causes deforestation. The lowland tropical rainforest in which the oil palm thrives, and is most productive, have an extraordinary rich plant and animal life. With the establishment of new oil palm plantations land needs to be converted from something else and when oil palm expansion occur at the expense of forests the habitat of numerous species is threatened. Studies have suggested that oil palm agriculture constitutes the biggest threat to biodiversity in Southeast Asia (Wilcove & Koh 2010). Land use conversion into oil palm is not only associated with biodiversity loss. Southeast Asia also contains much of the world's peatlands. These peatlands constitute enormous carbon stocks and converting them to oil palm produces sizable greenhouse gas (GHG) emissions. Other negative impacts on the environment blamed on the palm oil industry are for example the poor management at the oil palm mills which causes pollution of both air and water.

At the same time the oil palm is considered one of the most environmentally friendly oil crops by some. Oil palms are more productive than other oil crops and, thus, relatively small areas are needed to produce the same amount of oil from oil palms than from for example soybeans or rapeseed. Statements such as "[p]alm oil is indeed a nature's gift to Malaysia, and Malaysia's to the world" (Sumathi et al. 2008) are not uncommon, and certainly not without validity.

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[1] Nigeria also has a considerable area under oil palm, however production is relatively low.

Harmful for the environment or not, the palm oil industry continues to expand. Since the 1970s many studies concerning palm oil have been carried out. However, only a small fraction of these have touched upon environmental aspects and there is a growing need to address possible environmental impacts of the industry (Turner et al. 2008).

Aim and approach

The overall aim of this study is to identify and account for the multiple environmental consequences of palm oil production in Malaysia. Particular emphasis is placed on land use change over the last few decades.

The approach will use the Drivers–Pressure–State–Impact–Response (DPSIR) framework within which the many ecological, social and economic problems and benefits, and the relations between them, are systematically addressed. The DPSIR framework is described in the next section.

Following the DPSIR framework, this thesis addresses the following questions:

- What are the main *driving forces* behind the rapid expansion of oil palm agriculture in Malaysia?
- What kind of *pressure* does the Malaysian palm oil production and oil palm expansion exert on the environment? What type of land does the oil palm development exploit? Are there any pollutants or leaching of fertilizers from the industry into the environment?
- What is the *state* of oil palm agriculture in Malaysia today? What is the spatial extent of primary and secondary forests and how much has become oil palm? What is the current quality of water and air?
- What are the *impacts* on ecosystems that follow the changed state?
- How has society *responded* to the environmental threats of palm oil production e.g. are there any policies prohibiting deforestation due to oil palm, or subsidies for producing with less emissions of pollutants?

This is a literature review based mainly on academic publications, reports and statistic data (e.g. from FAO and MPOB). Sometimes examples from Indonesia are used when information on Malaysian conditions have not been found.

THE DPSIR FRAMEWORK

Environmental issues involve many different aspects and the interactions linking them together are complex. Therefore, when studying environmental problems, it is important to have a clear structure for the cause-effect relationships (Ness et al. 2010). The Drivers–Pressure–State–Impact–Response (DPSIR) scheme can be helpful when organizing the key factors involved in a specific issue.

Figure 1 shows a generalized diagram of the DPSIR framework. In summary, the DPSIR represents a chain of causal links starting with *driving forces* (or *drivers*) behind a development that exerts *pressure* on the environment which moreover influences the *state* of the environment. The state can in turn have an *impact* on both ecosystems and human health which calls for societal *responses* that either are directed towards the impacts, state or pressures, or directly towards the origin – the drivers (EEA 1999, Ness et al. 2010).

Driving forces refer to the social, demographic and economic developments that lead to change towards a specific target (e.g. towards maximized palm oil production) (Ibid.). Pressures refer to the changes in use of land or release of substances (e.g. GHG emissions or pollutants) that are consequences of the driving forces and result in a change of environmental state. The state describes current condition of the environment; for example, how the air quality is affected by emitted pollutants. Impact is the assessable damage resulting from the changed state (e.g. haze due to pollution). Finally, the responses are the societal attempts to prevent, compensate, ameliorate or adapt to the changes and their impacts (EEA 1999).

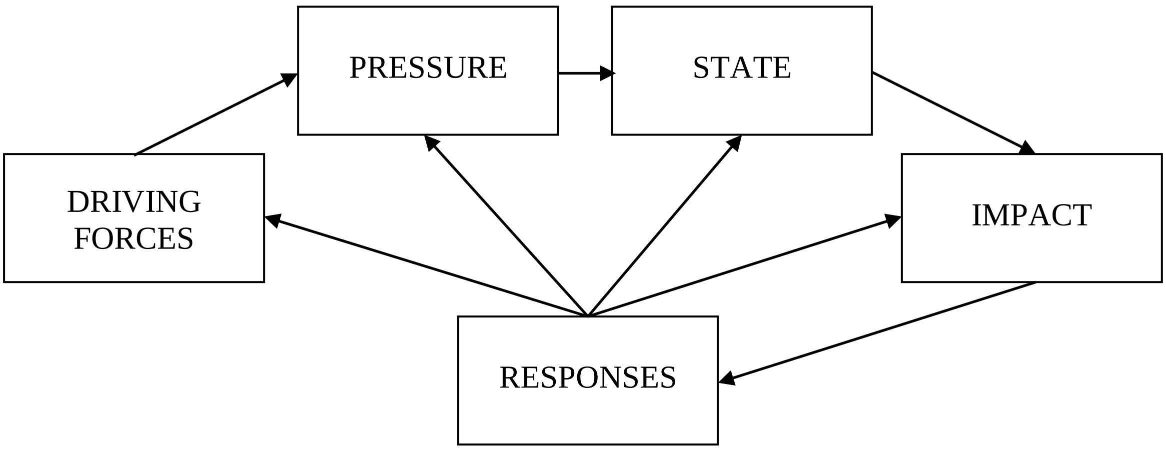

Figure 1. A generalized diagram of the DPSIR framework where driving forces, pressure, state, impact and responses are linked together.

The DPSIR framework was developed by the European Environment Agency (EEA) in 1999 and is an extended version of the PSR model (Pressure–State–Response) used by the Organization for Economic Co-operation and Development (OECD) (Carr et al. 2007). DPSIR is mainly used as a support to policy makers as it gives an overview over the issue and pinpoints to key factors in the causal chain of causes and consequences. The DPSIR scheme can be useful in studies on environmental issues on all scales – from local to global.

DPSIR applied to palm oil production

The Malaysian palm oil industry is enormous, generating billions of US dollars with plantations extending over 46.9 thousand km^2. To get an overview of the environmental impacts and the many different factors influencing the industry a comprehensible structure is fundamental. In this study the DPSIR framework will be applied in order to categorize the many ecological problems and possible benefits associated with palm oil production and oil palm expansion. This study is carried out on a federal level considering a short time scale; therefore climate change and other long-term hard-to-measure global factors are excluded.

DPSIR is often used to address social and economic impacts of certain developments as well as the environmental impacts. In this study only environmental consequences are taken into account. Since particular focus will be placed on land use conversion (and its consequences) over the last few decades some aspects of the DPSIR framework are emphasized. For example, driving forces are particularly relevant because they have caused the expansion of oil palm agriculture which has led to land use conversion. Pressure, state and impact are also of major concern as they refer to the actual consequences. Current societal responses however, will only briefly be examined because they will affect future land use conversion which is excluded in this study.

INTRODUCTION TO THE STUDY AREA: MALAYSIA

General facts

Malaysia comprises two separate land regions between about 1°-9°N and 99°-120°E (Fig.2). Divided by the South China Sea, Peninsular Malaysia (or West Malaysia) is located in the southernmost part of the Malacca peninsula, while East Malaysia (or Malaysian Borneo) is located along the northwest coast of Borneo. East Malaysia is divided in two provinces, Sabah in the north and Sarawak in the south. Peninsular Malaysia, Sabah and Sarawak are often separated administratively, having for example different forest departments.

Malaysia is more than five times smaller than Indonesia which is the other world leading palm oil producing country. The total country area is a bit less than 330,000 km^2 (about 70 % of the area of Sweden) of which about 40 % is made up by Peninsular Malaysia (Encyclopaedia Britannica 2011). Malaysia has more than 28 million inhabitants and most people live in urban areas (72 % of the total population in 2010; CIA World Factbook 2011).

The Malaysian GDP per capita is US$ 14,700 (2010 est.) (Ibid.). Palm oil and related products are the second largest export of Malaysia, after electronics (Sulaiman 2010). Palm oil dominates the country's agricultural production with 17.5 million tonnes produced in 2009, this accounts for about 40 % of the world's produced palm oil. In 2008 Malaysia exported 14.1 million tonnes of palm oil (with a value of 903 US$/tonne) (FAOSTAT 2011).

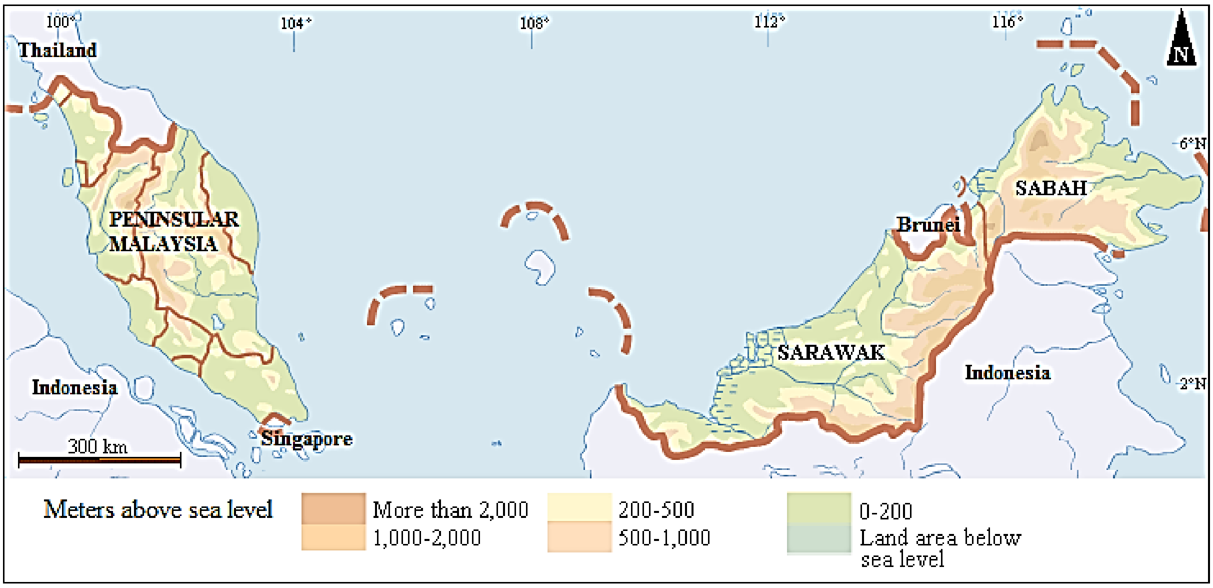

Figure 2. Location and physical geography of Malaysia. Thick red continuous and dashed lines mark country borders, thin red lines separates regions within the country. Source: modified from Nationalencyclopedin 2011

Geology and climate

As implied in the map above (Fig.2) most of Peninsular Malaysia is lowland (about half is below 150 m.a.s.l. and the highest point reaches 2,189 m.a.s.l). Inland East Malaysia is hilly, and along the border to Indonesia mountainous with the highest peak being Mount Kinabalu reaching 4,101 m.a.s.l.. The climate of Malaysia is tropical with even temperatures throughout the year (Encyclopaedia Britannica 2011). Oil palms are grown in the lowlands where the mean annual temperature is 27° C which is ideal for their growth (Tengnäs & Svedén 2002).

The oil palm requires a moist climate which makes Malaysia suitable. The mean annual rainfall in Peninsular Malaysia averages at about 2,500 mm but it varies between regions. The wettest area receives around 5,000 mm per year, while the driest receives around 1,650 mm. In Sabah the mean annual rainfall varies between 2,030 to 3,560 mm and Sarawak annually receives around 3,050 mm or more (Behrens 2011). The rainfall patterns are affected by local topography and the monsoons. Due to the northeast and southwest monsoons less precipitation is expected in April-May and September-October (Wong & Chen 1999).

Land use

Three land use types are of main concern for this study; namely oil palm plantations, tropical rainforests and peat swamp forests. The latter two are considered because it is often claimed that oil palm cultivation replaces them, with resulting environmental impacts. Tropical rainforests are often divided into primary and secondary forests, where primary forests are forests that never have been cleared and secondary forests are forests that have regrown after earlier clearing. Peat swamp forests are waterlogged forests found in low-lying areas. They grow on a thick layer (up to 20 metres) of dead organic material which has been formed due to slow decomposition because the vegetation is inundated by water (UNDP 2006).

Figure 3 and Table 1 gives a general idea of the total land use in Malaysia even though peat swamp forests are not included and primary and secondary forests are not separated. It can be seen that about 60 % or slightly less than 200 thousand km^2 of the country is under forest cover, even though a large amount of the original Malaysian rainforest has been cleared for agricultural or commercial purposes (UNDP 2006, FAO 2011). Forests cover about 40 % of Peninsular Malaysia and 66 % of East Malaysia (Encyclopaedia Britannica 2011). Malaysia contains about 11 % of the world's tropical peatlands and of the country's forests between 12.7 and 15.4 thousand km^2 are peat swamp forests (Page et al. 2009, UNDP 2006, Department of Statistics, Malaysia 2009). In 2007, arable land constituted 8,440 km^2 and about 54,450 km^2 had permanent crops such as rubber and oil palm (FAO 2010).

