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Planetary Boundary for Chemical Pollution

- a review of the case chemical DDT

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ABSTRACT

Chemical industry has been given a great deal of attention after several chemicals have shown global distribution and incidents with high toxic effects. The effects observed with some chemicals poses as a threat to both human health and to the environment, and these threats include effects on society and economy, all aspects of sustainable development.

With the publication of *Planetary Boundaries*, by Rockström et al. (2009), a new way of looking at human impact and sustainable development was presented. By dividing human impact between nine different categories, and focusing on global resilience, the reader was forced to reflect and consider whether the current human operations could continue as they have, and for how much longer. The framework within Planetary Boundaries is still not yet complete, with two categories not being quantified, Chemical Pollution being one of them.

This review investigates whether a boundary for chemical pollution is possible, through a case study of one single chemical. The selected chemical is DDT, and its metabolites. By setting criteria for a chemical boundary, a suggestion for a chemical boundary for DDT was made. An extensive literature search was used to examine the possible toxic responses to different species, to further assess possible thresholds and slow variable impacts on other planetary boundary categories.

Thresholds, boundary levels and additional concerns were among the results of this review. General for bird species a 16-18% eggshell reduction, due to DDT exposure, was set as a boundary level indicating population decline and possible threshold impact, loss of bird species. For raptorial birds a less accurate, but indicative level of 16 ppm of DDE in eggs was set as a level with high risk of raptorial bird species loss. Fish has been given both acute and chronic tolerable exposure concentration levels of DDT. DDT levels of 0.001 µg/L for chronic exposure for both freshwater and saltwater fish, and 1.1 µg/L for freshwater fish and 0.13 µg/L for saltwater fish for acute exposure. Going beyond these concentrations might cause the threshold loss of aquatic species. Additional concerns were given to insect diversity, especially the honey bees, and to humans, especially to groups with additional concerns, such as pregnant females, young children and those with HIV/AIDS.

With these thresholds and other underlying theories on combined effects and population resilience, DDT was given a placement beyond safe operation, but within a zone of uncertainty, according to the Planetary Boundary framework. A proposal for a boundary level seemed possible for DDT, using literature review as a method, but could be too extensive for several, and needs to be further discussed together with the proposed criteria for which chemicals to be included.

It was difficult to define whether the current use of DDT is a threat to sustainable development, due to the presence of the historic use, and that previous use is still being investigated. It is concluded that it is

likely that DDT still has the possibility to pose as an irreversible threat to the globe, depending on several factors such as climate change, the chemical cocktail, and habitat change.

NORWEGIAN ABSTRACT

Industrielle kjemikalier har fått en del oppmerksomhet, etter at flere kjemikalier viser en global distribusjon og hendelser med kraftige toksiske effekter. Effektene observert hos noen kjemikalier kan være en trussel for bade human helse og for miljøet, og videre føre til endringer i samfunn og innen økonomi, det vil si alle aspekter innenfor bærekraftig utvikling.

Ved publiseringen av *Planetary Boundaries* av Rockström et al. (2009), presenterte de en ny måte å se på menneskelig påvirkning på bærekraftig utvikling. Ved å dele opp mulig menneskelig påvirkning inn i ni kategorier, og ha fokus på global motstandskraft, ble leseren tvunget til å reflektere og vurdere hvordan den nåværende menneskelige driften av jorden har vært, og hvor lenge den kan fortsette. Men rammeverket presentert var ikke fullkomment, da to kategorier fortsatt var uten grenseverdier, hvor den ene var kjemisk forurensning.

I denne oppgaven blir det vurdert om en grenseverdi for kjemisk forurensing er mulig eller ikke, gjennom en teoretisk vurdering av litteratur om et eksempelkjemikalie. Det valgte kjemikaliet er DDT, sammen med dets metabolitter. Ved å sette visse kriterier for en kjemisk grenseverdi, kommer et forslag på en global grenseverdi for DDT. Litteratursøk ble brukt som metode, for å undersøke forskjellige dyregruppers toksiske effekter av DDT, for så å foreslå mulige terskelverdier for toleranse og påvirkninger på og fra andre kategorier.

En del av resultatet fra denne oppgaven er terskelendringer og diverse nivåer som muligens kan benyttes som grenseverdier. Generelt for fugler ble 16-18% eggeskallfortynning, på grunn av DDT eksponering, foreslått som en indikasjon for populasjonsreduksjon, som en fare for terskelverdien tap av fuglearter. For rovfugl ble en mindre presist nivå, en konsentrasjon av 16 ppm av DDE i egg satt som nivå med stor sannsynlighet for nedgang av rovfuglpopulasjoner. For fisk ble det brukt både kroniske og akutte nivåer for eksponering, hvor det var muligheter for høy risiko for terskelen tap av biodiversitet. En konsentrasjon av DDT på 0,001 µg/L er satt som farlig nivå for kronisk eksponering, for bade saltvann og ferskvann, mens ferskvann har 1,1 µg/L og saltvann 0,13 µg/L for akutt eksponering. Tilleggsbekymringer ble fremtstilt for diversitet av innsekter, med spesiell bekymring opp mot honningbien, og for human helse, spesielt opp mot gravide, barn og personer med HIV/AIDS som spesielt utsatt gruppe.