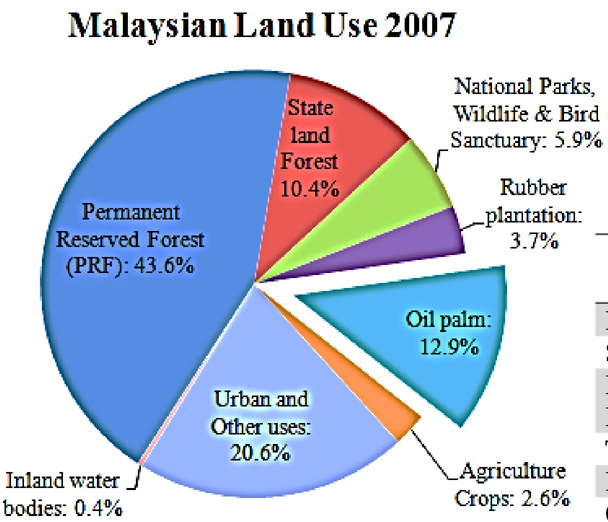

Figure 3. Distribution of Malaysian land use in 2007. Source: data from FAO 2010

Table 1. Malaysian land use in 1990 and 2007. Total forest cover in 1990: 205,400 km^2 and in 2007: 196,630 km^2. Note also that the area under oil palm plantations have more than doubled since 1990 while the areas of both rubber plantations and agriculutural crops have slightly declined.
Source: data from FAO 2010

	Area (km^2)	
Land Use	**1990**	**2007**
Permanent Reserved Forest (PRF)	126,000	143,010
State land Forest	68,200	34,160
National Parks and Wildlife & Bird Sanctuary	11,200	19,460
Total forested Area	**205,400**	**196,630**
Rubber plantation	18,360	12,070
Oil palm	20,290	42,380
Agriculture Crops	14,610	8,440
Urban and Other uses	68,440	67,580
Inland water bodies	1,200	1,200
Total area for country	**328,300**	**328,300**

Flora and fauna

Since one of the main environmental concerns of palm oil production is the oil palm cultivation's interaction with natural biodiversity it is important to review the Malaysian flora and fauna. Malaysia is well known for its rich biota. With about 15,000 plant species the Malaysian flora is among the richest in the world (MNS 2011). The Malaysian biota is also known for being threatened by various factors, of which oil palm expansion is one. Myers et al. (2000) recognize Malaysia together with Brunei, parts of Indonesia and Thailand as one out of 25 global *biodiversity hotspots*. To be considered a biodiversity hotspot, a region must have a great number of endemic plants and (non-fish) vertebrates, and these endemic species must be under threat (indicated by natural habitat loss) meaning they are in urgent need of conservation (the number of biodiversity hotspots has increased since 2000 when Myers et al. firstly published their article, currently there are 34 hotspots; www.biodiversityhotspots.org). Malaysia is also recognized as one of 17 *megadiverse countries*; 17 countries that together contain more than 70 % of the world's biodiversity (ASEAN 2009).

The typical indigenous vegetation is dense tropical rainforest with a fraction of the country covered by peat swamp forests. There are several distinctive vegetation zones caused by different soil types and climate (due to elevation differences). Along the coasts are tidal swamp forests, on the ill-drained parts of the coastal plains are freshwater- and peat swamp forests and on the well-drained parts and foothills (up to about 600 metres) are lowland rainforests. At higher altitudes submontane and montane forests can be found (Encyclopaedia Britannica 2011).

The lowland rainforests and peat swamp forests are most suitable for oil palm conversion. Lowland (dipterocarp) tropical rainforests (refers to the majority of the world's rainforests) grow at elevations below 1,000 metres (Butler 2006). These forests typically have many canopy levels and a great variety of fruiting trees and thus, a great variety of animals adapted to feed on their fruit. Lowland forests generally have more large animals than montane forests (Ibid.). In Malaysia there are about 185,000 animal species of which about 300 are mammalian species (MNS 2011). Large animals found in East Malaysia are for example the endangered orangutan (*Pongo pygmaeus*) and Sumatran rhinoceros (*Dicerorhinus sumatrensis*) both highly threatened by the oil palm expansion. Peninsular Malaysia is inhabited by for example sun bear (*Ursus malayanus*), Indian elephant (*Elphas maximus indicus*), clouded leopard (*Neofelis nebulosa*) and tiger (*Panthera tigris*) (Gärdenfors 2011). All of these are affected by the oil palm expansion.

THE OIL PALM: FROM PLANTATION TO FINAL USE

The oil palm and its ecological requirements

Palm oil is extracted from the fruit of oil palm species (*Elaeis* sp.) and in for example West Africa it has been used in food preparation for centuries (in Malaysia however, the oil palm was not introduced until the late nineteenth century; see Appendix II). There are two species of oil palm, one that (most commonly believed) originated in West Africa (*Elais guineensis*), and one that originated in Central and South America (*Elaeis oleifera*). Both oil palms are closely related to other oil producing palms such as the coconut palm (Tengnäs & Svedén 2002). The species introduced to Malaysia was the West African *Elais guineensis* which is still grown today. A fully grown oil palm is usually around 15 metres tall but it can grow to be 20 or 30 metres, and can live for up to 200 years.

One reason for the success of palm oil production is that, compared to other vegetable oils, palm oil has a very high yield per hectare. While the average productivity of for example rapeseed oil and soy bean oil is about 0.5-0.7 and 0.3-0.4 tonnes per hectare respectively, the average productivity of palm oil is about 3.6-4.2 tonnes per hectare of planted oil palm (note that all values are averages and the production can be considerably higher in some areas) (Fairhurst & Mutert 1999, Mekhilef et al. 2011, Sumathi et al. 2008). Also, palm oil is more energy efficient than other commercially grown oil crops because of its large energy input to output ratio. The oil palm produces 22 % of the world's vegetable oils on less than 2 % of the area used for oil crops (Tengnäs & Svedén 2002).

To produce the highest yield, oil palms require plenty of sunshine, a temperature of about 24-27° C and high moisture (yearly precipitation of around 1,500-3,000 mm). Cultivation of oil palms is therefore limited to areas with an altitude less than 500 metres above sea level, between 10° N and 10° S (Tengnäs & Svedén 2002). Hence, much of Malaysia is highly suitable for oil palm. The oil palm is believed to have evolved in swampy, wet levees and the well-drained alluvial soils along for example Malaysia's coast are probably the best possible soils for oil palm (Mutert 1999). Oil palms prefer moderately deep soils with pH 5.5-7 but with added fertilizers, the oil palm can grow in more acid soils (Tengnäs & Svedén 2002). Malaysia comprises about 20-25 thousand km^2 of peat and organic soils that has a naturally low pH (pH 3.0-4.5) (Wong & Chen 1999, ASEAN 2009). These soils have a low fertility and are not favourable for many crops, e.g. rice; therefore oil palm has become an alternative. Of the world's oil palms, approximately more than 95 % grow on acid soils (Mutert 1999).

Palm oil processing

The fruits of the oil palm are small (weighs about 6 to 20 g) and occur in bunches of about 10 to 40 kg. Naturally a bunch holds about 200 fruits; however, cultivars of oil palm can have bunches with up to 4000 fruits (Tengnäs & Svedén 2002). The fruit is orange-red in colour (due to a high content of carotene) and it comprises a kernel enclosed in a shell (endocarp) surrounded by pulp (mesocarp) (Fig.4). Two types of oil can be obtained from the oil palm fruit: *palm oil* from the fibrous mesocarp (only two mesocarp oils are available commercially, the other is olive oil) and *palm kernel oil* from the kernel. The ratio of produced palm oil and palm kernel oil is about ten to one (MPOC 2011a).

Palm oil production can be divided into three stages, namely plantation, transportation to the mill and milling (Yusoff & Hansen 2007). Hence the production involves three sectors: agriculture (plantation stage), transport and industry (milling stage). Every stage includes phases stressing the environment which means that the palm oil production faces a triple environmental challenge (Ibid.). The pressures will be discussed later in this report, first follows short introductions to the three stages.

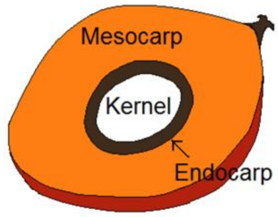

Figure 4. Cross section of an oil palm fruit. The mesocarp (pulp) contains the palm oil.

1. When establishing an oil palm plantation the land needs to be cleared. In Malaysia, this is commonly done by burning (Tegnäs & Sveden 2002). Before planting, the land is prepared by ploughing and weeding (Clay 2004). About four or five years after planting the oil palm is mature enough to produce fruit (Rehm & Espig 1991). After this, the fruit bunches are cut down by hand. At larger plantations, harvesting is done with the help of mechanical lifts; otherwise, knives are attached to long bamboo-sticks. As mentioned, oil palms grow tall and, thus, after about 25-30 years harvesting becomes too complicated and the plantation needs to be renewed (Ibid.).

2. Transportation of the fruit bunches to the mill needs to be done as fast as possible. Within 24 hours after detachment the fresh fruit bunches has to be processed if high quality and value is to be obtained (Rehm & Espig 1991). Therefore palm oil mills are normally located close to the plantations.

3. The procedure of extracting oil from the oil palm fruit is complex and can be summarized as follows: firstly the fruit bunches, reaped from the oil palm plantations, has to be steam-heat sterilized in order to destroy enzymes (that cause fermentation) and kill micro-organisms. The fruits are then detached from the bunch and the stripped bunches can be utilized e.g. as fertilizer (Fig.5) while the fruits are digested (heated and stirred) so that the oil cells are split open and the mesocarp is released from the nut. The resulting mash is pressed to extract oil. This extracted oil is clarified by removing all small bits; resulting in bright orange-red crude palm oil (CPO) and palm oil mill effluent (POME) which is a waste product. At a refinery, the CPO is further treated (deodorized, freed from pigments, free fatty acids and phospholipids) producing refined, bleached, and deodorized (RBD) palm oil. The palm cake obtained from pressing is sent to a kernel-crushing plant where the fibre is removed from the nut, the nut is cracked and the endocarp separated from the kernel. The kernel is further processed (e.g. pressed) to obtain crude palm kernel oil (CPKO) (For more detailed information, see for example Subramaniam et al. 2010a, 2010b).

Palm oil characteristics and usage

Both palm oil and palm kernel oil are used in a variety of products (Fig.5). The two oils are however chemically and nutritionally dissimilar. In palm oil there are equal proportions of saturated and unsaturated fatty acids, while palm kernel oil contains mostly saturated fatty acids (Teoh 2002). Palm oil has a good resistance to oxidation due to its high natural content of the antioxidants carotenoids and vitamin E (MPOC 2011b, Edem 2002). Both CPO and CPKO can be fractionated into liquid (palm/palm kernel *olein*) and solid (palm/palm kernel *stearin*) components used for different purposes (MPOC 2011b).

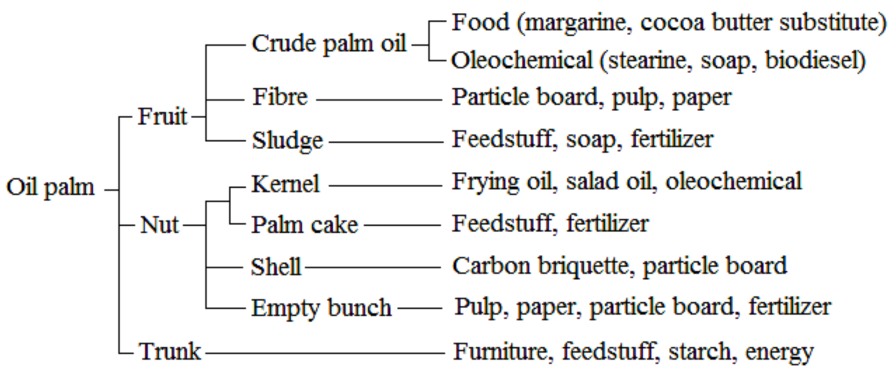

Figure 5. Some of the uses of palm oils and biomass. Source: modified from Fairhurst & Mutert 1999

Palm oil for food purposes

Palm oil has been criticized for being unhealthy (Lam et al. 2009) but according to the Malaysian Palm Oil Council (MPOC) palm oil is highly suitable as edible oil because of its many nutrients and vitamins (MPOC 2011b). Whether or not palm oil is healthy, about 80 % of the world's produced palm oil is used for food purposes (Basiron & Weng 2004). Since palm oil is resistant to oxidative deterioration it is good as frying oil. Potato chips, fries and doughnuts are often fried in palm oil (Sumathi et al. 2008). Palm oil is also a major component of shortenings and margarines, and is commonly used in products such as reduced fat spread, ice cream, coffee whiteners, whipping cream, filled milk, mayonnaise and salad dressings, palm-based cheese and coconut milk powder (Basiron & Weng 2004). Natural palm oil is trans-fat free and hence often blended with other oils producing trans fatty acid-free formulations (Gee 2007).

Palm oil in non-food products

According to Basiron and Weng (2004) the non-food application of palm oil and palm kernel oil is only about 20 % but adds a high economic value. Palm oil can be used in soap and other personal care products such as many cosmetics and toiletries; and is also used in lubricants and greasers, printing ink, drilling mud and as an inert ingredient in pesticide formulations (Ibid.). Furthermore, palm oil is used as biofuel. Refined palm oil can either be converted into methyl ester and then be directly used as biodiesel, or be blended with petroleum diesel obtaining diesel fuel (Mekhilef et al. 2011). The methyl ester of palm oil is known as palm oil diesel (POD) and the blending (if containing certain percentages) is known as Envo Diesel (Ibid., Kalam & Masjuki 2002).

Other products from the oil palm

As can be seen in Figure 5, several products can be produced from other parts of the oil palm. For every kilogram of obtained palm oil, approximately 4 kg of dry biomass is also produced (Sulaiman 2010). A third of this biomass is found in the fresh fruit bunches (FFB) and the other two thirds constitute trunk and frond material (Ibid.). When replanting, about 75 tonnes of dry matter per hectare is produced (Basiron & Weng 2004). Normally the empty fruit bunches are burned to produce energy, or used in mulching as a fertilizer (Subranamian et al. 2010a). The pressed palm cake and the sludge that is left after clarifying CPO can also be used as fertilizer or as animal feedstuff (Fig.5). According to Fairhurst and Mutert (1999) about 25 % of the palm biomass can be returned to the field as nutrient rich mulch.

DRIVING FORCES BEHIND OIL PALM EXPANSION

Both the area under oil palm cultivation and the production of palm oil/palm kernel oil have increased rapidly during the last decades (Fig.6-7). Between 1961 and 2009, palm oil production experienced an astonishing 185-fold increase. The area planted and harvested has increased sevenfold and tenfold respectively between 1975 and 2008 (with a corresponding 14-fold increase in productivity). There is no single driving force behind this increase; instead there is a combination of synergistic driving forces. This thesis does by no means attempt to describe everything that has influenced the palm oil development since the 1960s – this section is only briefly discussing some of the main factors contributing to the expansion.

Factors affecting oil palm development include demographic (e.g. population increase), economic (e.g. market price fluctuations), cultural (e.g. changed consumption patterns encouraging economic investment), institutional (e.g. policies on land use and economic development) and technological. The technological factors are excluded in this study since they require more extensive research. In one way they are not drivers of further oil palm expansion but rather work in the opposite way by increasing the palm oil productivity. The technological factors include for example more effective ways of extracting palm oil and more efficient fertilizers and pesticides used which leads to higher yield per area and thus prevent oil palm expansion. At the same time, however, technologic development increases the competitiveness of palm oil production and thus increases the incitement to invest in further palm oil industrial development.

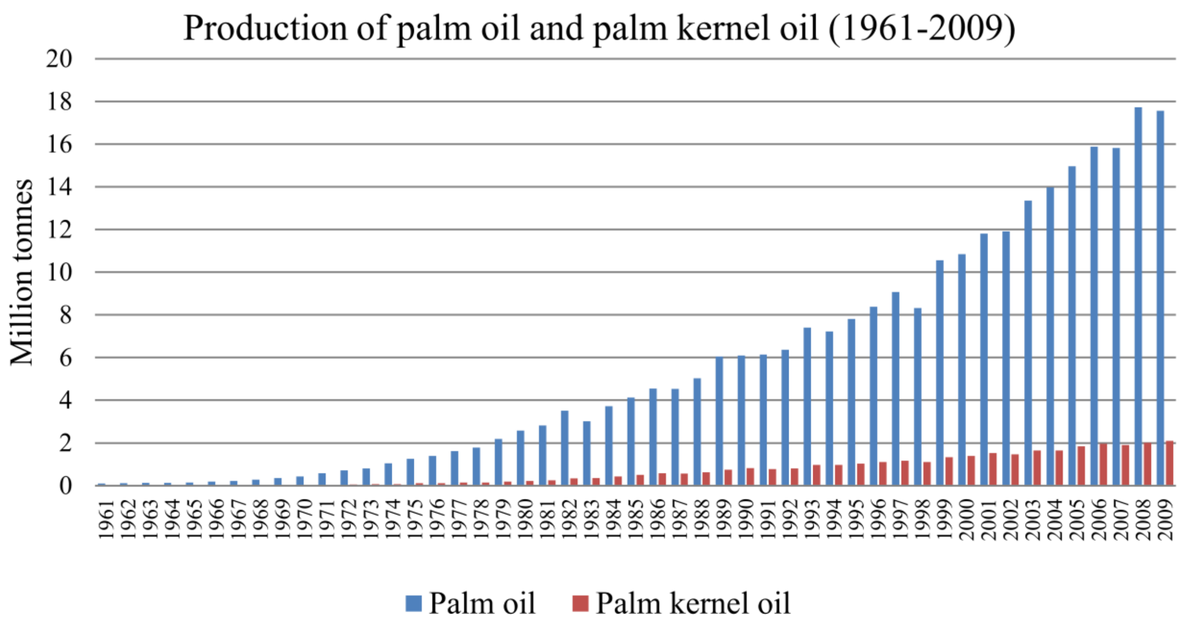

Figure 6. Malaysian production of palm oil and palm kernel oil between the years 1961 and 2009. Amount of palm oil produced was 94,846 tonnes in 1961 and 17,564,937 tonnes in 2009. Amount of palm kernel oil produced was 2,000 tonnes in 1961 and 2,097,096 in 2009. The highest produce of palm oil was obtained in 2008 (17,734,441 tonnes). Source: data from FAOSTAT 2011-04-29

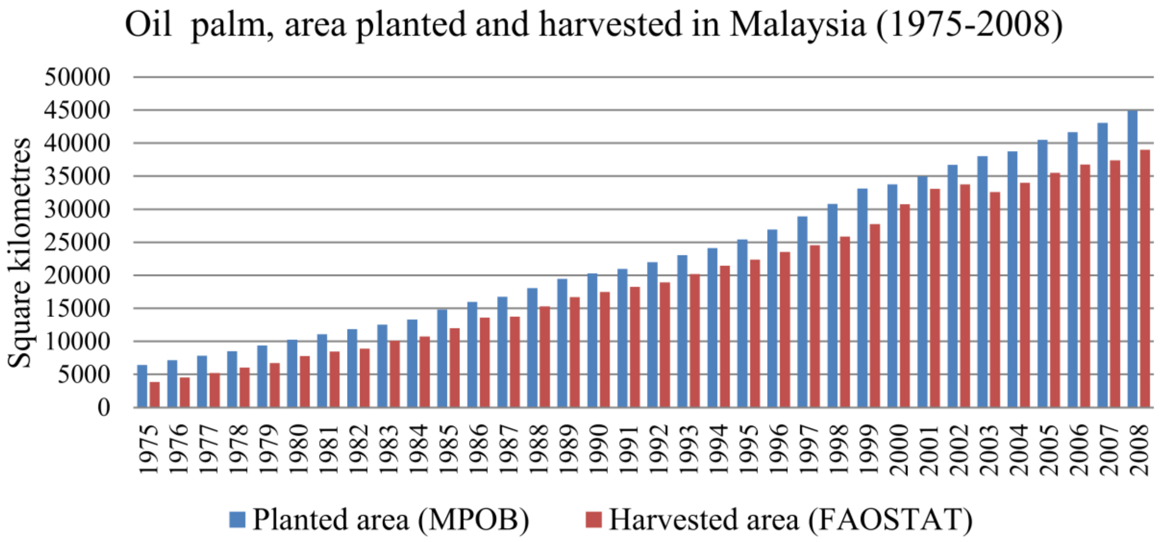

Figure 7. Area planted with oil palm in Malaysia between the years 1975 (6,418 km^2) and 2008 (44,880 km^2) in 2009 the planted area was 46,912 km^2. Area harvested between the years 1975 (3,857 km^2) and 2008 (39,000 km^2). For area harvested the figures from 1999-2008 are unofficial. Source: data from FAOSTAT 2011-03-29 and MPOB 2011 http://econ.mpob.gov.my/economy/annual/stat2009/Area1_1.pdf

Institutional factors

Governmental policies for economic growth and independence

In the late 1960s the palm oil industry began to expand rapidly. Rubber had become the leading industry in the early twentieth century (even though it was introduced about two decades after the oil palm) but in the 1960s, the natural rubber industry experienced an economical setback when synthetic rubber entered the market (see Appendix I for a historical background). Because oil palms have natural advantages over rubber with a more rapid maturation time and because the world market price for palm oil was high, the returns from oil palm were better than from rubber. Hence, in the 1960s, everything pointed towards the expansion of oil palm cultivation (Tate 1996).

Reinforced by new economic policies set up by the Malaysian government the palm oil industry expanded. The new economic policies aimed at self-government and independence. The government wanted to reduce Malaysia's economic dependence on rubber and tin and this was to be done by industrialization and agricultural diversification. In 1966 Malaysia became the world's largest exporter of palm oil (Ibid.). In 1981, for the first time the palm oil production exceeded the natural rubber production and since then, oil palm has been the most produced crop in Malaysia (FAOSTAT 2011).

The growth of the industry obviously continues today with new economic policies encouraging oil palm expansion. With globalization, the level of competitiveness in the international market has escalated. In the latest economic plan (Ninth Malaysian Plan 2006-2010) the government promote new sources of growth in the agricultural sector, this to enhance additional income and to develop new sources of economic wealth.

Land use policies

Further affecting the early oil palm growth was the founding of the Federal Land Development Authority (FELDA) by the Malaysian government in 1956 (Teoh 2002). The goal for FELDA was to reduce rural poverty by developing agricultural land. By planting oil palm at large areas working opportunities and income were provided to people who did not possess any land. Other governmental rural development agencies are Federal Land Consolidation and Rehabilitation (FELCRA) and Rubber Industry Smallholders' Development Authority (RISDA) and both have been planting oil palm over large land areas (Basiron et al. 2004).

Economic factors

The success of oil palm as a crop (and, hence, its expansion) is dependent on how profitable palm oil sales are. The profits from palm oil sales are in turn dependent on the market price of palm oil and on the costs of production. Because of increased yields and improved extraction rates the price of palm oil on the world market declined from US$ 1,102 per tonne in 1960 (when it was high because of a fast expansion of the world market for vegetable and other natural oils) to US$ 307 per tonne in 2000 (Tate 1996, Clay 2004). Since the oil palm is a perennial crop it is often unaffected by for example unpredictable weather and thus the supply of palm oil is kept stable when other oils experience setbacks. Because of the low prices and steadily increasing supply the palm oil expanded into new markets, replacing other oils (Basiron et al. 2004). Since 2000 the market price has risen to US$ 1,041 per tonne in 2008 (Nantha & Tisdell 2009). During this increase the production costs stayed quite low, only rising slowly, leading to increased profit margins which have encouraged palm oil expansion in recent years (Nantha & Tisdell 2009).

Demographics

The world's population is growing with about 1.1 % per year. The largest population growth is taking place in Asia. Europe constitutes one of the traditional markets for palm oil and is still importing large amounts. The population growth in Europe is however small compared to most developing countries. In these countries the available land for food production is shrinking along with the increasing population, urbanization and industrialization (Basiron et al. 2004). With an annual consumption of oil and fats which often is below recommended levels there is a need for cheap oil. According to Basiron et al. (2004) the oil palm is the most important source of vegetable oil to meet the growing oil and fats demand of the growing global population. About 80 % of the palm oil is today imported by developing countries (compared to about 30 % in the 1960s) with India and China being the top importers (Ibid., FAOSTAT 2011). Malaysia is one of only seven countries (the others being Canada, USA, Brazil, Argentina, Indonesia and the Philippines) in the world that are major net exporters of oils and fats, many countries are dependent on having their oils and fats requirements imported from Malaysia (Basiron et al. 2004).

Malaysia's own rapid population growth has naturally also affected the palm oil industry. Since 1980 the country has more than doubled its population and since 1960 the population has been quadrupled (from 6,919 in 1960, 13,879 in 1980 to 28,307 in 2009; Department of

Statistics, Malaysia 2011). With an increasing population the demand for palm oil within the country has increased. Moreover, a growing population adds workforce and hence, salaries can be kept low within the industry.

Cultural factors: Consumption patterns

Apart from an increasing global and local population which increases the demand for dietary oils, the global demand for palm oil is increasing because of changed consumption patterns. With higher income in the developing world, the consumption of an energy-dense high-fat diet has increased (WHO/FAO 2003). The types of edible oils used in developing countries is also changing and palm oil has in recent years become more and more important in much of for example Asia. In the early 1960s only countries with a per capita GNP over US$ 1,475 had a diet providing 20 % of energy from fat but now countries with a per capita GNP of US$ 750 have the same diet (both values of gross national product are given in 1993 US$; Ibid.).

In recent years the demand for palm oil has further increased because it is trans-fat free. The European Food Safety Authority (EFSA) states that a high consumption of trans-fatty acids leads to a higher risk for coronary heart disease and cardiovascular disease (EFSA 2004). In some regions trans-fatty acids in food have been forbidden (e.g. in Denmark 2004) and in others the use of trans-free fat has been highly reduced. Palm oil is used in oil blendings produced to have a healthy fatty acid composition in order to meet the food industry's increased demand for trans-free fat. Because of this increased consumption of dietary oils, prices of CPO and CPKO have been strong encouraging investors to develop oil palm plantations in Malaysia (Fairhurst & Mutert 1999).

Increased use of biofuels

The demand for renewable energy sources is growing in phase with increasing petroleum prices and the decline in supply of non-renewable fossil fuels. In addition, there is an ongoing debate about the environmental impacts of the burning of fossil fuels which releases greenhouse gasses (GHG) causing global warming (Yee et al. 2009). In search for renewable energy, during recent years other biofuels than the ethanol produced by the United States and Brazil (produced from corn and sugar cane) has gained more attention (Mekhilef et al. 2011). Palm oil, with its high yield per hectare, is often considered to be a renewable energy source with enormous future potential (Ibid.).

Malaysia is, as a non-Annex I country, not required do reduce its GHG emissions; nevertheless the country has committed itself to a sustainable development under the Kyoto protocol and has set up a goal to reduce its GHG emissions (Basiron & Weng 2004, Murad et al. 2010). Biofuel production has therefore become more important within the country. Currently, Malaysia is producing an annual amount of 500,000 tonnes of biofuel and the government plans to raise this amount (Sumathi et al. 2007). The National Biofuel Policy aims at (among other things) "supplementing the depleting supply of fossil fuels with renewable resources" and "benefiting from the spin-off effect of more stable prices for palm oil". With an increased use of biofuels, they hope to create a new demand for palm oil (Ministry of plantation industries and commodities 2006).

PRESSURE ON THE ENVIRONMENT

Pressures do not necessarily need to be harmful, rather they represent the consequences, both negative and positive, of the driving forces and further they affect the current state (Ness et al. 2010). As mentioned, producing palm oil is a three-staged process including plantation, transport and milling. The environmental aspects of the plantation stage involves clearing of the land (hence forest decline and carbon release) and use of fertilizers and pesticides. In the transportation stage emissions are released to the air, and roads are extended leading to, for example, soil compaction and further loss of forested areas. The main environmental pressures in the milling stage comes from sterilization of the fresh fruit bunches and release of palm oil mill effluent (POME).

The processes that seem to exert most pressure on the environment are summarized in Table 2. Marked with a star are pressures that are excluded in this thesis. Emissions from transportation are for example neglected since they are considered to be relatively low (Yusoff & Hansen 2007).

Table 2. The three stages in palm oil production, and the major environmental pressures associated with them.