Med de gitte grenseverdiene sammen med teori om kombinerte effekter og populasjoners motstandsevne, ble DDT plassert over nivået som indikerer sikker bruk, men fortsatt innenfor et rom for usikkerhet, innenfor rammeverket for Planetary Boundaries. Gjennom en vurdering av litteratur var det mulig å lage et forslag på en grenseverdi for DDT, men det må videre vurderes om det vil bli en for stor oppgave når flere kjemikalier skal inkluderes. Denne vurdering må gjøres sammen med de foreslåtte kriteriene for hvilke kjemikalier som kan inkluderes.

Det er vanskelig å definere om den pågående bruken av DDT er en trussel mot bærekraftig utvikling, på grunn at den historisk bruken fortsatt påvirker omgivelsene, og at det fortsatt er mye forskning på den historiske bruken. Det er konkludert med at DDT fortsatt har muligheten til å føre til irreversibel skade på et globalt plan, avhengig av flere faktorer som fremtidige klimaforandringer, den kjemiske cocktailen og endring av habitater.

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ABBREVIATIONS

AIDS	acquired immune deficiency syndrome
AMAP	arctic monitoring and assessment programme
ATSDR	agency for toxic substances and disease
CAS	Chemical Abstract Service
CNS	central nervous system
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
ECHA	European chemical agency
EDC	endocrine disruption chemical
EEA	European economic area
EPA	United States environment protection agency
EU	European union
E	extinctions
HIV	human immunodeficiency virus
IPCS	international programme on chemical safety
IRS	indoor residual spraying
ITN	insecticidal treated nets
IVM	integrated vector management
LC_{50}	lethal concentration, 50%
LD_{50}	lethal dose, 50%
LLIN	long-lasting insecticidal nets
MDG	millennium development goals
MSY	million species per year
NINA	Norwegian institute for nature research
NTNU	Norwegian university of science and technology
PCB	polychlorinated biphenyl
PIC	prior informed consent
POP	persistent organic pollutant
ppm	parts per million
REACH	registration, evaluation, authorization and restriction of chemicals
SDG	sustainable development goals
SRC	Stockholm resilience centre

UN	united nations
UNEP	united nations environmental programme
WHO	world health organization

1 INTRODUCTION

Humans have with agriculture and modern time industry had a massive impact on their surrounding environment. Through chemical industry, and the production of DDT, humans were able to revolutionise agricultural pest control and limit insect transmitted diseases (WHO, 1992, Pimentel and Greiner, 1997). DDT was widely used until incidents such as groups of birds suddenly dying in the areas where the chemical was used, which made it an important topic on the political agenda (Mrema et al., 2012). With monitoring and research, the use was restricted and DDT was deemed a global hazard (EPA, n.d.-b). This thesis it will be reviewed whether there is a global scale impact of DDT, within the selected framework, the Planetary Boundaries by Rockström et al. (2009).

Due to the impact humans have on the planet, and the possible harmful feedback that might occur as result of the natural systems changing, there is a need for changes in the way humans operate (Griggs et al., 2013). As a contribution to the debate on how big an impact humans have had, how much more the globe tolerates and what possible consequences there are, the Planetary Boundaries were presented (Rockström et al., 2009). This is a framework of nine categories, which shows the impact humans have had, where we still can make it right, and the possible changes due to the present impact (Steffen et al., ø2011). Two of the categories have not yet been presented, and one of these is chemical pollution. This review will explore the reasoning behind not being able to present a planetary boundary for chemical pollution, and look at the possibility of making one.

An already existing image of how large an impact human activities is the anthroposphere being added as a separate sphere in the description of the planets large systems and their influence of each other (Steffen et al., 2011). The other four being the biosphere, geosphere, hydrosphere and atmosphere. The anthroposphere represents humans as a separate system which is linked with the four other systems (Zalasiewicz et al., 2011). Synthetically produced chemicals is an example of a contribution to the earths systems from the anthroposphere, and through toxic responses in biota and altered chemical composition of the earth's crust, water and air, the natural systems are changing (Steffen et al., 2011). The deposition of unnatural chemicals has reached such great level that is poses a major concern for the planet, and therefore also for human health (Mrema et al., 2012).

The anthroposphere is now getting feedback from the other systems such as climate change, ocean acidification, danger of losing food production and increased radiation due to reduction of ozone in the atmosphere (Steffen et al., 2011, Griggs et al., 2013). The political measures taken towards ozone depleting chemicals (the Montreal protocol), could be called a success story (McKenzie et al., 2011). The global and direct effect it had on human health was clear and obviously dangerous, and the changes made had a positive feedback, with the level of ozone no longer decreasing (McKenzie et al., 2011). Still there are chemicals being used that also show toxic and dangerous effects, and the need for documentation and evaluation of their impact is needed. Political control and intergovernmental cooperation is essential to cope with a global threat.