Stage	Process	Pressure
Plantation	Land clearing	Forest decline, carbon release, diesel emissions
	Cultivation maintenance	Fertilizer/pesticide emissions
Transport	Transportation	Diesel emissions*
	Road extension	Soil compaction, forest decline*
Milling	Sterilization of fresh fruit bunches	Boiler stack emissions
	Energy used at mill	Emissions*
	Waste disposal	Biogas emissions from palm oil mill effluent (POME)* POME discharge to waterways

*Not included in this study

Land use conversion

The most obvious environmental pressure exerted by oil palm cultivation is land use conversion. Land use conversion "involves human induced change in ecosystem type to one dominated by different physical environment or plant functional type" (Chapin 2002:321). Establishment of an oil palm plantation creates both a different physical environment and a different plant functional type. Oil palm agriculture in Malaysia has been expanding with about 1,300 km^2 annually for the last ten years; hence, 1,300 km^2 have annually been converted from some other land use into oil palm. There are however controversies concerning what type of land that has been converted, and there is an ongoing debate on what should be classified as forest vs. non-forest. For example, some oil palm analysts declare that oil palm plantations actually are forests and hence do not contribute to deforestation (Sheil et al. 2009). By analysing FAO data, Koh and Wilcove (2008) estimates that more than half (about 55-59 % depending on different scenarios) of the Malaysian palm oil expansion between 1990 and 2005 came at the expense of primary or secondary forests; the remaining palm oil expansion (between 41-45 %) occurred on land converted from pre-existing cropland including rubber plantations. The Malaysian Palm Oil Council (MPOC) nonetheless claims that most of the palm oil cultivation during the last 50 years has expanded onto land converted from rubber, cocoa and coconut cultivation (MPOC 2006).

Making reliable estimations of the land use conversion (and hence determining the link between palm oil and deforestation) is difficult. According to Fitzherebert et al. (2008), recent change of forest-definitions, minimal independent monitoring of government statistics and lack of information on sub-national patterns and causes of land cover change has undermined the usefulness of land cover data from FAO (which provide the most commonly used land use data sets). For example, the Malaysian government has lobbied, with success, for rubber plantations to be classified as “forests” by FAO (Clay 2004). If this is done for oil palm, future conversion might occur and pass unnoticed in the statistics.

Even though an exact figure of the palm oil industry’s contribution to deforestation is hard to find, most statistics imply that considerably large proportions of the Malaysian deforestation is due to oil palm expansion. For example, the data provided in Table 1 and displayed in Figure 8 shows that between 1990 and 2007 there has been a total decline of 12,460 km^2 in rubber and agricultural land, at the same time oil palm plantations have increased by 22,090 km^2. If these numbers are correct, and assuming direct conversion into oil palm occurs with no intermediate conversions (e.g. from forest into rubber and then into oil palm) – a simple calculation reveals that at least 9,630 km^2 of the oil palm plantations has not expanded onto converted rubber and other agricultural land. Instead, with a total forest decline of 8,770 km^2, about 40 % of the oil palm expansion must have been at the expense of forests. If assuming, however, that the deforested areas firstly were turned into rubber plantations, the direct conversion of forest to palm oil is less. Then oil palm should not be identified as a driver of deforestation (Fitzherbert et al. 2008).

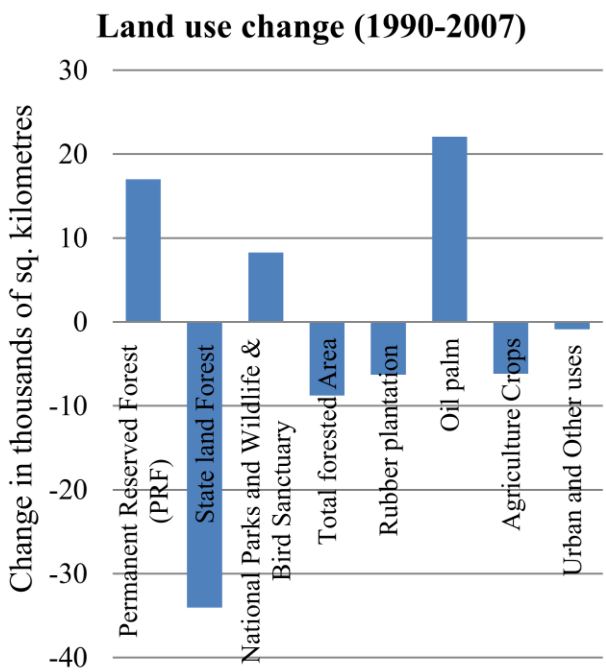

Figure 8. Land use change based on data in Table 1.

Either way it is apparent that palm oil agriculture has indirectly or directly replaced tropical rainforest. Most authors suggest that oil palm plantations more often than not are established directly on newly cleared tropical forests (e.g. Clay 2004, Tegnäs & Svedén 2002, Koh & Wilcowe 2008). Clay (2004) explains that this often is due to the fact that planters feel it is more expensive to plant on grasslands or in degraded areas because of the greater amount of chemical fertilizers needed to make these areas fertile.

According to Clay (2004:218-219) "[t]here is a direct relationship between the growth of oil palm estates and deforestation in Malaysia and Indonesia". How oil palm expansion and deforestation are linked together is complicated and resolving the different linkages is often not possible. The ways in how oil palm expansion can contribute to deforestation have been summarized by Fitzherbert et al. (2008). Oil palm expansion can either be *i*) the main motive for deforesting primary forest; oil palms can *ii*) replace degraded forests that have been harmed by either logging or fire; *iii*) be part of larger economic projects where timber, plywood or paper pulp profits pays for the establishment of oil palm plantations; or oil palm contributes *iv*) indirectly because of road expansion for accessing plantations, and displacement of other crops into forests.

In Malaysia conversion of primary forests to oil palm has in recent years been restricted by governmental agencies because of demands from environmentalists. Logged forests are however not considered worthy of protection (Edwards et al. 2011). Of the remaining Southeast Asian forests, most are classified as production forests which makes them open for logging (Johns 1997). After logging the forests are often left greatly degraded and, hence, vulnerable to oil palm conversion.

The role of land use conversion for greenhouse gas emission

Some studies claim that palm oil plantations act as effective sinks of carbon which could let oil palm plantations gain carbon credits under the Kyoto protocol (e.g. Basiron et al. 2004) but most studies estimate that when converting forests into oil palm there is a net carbon release. A full grown oil palm plantation contains much less carbon than a full grown tropical forest. UNDP (2006) states that tropical forests store about 300–500 tonnes of carbon per hectare; and Lasco (2002) estimates that one hectare of primary rainforest contains 250 tonnes of carbon, while one hectare of mature oil palm plantation contains 100 tonnes. Considering Lasco's figures, replacing tropical forests with oil palm releases about 150 tonnes of carbon per hectare. If all of this carbon is lost as CO_2 about 950 tonnes of CO_2 would be released per hectare (Yusoff & Hansen 2007). Similarly, Danielsen et al. (2009) estimate that 163 tonnes of stored carbon per hectare is emitted to the atmosphere when rainforest is converted to oil palm, a number based on aboveground carbon stock. It is important however, to take into account that if the palm oil plantation, after closing down, is allowed to grow into secondary forest (and thus take up CO_2) the net release of carbon will decrease (Yusoff & Hansen 2007).

Land use conversion not only affects the carbon stocks of aboveground biomass; belowground biomass, soil carbon and carbon stored in dead organic matter is also affected (Wicke et al. 2008). About 12.7-15.4 thousand km^2 of the Malaysian forests are peat swamp forests situated on tropical peatlands. Tropical peatlands can store large amounts of carbon; a 10-metre deep peat swamp can store about 5,800 tonnes of carbon per hectare (UNDP 2006). Peat forests are relatively easy to clear and thus peat areas are often converted into oil palm (Clay 2004). According to Page et al. (2009) much of the official development of peatland in Malaysia (and Indonesia) has focused on palm oil agriculture since the mid-1990s; and the palm oil plantations has been established on remaining forested peat swamp areas rather than on deforested, degraded peatland. Clearing of these waterlogged forests on behalf of oil palm includes drainage. The aerobic condition created generates release of CO_2 and N_2O. The emissions from oxidation of peat are alone as large as the emissions from the entire CPO producing process (Wicke et al. 2008). Therefore, deforestation of these peat swamp forests releases even more carbon to the atmosphere as CO_2 than clearing of other tropical forests.

Danielsen et al. (2009) have estimated that using palm oil, produced from oil palms planted on cleared forests, as biofuel would lead to:

> […] greater CO_2 release than would refining and using an energy-equivalent amount of fossil fuel for 75 years. If the forest vegetation was cleared with fire, […] compounds that have a net greenhouse effect equal to 207 t/ha of carbon would be emitted. We estimated that recapture of this carbon would take 93 years.

If the oil palms were planted on peatland the recapture of the lost carbon would take an even longer time (692 years). But if they were planted on degraded grassland, there would be a net uptake of CO_2 within 10 years (a 10-year-old oil palm plantation has an aboveground carbon stock of 40 tonnes per hectare compared to the typical carbon content of the degraded grassland, 39 tonnes per hectare) (Ibid.).

When establishing a palm oil plantation the ground needs to be cleared (whether planted on forest or other agricultural land) and in Malaysia many palm oil companies use fire for clearing the tropical forest before planting oil palm (Yusoff & Hansen 2007, Tengnäs & Svedén 2002). Even though Malaysia has introduced a zero burning policy, there are still frequent forest fires (Yusoff & Hansen 2007). For example, in 1997-1998 Malaysia and Indonesia experienced extremely dry conditions because of an El Niño-Southern Oscillation (ENSO) event, resulting in forest fires (Tengnäs & Svedén 2002). The approximations of area burned vary greatly. Murdiyarso and Adiningsih (2007) have calculated that in Indonesia alone up to 116 thousand km^2 of land burned, the extent of Malaysian fires was however less. Small-scale farmers were blamed for causing these fires (as they often are) but later studies have shown that up to 80 % of the fires on Borneo and Sumatra were probably caused by different companies within the palm oil industry. Ironically, the fire was frequently spread to oil palm plantations (Tengnäs & Svedén 2002). Drained peatlands are extra vulnerable to fire (Yule 2010). Page et al. (2002) estimates that in Indonesia alone somewhere between 0.81 and 2.57 gigatonnes carbon were released into the atmosphere during the fires of 1997 (because of burning of vegetation and peat). These figures correspond to 13-40 % of the mean annual global carbon emissions from fossil fuels. In conclusion, the conversion of forests to oil palms result in a net carbon release; with the emissions from additional forest fires the total amount of GHGs to the atmosphere gets very high.

Fertilizers and pesticides

Fertilizers and pesticides used in oil palm agriculture are often stated to add pollutants and additional nutrients to rivers adjacent to the plantations. Palm oil is as mentioned energy efficient with low energy input compared to a high output. Thus relatively low fertilizer and pesticide amounts are needed in oil palm plantations (Sumathi et al. 2008, Mekhilef et al. 2011). Even though oil palm plantations require less fertilizer than many other crops, the fertilizer and pesticide amount used in oil palm plantations is not negligible but indeed exerts pressure on the environment. Soils of tropical rainforests have a naturally low nutrition value and the nutrition that exists is bound to the vegetation (Tegnäs & Svedén 2002). When converted the soil is only fertile for a short period of time without added fertilizer. According to Clay (2004) fertilizers are very important for obtaining high yields (the cost of fertilizer constitutes about 40-60 % of the total maintenance cost, or 15-20 % of the total production cost; Syamsulbahri 1996). Oil palm plantations established in mineral soils require about 354 kg added N and 118 kg added P per hectare during the first five years (Guyon & Simorangkir 2002). Yusoff and Hansen (2007) estimate that the fertilizer input (both artificial and organic) used for the production of one tonne CPO result in an output of 5 kg N and 2 kg P_2O_5 to the surrounding soil and water, and 0.5 kg NO_2 and 1.2 kg SO_2 is emitted to the air.

The most commonly used weed killer in oil palm plantations of Southeast Asia is paraquat dichloride ("paraquat") which is very toxic (Wakker 2005). Other toxics used are pesticides and Clay (2004) declares that rat poison is one of the main environmental problems from oil palm plantations. However, if ground conditions are maintained properly, palm oil plantations provide habitat for naturally occurring pest predators which means that use of pesticides is not necessary (Fairhurst & Mutert 1999). For example are barn owls (*Tyto alba*) sometimes used for rat control instead of poison (Teoh 2002).

Emissions from the milling process

Just as any other industry, the palm oil industry has wastes. Because of the large scale of the palm oil industry, it may be the most polluting rural industry in Southeast Asia (Wakker 2005). Since fresh fruit bunches need to be processed quickly after harvesting, there is usually one CPO mill for about every 40-50 km^2 of plantation (Ibid.). Therefore, hundreds of mills are operating over the Malaysian countryside, all of which generates waste and have different ways of treating it. The most polluting waste product from palm oil production is palm oil mill effluent (POME). POME is a mixture of water, crushed shells and a small amount of fat residue (Ibid.). The production of one tonne of CPO generates on an average 0.9-1.5 m^3 of POME (Sumathi et al. 2008). It is often stored in outdoor basins (which easily overflow) or sometimes it is released directly in adjacent streams. POME has a high Biological Oxygen Demand (BOD) which is a measure of the amount of oxygen that will be consumed by microorganisms to break down all organic compounds in one litre of (waste)water (Wakker 2005). BOD is highly polluting to waterways. The amount of BOD in one litre of POME is about 25,000 mg (Ahmad et al. 2003).

Murad et al. (2010) shows a "direct and significant link between per capita CO_2 emissions and agricultural production index in Malaysia", in other words – high agricultural production causes higher per capita CO_2 emissions. At the milling stage of palm oil production, the boiler is the most significant contributor of air pollutants (Yusoff & Hansen 2007). Typically the Malaysian palm oil mills burn some of the wastes (e.g. the empty fruit bunches) to produce electricity and steam required for sterilization of the fresh fruit bunches (Yusoff 2006). This is economically efficient but the combustion process of the boiler releases emissions such as particulate matters, CO, NO_x and SO_2. (Ahmad et al 2004). To produce one tonne of CPO the boiler stack is estimated to release 0.64 kg of NO_x and 5.64 kg C to the air (Yusoff & Hansen 2007).

PRESENT STATE

How much the oil palm expansion contributes to the current state of the environment in Malaysia is difficult to estimate. This section presents officially available figures on oil palm and forest extent and present air and water quality.

Oil palm

In 2009 the total Malaysian area planted with oil palm was 46.9 thousand km^2. Out of this, 24.9 thousand km^2 was planted in Peninsular Malaysia, 13.6 thousand km^2 in Sabah and the rest, 8.4 thousand km^2 was planted in Sarawak (MPOB 2011). In Peninsular Malaysia there is almost no space for further expansion and hence in the years to come most oil palm plantations are therefore expected to be established in Sabah and Sarawak (Fig.10 presents a view of an oil palm plantation in Sabah). The oil palm expansion growth is about 2 % in Peninsular Malaysia compared to approximately 7 % in Sabah and Sarawak (Mekhilef et al. 2011). It can be seen in Figure 9 that Johor in south Peninsular Malaysia is the most oil palm dense region, with more than 36 % of the total state covered with oil palm plantations. Only 7 % of Sarawak is covered by oil palms, partly because this region has more highland areas.

So, who owns the oil palm plantations? Of the oil palm estates in Malaysia, about 60 % are under private ownership (most by plantation companies), 28 % were under Government land schemes (e.g. FELDA 15 %, RISDA 2 %) and the last 12 % were owned by individual smallholders (MPOB 2011).

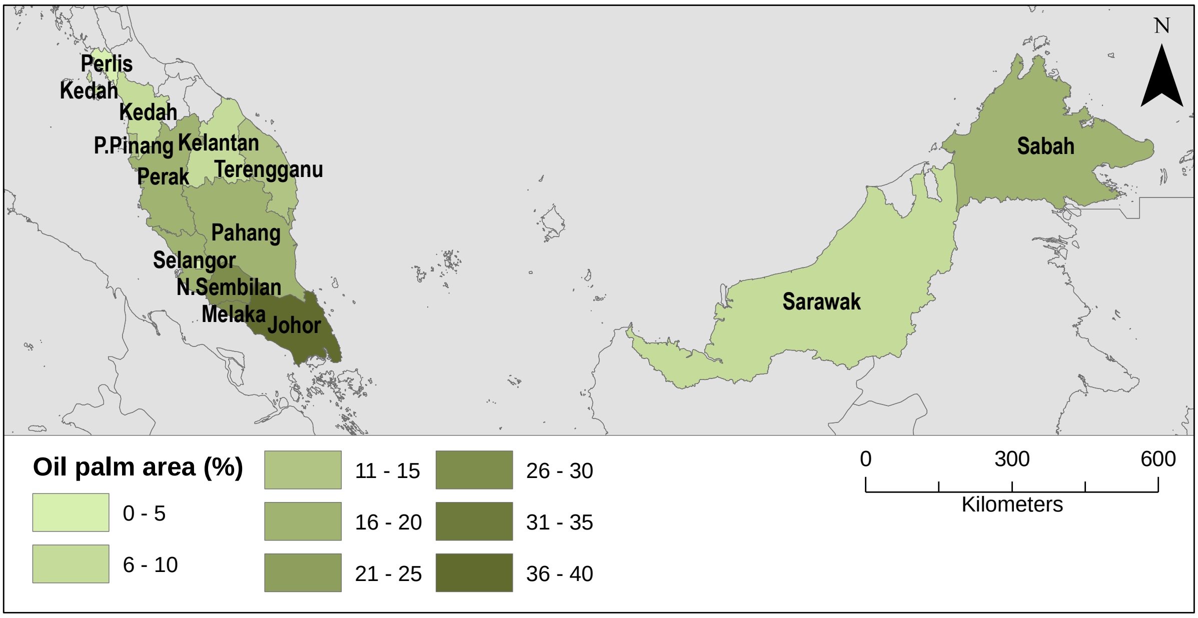

Figure 9. Map showing percentage of area planted with oil palm (compared to total state area) in Malaysia's 13 states respectively in 2009. Source: statistics from MPOB 2011-04-27 and vector layers in ESRI shape format from GIS LAB, available at: http://gis-lab.info/qa/vmap0-eng.html

Figure 10. (Left) Oil palm plantations and forest. Location: Sabah, Malaysian Borneo. Courtesy of Rhett A. Butler, reprinted with permission. Available at: http://travel.mongabay.com /malaysia/images/borneo_2831.html

Table 3. Forested area of Malaysia in 2010. Also, annual rate of change the last two decades. Source: data from FAO 2011.

Extent of forest 2010	
Forest area (km^2)	204,560
Of land (%)	62
Area per 1000 people (km^2)	7.57
Annual change rate	
1990-2000 (km^2)	-790
1990-2000 (%)	-0.4
2000-2010 (km^2)	-1,140
2000-2010 (%)	-0.5

Forested areas

According to the Global Forest Resources Assessment 2010 country report for Malaysia (carried out by FAO 2010) the total forested area in 2007, was 196,630 km^2. According to the State of the World's Forest report 2011 (carried out by FAO 2011) the total forested area was 204,560 km^2 in 2010. Both documents reports on forest decrease in Malaysia; however the numbers suggest a forest increase. Probably this increase is due to different classification definitions as sometimes rubber plantations are classified as forests (see Land use conversion).

The average annual rate of deforestation in 1990-2000 and 2000-2010 was -0.4 % and -0.5 % respectively. For Southeast Asia in total these numbers were -1.0 % and -0.4 %, and the global annual average was -0.2% and -0.1 % in the respective periods (FAO 2011). However, primary forests have not been logged or turned into oil palm, the area under primary forest have remained at 38,200 km^2 since 1990 (Tab.4).

As can be seen in Table 4, there are many different forest classifications and they overlap each other which makes it complicated to sort them out. For instance, forest area with a management plan is 189,410 km^2; however, forest area under *sustainable* forest management is 143,010 km^2. Also, the classifications have been changing between years and hence figures from different years are difficult to compare. For example the protection of soil and water areas has decreased "due to the forestry department's exercise to reclassify and recalculate of forests for protection of soil and water within the PRF's" (FAO 2010).

Table 4. Forest facts of Malaysia. Classifications according to Forest Resources Assessment (FRA) 2010 Categories, developed by FAO. Where *primary forest* is naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed; *other naturally regenerated forest* is naturally regenerated forest where there are clearly visible indications of human activities; and *planted forest* is predominantly composed of trees established through planting and/or deliberate seeding. All figures in square kilometres. Source: data from FAO 2010.

	1990	2000	2005	2010	Change (1990-2010)
Primary forest	38,200	38,200	38,200	38,200	0
Other naturally regenerated forest	166,000	161,120	154,970	148,290	-17,710
Planted forest	19,560	16,590	15,730	18,070	-1,490
Production	117,360	129,210	118,190	127,390	10,030
Protection of soil and water	27,000	29,100	38,100	26,940	-60
Conservation of biodiversity	11,200	11,200	11,200	19,460	8,260
Multiple use	68,200	46400	41,410	30,770	-37,430
Permanent Forest Reserve (PRF)	126,000	144,000	144,000	143,010	17,010
Forest area within protected areas	38,200	40,300	49,300	46,400	8,200
Forest area under sustainable forest management	126,000	144,000	144,000	143,010	17,010
Forest area with management plan	164,200	184,300	193,300	189,410	25,210

Furthermore, the area for production forests has increased since 2005 due to “new gazettment of PRF and establishment of planted forest” (FAO 2010). Gazettement is the process by which the land resource is partitioned between forestry and agriculture (McMorrow & Talip 2001). Since the area of PRF’s has decreased between 2005 and 2010 and the area under planted forests has increased between 2005 and 2010 these three have somehow replaced each other on the expense of PRF.

FAO makes no distinction between different types of forests, e.g. lowland rainforests and montane forests. Since only lowland tropical rainforests and peat swamp forests are suitable for oil palms (and many other agricultural crops) these forests most certainly experience higher deforestation rates than montane and submontane forests. The pressure on lowland forests is further increased since their flatter terrain makes them accessible for loggers.

Peatland area and peat swamp forests

In Malaysia there is between 20,000 and 25,000 km^2 of peatland. About 9,000 km^2 of this peatland is located in Peninsular Malaysia and pristine peatland amounts to about 500 km^2 (ASEAN 2009). About 25 % of palm oil in Malaysia and Indonesia is currently produced on peat soils and according to Page et al. (2009) the development plans over the next 20 years include conversion of an additional 60,000 km^2.

The Department of Statistics, Malaysia (2009) states that the total area of peatland forests has increased in recent years. In 2007 the total area was 12,650 km^2 and in 2008 it was 12,688 km^2 which means that the total area has increased with about 38 km^2 in only one year; since 2004, the peat swamp forests has increased with more than 700 km^2. Of the total peat swamp forests, Sarawak comprises the largest area (71.5 %), followed by Peninsular Malaysia, (19.0 %) and Sabah (9.5 %).

The peat land forests of Sarawak have according to the Department of Statistics, Malaysia (2009) increased from 8,865 km^2 in 2004 to 9,073 km^2 in 2008. However, when utilizing a pair of 250m spatial resolution land cover maps to analyse deforestation rates in Southeast Asia, Miettinen et al. (2011) found that Sarawak lost around half of its peat swamp forest cover between 2000 and 2010. Similarly, Starvision (2011) has found a decrease in peat swamp forests, between 2005 and 2010, 33.4 % of peat swamp forest area has been cleared. This indicates a much faster annual deforestation rate for peat swamp forests (about 8 %) than they found for other forests of Sarawak (2 %).

River water quality

There are three categories of river status in Malaysia: polluted, slightly polluted and clean. The majority of Malaysian river basins are considered clean (ASEAN 2009). Along the west coast of Peninsular Malaysia, however, most river basins are classified as slightly polluted. The regions of polluted rivers correspond quite well to the regions with a high percentage of oil palm plantations. Of Malaysia's total water pollution sources (both point sources and non-point sources) in 2006, were 20.5 % in Selangor and 19.7 % in Johor (Department of Environment, Malaysia 2010). Both of these regions have quite high oil palm density (see Fig.9).

Air quality

The numbers of days with an air quality that is classified as unhealthy are few in Malaysia (only four days in 2008) but the number of days with moderate air quality is quite high (146 days in 2008) (ASEAN 2009). Classification of Malaysian air quality is in agreement with the Environmental Quality (Clean air) Regulations 1978. These regulations have set up limits for gaseous emission and effluents from industries and motor vehicles (Department of Statistics, Malaysia 2010, Environmental Quality (Clean air) Regulations 1978). In 2008 the CPO mills of Malaysia showed an 85 % compliance with the regulations (a decrease from 92 % in 2004) (Department of Statistics, Malaysia 2009).

IMPACT ON ECOSYSTEMS

Much of the statistics indicates high deforestation rates in Malaysia and the water quality is often slightly polluted in the most oil palm dense regions. So, what are the impacts on ecosystems?

Impacts of land use conversion

Tropical rainforests are complex ecosystems where everything is connected. This means that disturbance of the flora has impacts on the fauna and the soil as well. Apart from being habitat for plant and animal species which in turn can provide medicinal products, the Department of Statistics, Malaysia (2009) identifies some of the other important roles of the Malaysian forests. For example, forests *i*) act as buffers against the impact of heavy rainstorms, *ii*) increase filtration of water into the soil, *iii*) minimize soil erosion and river siltation, *iv*) moderate temperatures and winds and *v*) have the ability to filter out and hence reduce air pollution levels (by absorbing and utilizing certain substances from the air). These benefits provided by forests are called ecosystem services or functions. When converting rainforests into oil palm cultivations the natural balance is disturbed resulting in a loss of some of these functions which affects both the environment and humans. There are no studies on how, or if, conversion of forest to oil palms affects winds and temperature, or if oil palms provide a less effective buffer to heavy rainstorms. However it is documented that conversion of forests to oil palm affects erosion and siltation rates as well as the soil's ability to filtrate water and the ability to absorb certain substances (e.g. CO_2). Furthermore, the ability to provide habitat for plant and animal species is significantly less in oil palm cultivations than in forests.

Terrestrial biodiversity loss

Tropical rainforests have evolved for more than 50 million years resulting in a diverse flora and fauna (Tegnäs & Svedén 2002). In an environmental assessment of agricultural land use, Mattson et al. (2000) compares the possible biodiversity impacts of Swedish rapeseed and Malaysian palm oil. As can be seen in Table 5, the difference is vast and because of the high number of species, conversion of Malaysian forests leads to a biodiversity loss that is greater than for most other areas.

Table 5. Number of species in the areas of cultivation in Sweden and Malaysia. Source: Mattson et al. (2000).

	Sweden: rural agricultural area	Malaysia: lowland rainforest
Trees	10-20	2,398
Other vascular plants	1,000	8-10,000
Mammals	35	203
Birds	50	460
Butterflies	50	1,014

More than one thousand plant and animal species in Malaysia are currently threatened and some species have become extinct (see Appendix III). It is difficult to tell how many of the threatened species that are threatened because of the palm oil industry; but since oil palm agriculture is the land use that expands most in Malaysia much of the disturbance is due to conversion to oil palm. All types of disturbance of forests are not bad for the biodiversity. Diverse habitat patches at different succession stages may be created when disturbance varies in time and space, these patches are often more diverse (at a larger scale) than totally undisturbed forests (Hassall et al. 2006). Oil palm plantations, however, constitute uniformly and greatly disturbed areas where biodiversity is relatively low.

Expansion of palm oil plantations causes fragmentation of the remaining natural forest. When reducing the size of the forest fragments (thereby increasing the distance between their edges) it is important to leave “corridors” or “stepping stones” to maintain animal movement, but this is seldom practiced. As implied in Figure 11, palm oil plantations provide a homogeneous landscape compared to the original rainforest. The canopy of a rainforest is naturally multi-layered, providing many habitats for different species. Monocultures, such as oil palm plantations do not share the canopy differentiation and therefore contain fewer species. The flora in an oil palm plantation is very poor compared to natural forests (Danielsen et al. 2009) and regarding most animal species there is less variety. Many bird species are for example adapted to low level vegetation and can therefore not find suitable habitats in an oil palm plantation (Tegnäs & Svedén 2002).

Figure 11. Aerial view of an oil palm plantation and a heavily logged natural forest.
Location: Sabah, near Lahad Datu, Malaysian Borneo. Courtesy of Rhett A. Butler, reprinted with permission. Available at: http://travel.mongabay.com/malaysia/images/borneo_2804.html

According to Turner et al. (2008) the research on oil palm and the related environmental issues has been extremely low (about 2 % of all palm oil related publications between 1970 and 2006), and most of the few studies carried out on biodiversity change have focused on larger animals. However, insect species are the most abundant and stand for most of the ecosystem functioning (e.g. nutrient cycling) and thus more research on invertebrates is needed to understand what kind of impacts land use conversion has on overall biodiversity.

The (few) studies that have been carried out on how species richness varies between primary forests, secondary forests and oil palm plantations always show the same result – overall species richness is lower in oil palm plantations than in forests. For example, Wycherley (1969) compares the number of mammalian species found in different vegetation types. In primary forests 75 species were recorded, in secondary forests there were 32 species, but oil palm plantations only had 11 species. More modern research by for example Danielsen et al. (2009) also witnesses of less species in oil palm plantations. Based on data from seven study sites (located in Indonesia, Malaysia, Thailand and Dominican Republic) Danielsen et al. estimate that the total vertebrate species richness of oil palm plantations is only 38 % that of natural forests. Brühl and Eltz (2010) have found that the habitat oil palms provide can sustain only about 5 % of the ground-dwelling ant species found in the forest. They suggest that the loss of species in oil palm plantations is due to the nearly complete absence of leaf litter (which reduces the availability of nest sites for litter-nesting species) and because of the hot and dry conditions.

According to FAO, there has not been any primary forest decline in Malaysia since 1990 (see Forested areas) hence the converted land has been predominantly previously logged forest. As mentioned, these degraded forests are considered to be of less value and therefore it is possible for planters to convert logged forests into oil palm. Selectively logged "degraded" forests have however repeatedly been proven to have a high ecological value (Edwards et al. 2011, Koh & Wilcove 2008, Danielsen et al. 2009). To begin with, these selectively logged forests can with time regain their species richness, but if converted into oil palm the chance of retaining the original flora and fauna is low. When studying degraded forests, Edwards et al. (2010, 2011) found that these logged forests often provide important habitat for many species and moreover, that these forests have a 200-fold greater quantity of (IUCN) Red-Listed bird species than oil palm plantations.

Much land use conversion to oil palm has not been at the expense of forests but of other agricultural land. It is suggested that this also results in fewer species. When studying birds Peh et al. (2006) have found that even when converting rubber plantations to oil palm there is a decrease in species richness and according to Fitzherbert et al. (2008) oil palm plantations generally support fewer forests species than most other agricultural options (e.g. *Coffea canephora* (coffee) and *Acacia mangium* plantations).

Media often focuses on the largest animals; the orangutan has for example gained much media attention in recent years. Inhabiting the peat swamp forests and lowland tropical forests of Borneo they compete with palm oil agriculture for the land. Traditionally the orangutan has been threatened by the widespread logging but the continuous conversing of their remaining habitat by oil palm cultivators is speeding up their extinction rate and is now considered as their main threat (Nantha & Tisdell 2008). Being such large animals their food requirements are relatively high, hence the population density is relatively low and about one km^2 is required per orangutan. Thus, where forests are converted to oil palm, many orangutans are starving to death (Nellemann et al. 2007). Forest fires (that as mentioned often are due to oil palm conversion) often affect entire animal communities, both directly and by the resulting environmental degradation, through impacts on water cycles and soil fertility (Guyon & Simorangkir 2002). This also accounts for the orangutans and in Indonesia, up to one-third of the orangutans might have died in the forest fires of 1997-1998 (Wakker 2005).

Other large animals that are affected by the oil palm expansion, according to Clay (2004), are for example sun bears, rhinoceroses and tigers. Elephants however are willing to inhabit the plantations. Elephants like to eat oil palm shoots and seeds and while doing it they have the potential to destroy large areas of young palms in just one night (Wakker 2005). Hence they frequently come into conflict with humans. Sometimes these conflicts end in disaster and both elephant and human deaths have been reported (Ibid.).

Soil degradation

When forests are cleared the protecting vegetation cover and network of roots is removed leaving the ground susceptible to degradation. Malaysia annually receives large amounts of rain (see Geology and climate) and in the tropics rainfall is often short but intensive. Rainfall after deforestation and/or burning of the vegetation cover can result in great runoff (Morgan 2005). After the establishment of an oil palm plantation and before the palms are large enough the ground is unprotected. Hence, most of the soil erosion from oil palm plantations takes place after the initial clearing and when the plantation is renewed. Later when the plantation is fully established it provides a continuous ground cover which inhibits soil erosion (Fairhurst & Mutert 1999, PORIM 1994). Planting of oil palms in rows up and down hill slopes instead of along the contour lines can however accentuate erosion, just as erosion often occur in plantations established on slopes of more than 26.8 % (15 degrees) (Clay 2004).

However, even on shallow slopes erosion occur. Huan (1990) have studied erosion rates from mature oil palm plantations at slopes between 6-8 % and found a soil loss of about 14 tonnes per hectare per year. Mature oil palms have closed canopies and therefore have little protective ground vegetation. Together with soil compaction on pathways, this causes low infiltration and high erosion. Erosion is also enhanced by drops that accumulate on the large palm leaves and fall with high speed and thus high kinetic energy to the ground (Ibid.). Depending on slope, Hartemink (2003) have summarized studies of erosion rates at oil palm plantations in Malaysia to 12.5-77.6 tonnes per hectare and year for oxisols, and 1.1-28.0 tonnes per hectare and year for ultisols.

So what are the impacts of soil erosion? Soil erosion is an irreversible process and therefore a severe type of soil degradation (Mattson et al. 2000). The loss of soil leads to a loss of plant nutrients and organic matter, which decreases the soil fertility leading to higher fertilizer requirement. When establishing an oil palm plantation, the top soil organic matter content is severely depleted after the initialising period when the land is prepared by clear felling, stumping-out, burning and levelling by bulldozer (Haron et al. 1998). Additionally, the loss of top soil due to erosion makes the ground lose its potential to store water leading to more runoff and potential flooding (Tegnäs & Svedén 2002). With high runoff and erosion, fertilizers and pesticides are carried along to waterways; impacts on water are discussed in the next section.

Impacts of emissions

Water and land pollution

The water quality of Malaysian rivers is classified as clean in Sabah and Sarawak. Along the west coast of peninsular Malaysia however many of the river basins are classified as slightly polluted. The slightly polluted river basins are generally located in states with much agricultural and industrial activity, while the polluted basins are located in ports and industry-intensive areas (ASEAN 2009). In general, Sabah and Sarawak have more clean rivers because of their great forest cover and fewer industries.

It is hard to tell exactly how much of the pollution is due to the palm oil industry especially since the manufacturing industry sector of Malaysia also is large. POME has however documented negative effects on aquatic life downstream oil palm mills. Because of the high content of BOD there are high levels of oxygen depletion in waters polluted by POME. With too low oxygen, some of the marine life suffocates. How POME affects the ecological functioning of streams is generally unstudied (Sheil et al. 2009). There are though observable effects recorded by local people. For example, in Indonesia villagers have reported decline in local fish stocks and complained about change in colour and smell of their drinking and bathing water (Wakker 2005). Also, female oil palm plantation workers in Malaysia have worse health than other women, which is believed to be because of palm oil pollution (Ibid.).

In a natural rainforest, rainwater infiltrates through the ground and is transported from mountainous areas to lowland areas. The ground is protected by vegetation inhibiting erosion leading to clear water reaching the sea which helps the coral reefs to develop (Tegnäs & Svedén 2002). This is conversely not the case for oil palm plantations. As mentioned, because of erosion, mud and added nutrients (from fertilizers) and pollutants (from pesticides and herbicides) from the oil palm plantations are transported to the sea through rivers and streams. There are no studies on how the Malaysian corals are affected by mud from eroded plantations, but in the Philippines Wesseling et al. (1999) show that too much sedimentation is devastating for coral development. Nutrient leach and toxics from fertilizers, pesticides and herbicides are known to have caused eutrophication and death of fish (Tegnäs & Svedén 2002). However, according to Sheil et al. (2009:35) the nutrient-rich runoff "is less than might be expected from the sums involved, perhaps because companies do not wish to see expensive fertilizer washed from their plantations".

Air pollution

The Malaysian air quality of 2008 was estimated as good or moderate most of the year. However, the general air quality has deteriorated since 1970 (Awang et al. 2000). The air pollution from palm oil mills is probably less than that of other industries in Malaysia. Instead the largest palm oil related contribution to air pollution is from forest fires initiated by burning during the establishment of oil palm plantations. Atmospheric particulate matter is the dominant pollutant in many Malaysian areas. In recent years, haze due to advection of suspended smoke particles from biomass burning has become a common feature in Malaysia and Indonesia (Radzi bin Abas et al. 2004). Much of this haze comes from Indonesian fires since the most severe forest fires occur in Indonesia and not in Malaysia. After the extensive forest fires of 1997-1998 Davies and Unam (1999) detected drastically elevated amounts of atmospheric particulate matter and concentrations of SO_2, CO and CH_4 several hundred kilometres from the nearest fires. This affected the local climate, causing lower temperatures and higher relative humidity. The air pollution even had a short-term effect on C sequestration of unburned forest because of the reduced levels of photosynthetically active radiation (PAR) – the spectral range of solar radiation that can be used in the photosynthesis (about 400-700 nm). The PAR levels were up to 92 % lower during the haze of 1997 (Ibid.). When the particulate matter is deposited on the ground, the nutrient balance and soil acidity may change which also affects the vegetation (Department of Environment, Ministry of Natural Resources and Environment, Malaysia 2005).

Between 70 and 300 million people in the Southeast Asian region were affected by the haze of 1997-1998, both in the long and short term; many because of damaged vegetation (Guyon & Simorangkir 2002, Awang et al. 2000). There are also human health related problems caused by sufficient amounts of particulate matter in the air. For example, it can cause eye and throat irritation as well as respiratory problems (Department of Environment, Ministry of Natural Resources and Environment, Malaysia 2005).

SOCIETAL RESPONSES

There are many different actors in the palm oil business, Teoh (2002) has "grouped them into clusters" and the main players are: "upstream producers, downstream producers, exporters and importers, customers, Government agencies and other players such as NGOs". Those who decide about the palm oil expansion include both company and government personnel (Clay 2004) but the future sustainability of the palm oil is also affected by the other players. Customers and NGOs have a growing influence; with the environmental debate on palm oil the demand for sustainable palm oil has increased. Obviously, with so many people involved, there are different opinions about what is to be considered as problems and flaws, and what is considered success. Some impacts are however definite. So, are there any attempts to prevent, compensate, ameliorate or adapt to the changes caused by palm oil production and its impacts on the environment?

Emission mitigation

Concerning emissions there has been some improvement. For example, use of the toxic herbicide paraquat has been forbidden by the Malaysian government despite its popularity among users (Wibawa et al. 2007). Research is done to find new alternatives that are more human and environmentally friendly; however no perfect substitute has been found (Teoh 2010). Regarding pesticides, different integrated biological pest management methods have been tried to reduce the pesticide use (as mentioned, for example barn owls for rat control). Some have been successful and others less successful (Yusoff & Hansen 2007). On more "enlightened" plantations the workers are instructed not to kill pythons and other rat-eating snakes (Clay 2004).

The release of POME in nearby water streams has been regulated. Instead of releasing untreated POME directly into streams, it is now often purified in order to be harmlessly discharged (Fitzherbert et al. 2008). Still the problem remains at some mills. Much more needs to be done in order to "keep up" with the rapid expansion of oil palm cultivation and palm oil production. Wakker (2005) explains:

> Most pollution related to oil palm plantations can be avoided and for producers it makes economic sense to reduce wastage of nutrients and replace agro-chemicals with biological alternatives. Thus, many companies have taken measures to prevent pollution but half-hearted mitigating measures cannot compensate for the enormous growth in the sector, inevitably leading to vastly increased pollution.

Regarding energy use there are measurements taken to increase the efficiency. Much of the energy used at the palm oil mills is derived from oil palm biomass. However, only a fraction of the potential energy is used; with more effective utilization of palm biomass more energy could be produced (Sulaiman 2010). MPOB carries out research on how to improve the efficiency in power generation and its use (Basiron & Weng 2004).

As mentioned, there is a zero burning policy to decrease forest loss due to fires. Peat land restoration is another alternative for decreasing fires and GHG emissions. Re-wetting of peat has been done in order to protect the remaining carbon stocks and to reduce the fire risk (Page et al. 2009).

Protected areas and biodiversity conservation

There are several protected areas, as shown in Table 4. These include for example wildlife reserves and national parks. Area for conservation of biodiversity covers 19,460 km^2 (about 5.9 % of total country area) in 2010 and the Malaysian primary forests are stated to be untouched since 1990.

In 1998 the National Biodiversity Policy was launched for the specific purpose to protect and conserve Malaysia's diverse biological heritage (UNDP 2006). There have also been attempts to point out areas of high conservation value for example by identifying High Conservation Value Forests (HCVFs) (Teoh 2002).

However, the problem of oil palm conversion of logged forests remains and even though there are attempts to protect the biodiversity of forests some species are still under threat. According to (Nantha & Tidsell 2009) orangutan conservation has not received enough "investment or support from the private and public sectors, on the economic grounds that it is a comparatively poor paymaster and employer". A National Ecotourism Plan was launched in 1996 (UNDP 2006). But besides ecotourism there is little direct use value in the orangutans; and ecotourism in the wild habitat of the orangutan is limited because of the (tourist)inaccessibility. Hence, the orangutans seen by most tourists are the ones that result from the absence of protection, namely the ones that are on view at rehabilitation centres (Nantha & Tidsell 2009).

Specific initiatives for palm oil sustainability

Because of the negative criticism and campaigns of environmentalists/conservationists accompanied by a raised environmental concern by consumers in recent years there have been several initiatives to support environmentally responsible and sustainable palm oil production. For example, the Malaysian Palm Oil Council (MPOC) has set up the Malaysian Palm Oil Wildlife Conservation Fund (MPOWCF). Launched and funded by the Malaysian government and administrated by MPOC, the MPOWCF serves the following purposes:

- Helps to portray the good image of Malaysian palm oil by providing concrete assurances that its cultivation does not cause deforestation or loss of wildlife and their habitat through a focused conservation research program to be undertaken by experts from the academia, government agencies and NGOs.
- Provides funds for studies on wildlife, biodiversity and environmental conservation while factoring the overall impact of the palm oil industry on these parameters.

(MPOC 2011c)

The most important initiative for environmentally friendly palm oil is the Roundtable on Sustainable Palm Oil (RSPO) (Fitzherbert et al. 2008). By a set of environmental and social Principles and Criteria, the RSPO wants palm oil production to be environmentally responsible and sustainable (RSPO 2011). Their members (including many of the Malaysian palm oil companies) manage more than one-third of the global oil palm area (Fitzherbert et al. 2008; see also http://www.rspo.org).

SYNTHESIS AND DISCUSSION

This thesis has discussed how population increase, economical drivers such as market prices in relation to labour payments, governmental policies on economic growth and reduction of poverty as well as changed global consumption patterns all work together to cause expansion of oil palm. These driving factors are difficult to disentangle. Rapid population growth along with an increased demand of palm oil promotes high productivity. The population growth also influences the workforce and thus the economy as well as poverty (hence, policies against poverty). Palm oil expansion will likely continue in the coming years, but much of the suitable oil palm areas in Malaysia are already exploited and thus, Indonesia will in the future probably experience most expansion. Still there are possibilities to enhance the productivity by technological solutions and there is ongoing research on this.

It seems that the primary environmental issue related to the palm oil industry is that of land use conversion which causes loss of secondary forests and, hence, loss of biodiversity and ecosystem functions. In addition, the land use conversion of especially peat swamp forests causes large emissions of GHGs. If oil palm expansion instead would be onto grasslands the palms would conversely act as a carbon sink (there are however few grassland areas in Malaysia and hence conversion of grasslands to oil palm is unlikely).

The most important types of environmental pollution from the palm oil industry are *i*) air pollution from forest and peat fires, *ii*) discharge of POME in waterways, and *iii*) leaching of excessive fertilizers, pesticides and herbicides. Also, *iv*) sedimentation of waters caused by erosion from the plantations has shown to be devastating for corals. Three of these pollution factors are directly connected to the land use conversion which together with poor plantation management causes intensified erosion rates, and thus sedimentation and added pollutants in waterways. Furthermore, most of the forest fires are still linked to palm oil expansion despite the government's effort introducing a zero burning policy. However, it appears as if the number of Malaysian fires has decreased. The most devastating fires often occur in Indonesia and haze from Indonesian fires reaches other Southeast Asian countries. The larger amount of Indonesian fires might be because Indonesia currently experiences a more rapid oil palm expansion (see Appendix I), while much of Malaysian oil palm plantations already are established.

There are also emissions from the palm oil mills. Palm oil mills are however only one of many industries polluting the Malaysian air, and the worst air pollutants that can be related to oil palms come from forest fires.

Measurements for reducing the impacts of the palm oil industry have been taken, but they are not sufficient. How the DPSIR factors are linked together is shown in Figure 12. When the air and water already has been polluted and when the soil has become degraded it is problematic to restore the former state, hence responses directed towards the "impacts" and "state" are few. Even if restoration of peatlands has been attempted (a measure which focuses on improving the current state) the most effective and easy way of keeping the carbon stocks and the biodiversity of peat swamp forests would be to leave them unconverted.

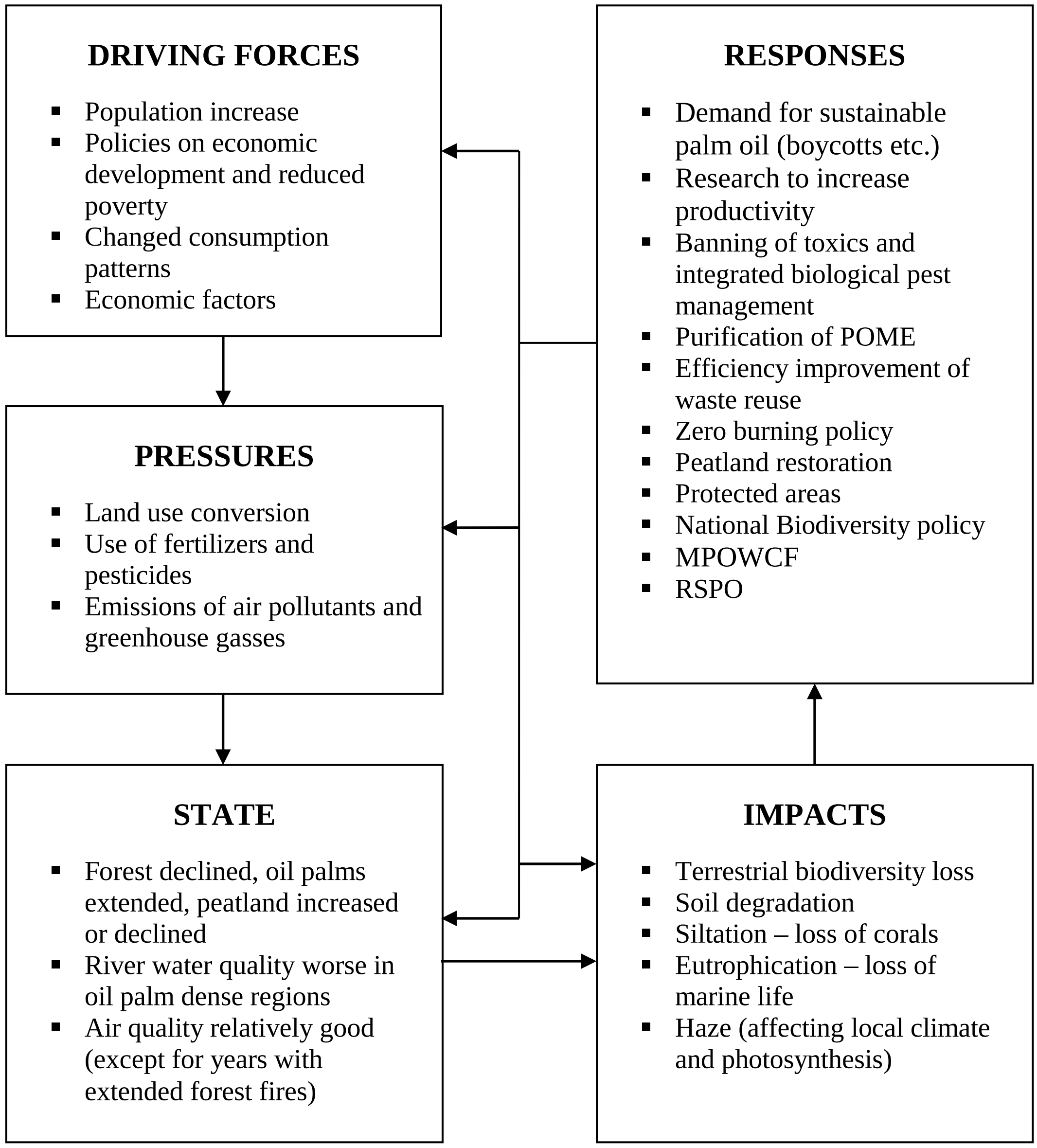

Figure 12. Linking together the DPSIR-factors. Most responses are directed toward the pressures (e.g. protected areas and emission control) others focus on changing the present state (e.g. restoration of peatland). There are also people avoiding palm oil products – a response directed towards the driving forces of palm oil expansion.

Because it is more effective (and easy) most societal responses focus on preventing the pressures. For example, by protecting certain areas of high conservation value from oil palm conversion, further biodiversity loss is inhibited; and by banning use of toxics and release of untreated POME into waterways, emissions are reduced.

The most efficient way to reduce the environmental impacts of the palm oil industry would obviously be to stop producing palm oil. This however is unrealistic unless the driving forces behind the oil palm expansion and increased palm oil production would diminish. But as the global and local population continues to grow along with the demand for palm oil, the palm oil industry also grows. The high return rates from oil palm production not only encourage private sector investment, it also contributes to public funds and rural employment (Nantha & Tidsell 2009). Currently the palm oil industry in Malaysia provides employment to more than half a million people and livelihood to approximately one million people (MPOC 2011d). Therefore, the government is supportive to the oil palm sector and it is unlikely that they would hinder its development. And there are positive ecological aspects of the palm oil development, at the same time as it is responsible for biodiversity loss and pollution – it also helps providing capital for research on and protection of forests (compared to the poorer Indonesia, Malaysia seem to have better regulations).

Concern for tropical ecosystems has made people (in the West) to avoid products containing palm oil (a response directed towards the driving forces). However, boycotting palm oil by a few environmentally concerned people will probably not make much difference as the largest importers of palm oil are India and China and they have shown little interest in buying the sustainable palm oil provided by members of RSPO. Additionally, Wilcove and Koh (2010) suggests that "simple, direct actions, such as boycotts, are unlikely to succeed" because palm oil is used in so many different products (palm oil is often labelled as vegetable oil and thus impossible to detect in lists of content).

The problem with deforestation is not a new one. According to McMorrow and Talip (2001) the problem of forest decline began already in the 1890s with logging, tobacco and rubber plantations – and is continuing today partly because of the palm oil development. Without palm oil, the logging intensity would probably increase for economic reasons. Even though conversion into oil palm normally causes a greater impact than logging does (since forests can recover after logging, and because even logged forests provide relatively better habitat for plant and animal life than do oil palms) if logging is not done selectively and sustainable many of the general problems (e.g. erosion) that exist in plantations would continue.

So, why is it important to preserve the rainforests and stop polluting waterways? This thesis has focused on the environmental issues of palm oil production but the impacts on ecosystems naturally affect human life as well (as humans are part of ecosystems). The values of preventing erosion are clear – less fertilizer is needed, which saves money, and keeping water clean is necessary for people dependent on the water to drink or for providing fish. As forests helps preventing erosion and water pollution they are important, but what if oil palm estates were managed in such a way that they also could provide these services? Would they not be worthy substitutes for forests? The opinions differ.

It is apparent that after conversion to oil palm cultivation, the land becomes poor in nutrients and thus it is difficult for forests to regrow to their original state when the plantation is closed down. Hence, oil palm estates lead to relatively permanent deforestation. As we still do not know much about the complexity of rainforests, which for example contain species that might provide medicinal products in the future as well as species that pollinates useful plants, it is a bit risky to eliminate them. In Malaysia species are lost before even being discovered. The stability of ecosystem functions increases with a wider range of species (Turner et al. 2008). Thus, for conservation of the Malaysian biota and persistence of the ecosystem functions it provides, it seems necessary to either make oil palm plantations more habitable or to stop further expansion onto land with high biodiversity.

Furthermore, forests are often considered to have an aesthetical value and to constitute a source of recreation, education and research. These values are of increasing concern as oil palms in recent years have become the countryside for most rural people in Malaysia. There are conflicts between oil palm expansion and the indigenous people of Malaysia. The traditional rice agriculture has much cultural value and many social relationships are based on it. When oil palm plantations expand over land that has traditionally been cultivated by indigenous people problems evolve. In Sarawak Colchester et al. (2007) detected some major issues. For example there have been conflicts and disputes over land, limited or absent payments of compensation and denial of people's right to represent themselves through their own chosen representatives (Ibid.).

It appears as the policymakers have an important role in determining the environmental consequences of future palm oil expansion. As Casson (2003) states it "[i]t seems clear that the fate of critical habitats [within for example Malaysia] will depend largely on the willingness of governments and companies to immediately implement best management practices and sound land-use policies". For example, the importance of selectively logged forests is not acknowledged by decision-makers and hence these forests are easily converted to oil palm.

Uncertainties

The topic of this thesis is of high controversy with many actors supporting different views; with environmentalists on one side and palm oil producers and lobbyists on the other. Hence, some articles and reports might have been distorted to amplify certain opinions. Articles from "both sides" are therefore included in an attempt to provide correct information.

Regarding the environmental impacts of oil palm agriculture there are, and probably will continue to be, different opinions. As has been shown repeatedly, there are uncertainties on how much peat swamp forests and tropical rainforests that actually have been cleared, and particularly how much that have been cleared because of oil palm conversion.

The figures provided by the Malaysian Department of Statistics differ greatly from those that have been compiled by aerial photograph interpreters. Even when looking at figures provided by FAO they differ from each other. That there are many uncertainties regarding deforestation is a well-known problem. For example, the Intergovernmental Panel on Climate Change (IPCC) has stated that "deforestation estimates [in tropical countries] are very uncertain and could be in error by as much as ±50 %" (Watson et al. 2000).

Why do the figures vary so much? First of all, large-scale mapping in Southeast Asia is challenging because of the many unique land cover features, and the persistently cloudy weather (Miettinen et al. 2012). The accuracy of interpreted aerial images thus varies between interpreters. Furthermore, there seem to be many definitions and views on what is to be considered forest, peat swamp forest, plantations etcetera.

With the rapid land use conversion into oil palm it appears urgent to decide on clear definitions. The need for up-to-date information on land cover and ecologically important areas is important for planning of future oil palm expansion (Miettinen et al. 2012, Clay 2004). Without proper information on forest loss and further research on the palm oil industry's effects on waterways it is difficult to determine the total impacts, and thus to prevent them.

Perspectives on the DPSIR framework

The DPSIR framework has been criticized for describing a static condition without accounting for the dynamics and capturing trends (Carr et al. 2007). Furthermore, some have argued that the DPSIR propose a linear, unidirectional causal chain. In this thesis, structuring environmental indicators in the DPSIR framework has been helpful, but certainly not without these types of problems. For example, land use conversion from forest to oil palms results in a decrease of forests and furthermore in erosion and soil degradation. Soil degradation, which is an "impact", causes an increased demand for fertilizers, which is a "pressure". As can be seen in Figure 1 and 12, there is no direct link back to pressure from impacts. Another factor that is hard to place within the framework is erosion. It is a consequence of the extended oil palm cultivation, which constitutes the "state". At the same time erosion contributes to water pollution.

Furthermore, using the DPSIR framework in a long-time context is sometimes problematic as some factors can be seen as both an impact and a driving force depending on the time scale. Therefore, when applying the DPSIR framework on an environmental issue, it is important to decide on the study's temporal (and spatial) extent. For example, global warming can be interpreted as an impact caused by GHG emissions (which then is a pressure). Clearing and burning of tropical forests worldwide is estimated to contribute with 22 % of annual global CO_2 emissions; this constitutes a significant contribution to the global warming (Dale 1997). Hence global warming is an impact caused by land use change (even though emissions from burning of Malaysian forests and in turn the proportion of this that is due to oil palm agriculture are relatively small). Global warming can, on the other hand, also be considered a driving force. The climate change is projected to directly affect the Malaysian oil palm cultivation. Higher mean annual temperatures (up to 31° C) and increased rainfall can lead to higher fruit production; if climate change, however, brings about drought it is estimated that 2,080 km^2 of Malaysia's oil palm cultivation might become unsuitable for oil palm (Ministry of Science, Technology and the Environment 2000). Another effect of climate change is sea level rise. About 1,000 km^2 of Malaysia's oil palm plantations are expected to become flooded and abandoned if the sea level rises one metre (Ibid.). Thus when considering longer time scales climate change can be seen as "forcing" oil palm expansion further inland.

As a support for decision making and for analysing causes and consequences of specific issues the DPSIR framework is powerful. Even though some factors are difficult to address within the framework it generally becomes clearer where to direct potential responses after classifying the different aspects of an environmental problem into driving forces, pressures, state and impacts.

CONCLUSIONS

The overall aim of this study was to identify and account for the multiple environmental consequences of palm oil production in Malaysia and the outline has followed the DPSIR framework. The rapid expansion of oil palm cultivation is connected to driving forces such as population growth, changed consumption patterns and policies to reduce poverty and increase economic independence. The environmental problem of highest concern appears to be the land use conversion of lowland tropical rainforests and peat swamp forests to oil palm cultivation since this results in biodiversity loss and thus loss of ecosystem services (such as protection against erosion). Furthermore, land use conversion to oil palm releases a considerable amount of GHGs to the atmosphere; especially if taking into account the forest fires caused when establishing oil palm plantations. The palm oil industry also adds pollution of waterways and air. The society has responded to the environmental impacts in different ways. There have been attempts to restore degraded areas but most responses have focused on preventing further emissions and land use conversion. However, the measures taken to prevent the environmental consequences are not keeping up with the rapid expansion.

As there are uncertainties concerning the conversion and deforestation rates, the impacts of the oil palm expansion are difficult to evaluate. There seems to be an urgent need for comprehensive land use cover maps that detect areas of ecological importance. Furthermore, there must be clear definitions of what is to be considered forest and non-forest in order to plan for sustainable future land use.

There are both strengths and limitations of the DPSIR framework when applying it to the environmental problems of palm oil production. Within a fixed temporal and spatial scale the DPSIR can be helpful, especially for policy makers.

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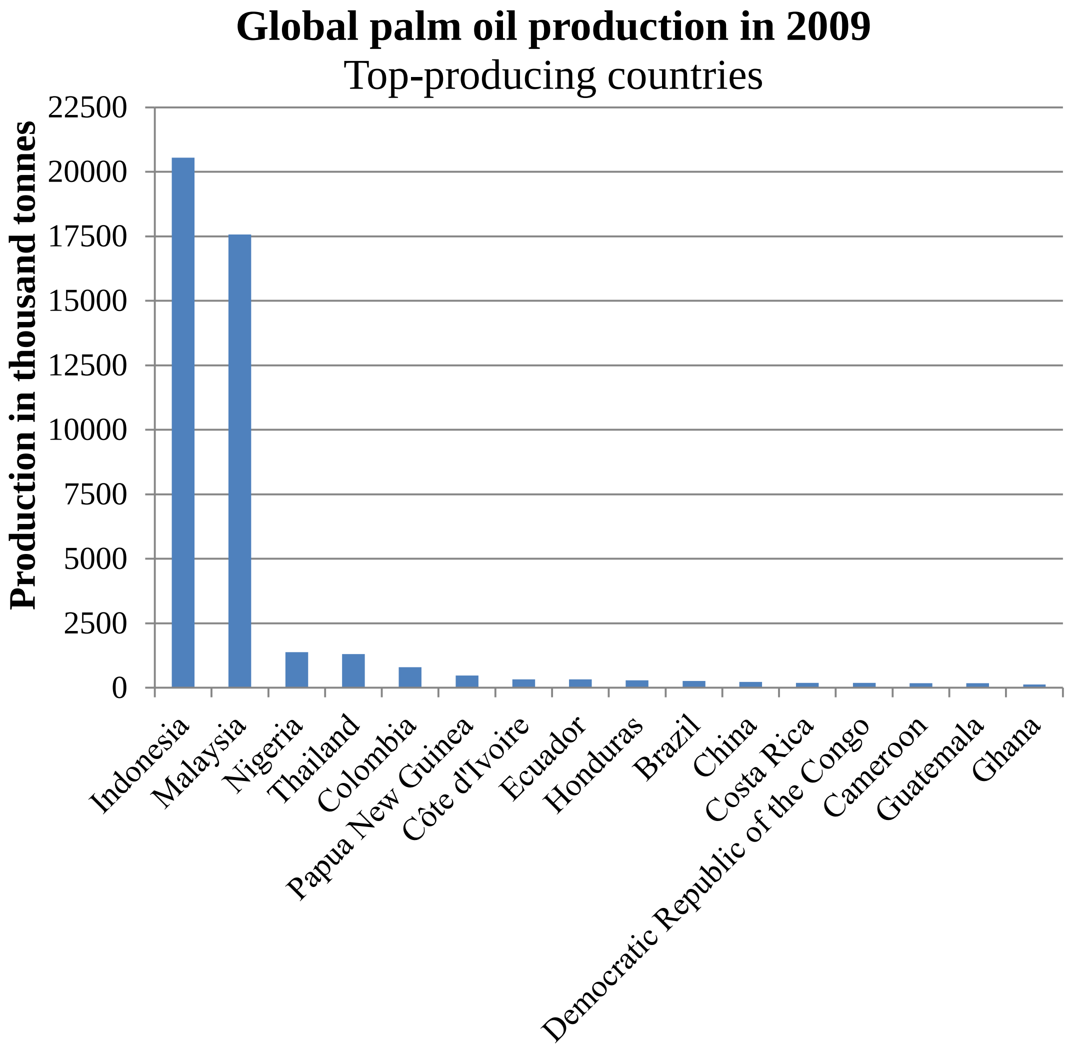
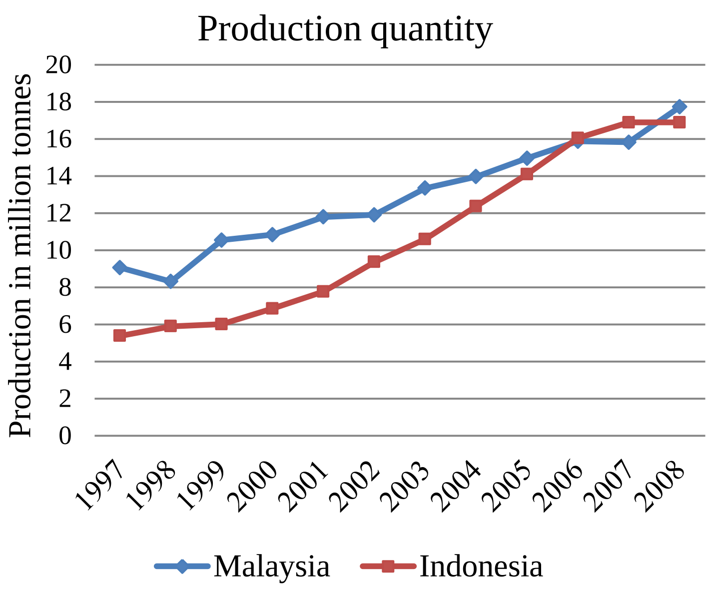
Appendix I: Palm oil production in the world

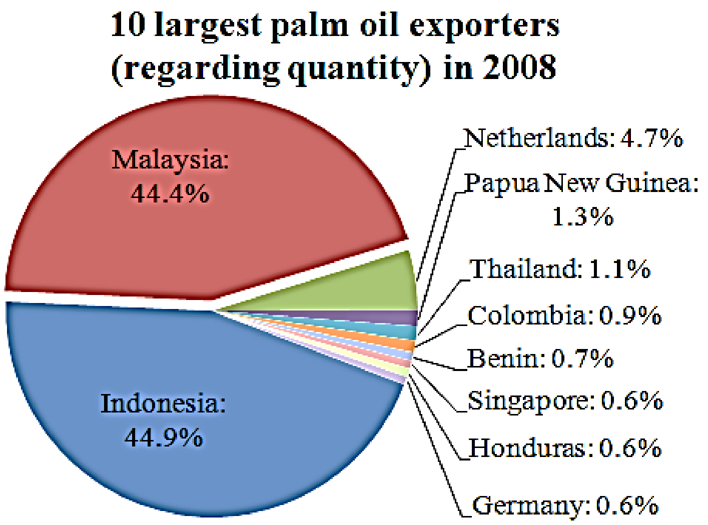
Most of the world's palm oil is produced in Malaysia and Indonesia. Malaysia has been leading the world production since the 1960s but Indonesia has in recent years "competed" with Malaysia when it comes to production quantity and export of palm oil. This appendix presents a figure showing the world production of palm oil in 2009 and two figures comparing Malaysia and Indonesia. All statistics are derived from FAOSTAT 2011.



The figure above shows the production quantities of the world's 16 countries that in 2009 produced more than 100,000 tonnes of palm oil. According to FAOSTAT (2011) there are 43 countries in the world that produces palm oil and together they produce 45,083,932 tonnes. In 2009 Indonesia produced 20,550,000 tonnes (46 % of the world production) and Malaysia produced 17,564,900 tonnes (39 %).



In 2006 Indonesia for the first time exceeded Malaysia in production quantity (FAOSTAT 2011). In 2008 Malaysia regained the first place but was surpassed by Indonesia again in 2009 (see the two figures above). In the future Indonesia is likely to surpass Malaysia for good because of the larger areas of still unused land available for oil palm conversion.



In 2008, even though palm oil production was larger in Malaysia, Indonesia exported a higher quantity of palm oil. When it comes to value however the Malaysian export was greater; this is because Indonesian palm oil is slightly cheaper (US$ 866 per tonne compared to Malaysian palm oil which had the unit value of US$ 903 per tonne in 2008) (FAOSTAT 2011).

Appendix II: Short historical background of the oil palm in Malaysia

Summarized from D.J.M. Tate's book *The RGA History of the Plantation Industry in the Malay Peninsula*. 1996.

Southeast Asia has been recognized as an important source of agricultural production since the "earliest days of international commerce and navigation" (p.3). The Malacca peninsula however constitutes an exception being almost free of commercial agriculture until the nineteenth century when it totally fell in under British colonial domination. Crops that soon established were pepper, coconuts and coffee. European explorers had brought the African oil palm from West Africa to Europe in the sixteenth century and in 1848 four oil palm seedlings for the first time reached South Asia. The seeds were brought from Amsterdam and Mauritius to the Botanic Gardens of Buitenzorg (today called Bogor) on Java, Netherlands East Indies[2]. A few decades later, in 1875, oil palm seeds (this time sent from the Kew Garden, London) also arrived in the Malaya[3].

At the time when the oil palm firstly arrived in Southeast Asia it was still no easy way to extract the oil and, hence, it the oil palm was not a very profitable crop, neither in Europe nor in South Asia. Also, no commercial use could be found for the oil palm's fruit or oil. Many of the first oil palm plants, even though flourishing, were therefore soon dug up and replaced by other crops. With the spreading of industrialization in the late nineteenth century came the technical breakthrough of oil processing and with it the development of most natural oil industry (e.g. coconut oil), but not for palm oil. Because of the "rubber boom" that already had taken place there were no room for oil palm as a plantation crop, and since oil palm was not considered suitable for smallholder cultivation the development of oil palm cultivation had to wait. In the early twentieth century however, the Malaysian production of oil palm began, a development which is ascribed the "far-sighted" Belgian entrepreneur Adrien Hallet and the Frenchman Henri Fauconnier. After a visit to Hallet's oil palm plantation in Sumatra in 1911 Fauconnier established the first commercial planting in Malaysia, at Tenammaran Estate, Kuala Selangor. In the beginning the oil palm were planted together with other crops but in 1917 the oil palm were, for the first time a sole crop. The palm oil industry has since then experienced many ups and downs. During the Second World War nearly all mills and machinery got destroyed and no one could expect the enormous oil palm expansion that would take place in the decades to come. From the 1960s and on the palm oil industry has been steadily growing.

[2] Netherland East Indies was the name of the Dutch colony that today is Indonesia.
[3] Malaya was the name of the British colony that today is Peninsular Malaysia. Until 1957, the Malaya federation was under British rule. In 1963 the state Malaysia was created by a fusion of the Malaya federation, British North Borneo (Sabah), the British colonies of Sarawak and of Singapore (which was excluded in 1965).

Appendix III: Biodiversity status

All Southeast Asian countries have a rich biodiversity and still new species are found every year. On the island of Borneo the number of new species found averages at three findings every month, over the last ten years there were 360 discoveries (WWF Malaysia 2011). According to the Malaysian Nature Society (MNS) “Malaysia tops the list under the IUCN Red List of Threatened Species” and in “the last 15 years, Malaysia has lost around 60,000 species of life forms a year as a result of natural areas being cleared to make way for development, logging, plantations, housing and various other human exploits” (MNS 2011).

Tables below show the number of endemic and threatened species recorded in Malaysia (in 2008). As can be seen, a total of 7,349 endemic species are found of which 7,136 are plant species. In 2008, 1,092 of the Malaysian species were threatened. Because of the high number of endemic species are many of these are considered globally endangered (ASEAN 2009).

Recorded endemic species in Malaysia. Data from 2008. Source: ASEAN 2009

Endemic species 2008	
Mammals	6
Birds	9
Reptiles	17
Amphibians	64
Butterflies	117
Plants	7,136
Total	**7,349**

Recorded threatened species in Malaysia. Data from 2008. Source: ASEAN 2009

Threatened species 2008	
Mammals	70
Birds	42
Reptiles	21
Amphibians	47
Mollusks	19
Other Invertebrates	207
Plants	686
Total	**1,092**

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