The Millennium Development Goals (MDG) is an example of an important framework for international cooperation, and with MDG reaching their deadline in 2015, it has been decided to continue the work of the United Nations (UN) with the establishment of the Sustainable Development Goals (SDG) (Griggs et al., 2013). This opens up for the opportunity to add more focus on global scale risks, such as chemicals.

As a work in progress, it has been suggested that the SDGs should have a larger focus towards the environment, referred to as Earth's life-support system. As shown in Figure 1, a new way of thinking of sustainable development moves from having economy, society and the environment as equal parts of sustainable development, to a sustainable development dependent on environment firstly and most importantly, having society dependent on the existence of environment, and the existence of economy dependent on both the latter (Hattingh, 2004, Griggs et al., 2013).

Griggs (2013) proposes six SDGs, which are based on research on earth's different life-support systems. The proposed SDGs are; *thriving lives and livelihoods, sustainable food security, sustainable water security, universal clean energy, healthy and productive ecosystems and governance for sustainable societies (Griggs et al.,* 2013*).* Within these goals the increase of unregulated use and production of chemicals pose a threat to several, such as human and ecosystem health, water and air quality, and food security (AMAP, 2009, Eskenazi et al., 2009, Abrol, 2012, Mrema et al., 2012). With this in mind, the main focus of the review will be on environmental changes caused by the chosen chemical DDT, but including how these effects will change the two latter spheres.

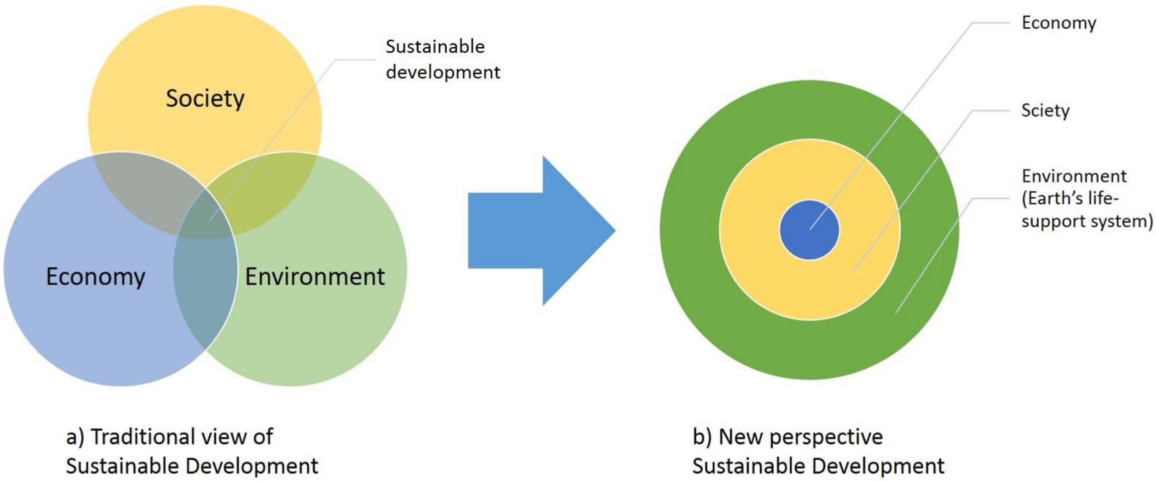

Figure 1: The proposed change from the traditional view of sustainable development (a) to a new perspective (b). a) The three spheres are of equal size, and equal amount within the center that indicate sustainable development. b) Sustainable development where environment is the largest sphere, indicating its importance, with society and economy within the initial sphere, to indicate their dependence for existence. Figure is adapted from Hattingh (2004) and Griggs (2013)

With the possible threats of chemicals and DDT together with the ideal of sustainable development, it would be important to have knowledge on the total impact chemicals might had, previously and at present, to further indicate to society what measures needs to be taken before it is too late (Persson et al., 2013).

DDT is a chemical that has been restricted because of its negative effects, but it is also one that is still allowed, through special regulations (Stockholm Convention, 2008a). Showing effects on different species and indications of human toxicity, but with unknown global impact and with a known area of use and distribution, indicate that DDT will be a good case chemical for this review.

To summarize this review will firstly evaluate the possibility of a chemical planetary boundary, by evaluating the planetary impact of DDT within the framework presented. Lastly, the review will evaluate whether the historic and present use of DDT is sustainable or if it has had an irreversible impact on the planet, though effects on economy, society and especially environment.

2 THEORETICAL FRAMEWORK

The theoretical framework for this review consist of the chosen framework, Planetary Boundaries, and the chosen chemical, DDT. The Planetary Boundaries will be presented with the underlying idea and goal, followed by criticisms and supplementary ideas. Further on the chemical properties, political development and current status for DDT, will be presented. This will be the basis of the further evaluation of DDTs toxicity and the current risk it might have, to further make an attempt at creating a planetary boundary for DDT, evaluate the global tolerance of DDT and further develop the framework.

2.1 The Planetary boundaries

Stockholm Resilience Centre (SRC), established the 1st of January in 2007, was a joint initiative between the University of Stockholm and Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences. The Foundation for Strategic Environmental Research in Sweden (Mistra) funds the Centre. The goal of SRC is to become a world-leading research center, across disciplines and to achieve a solid understanding of the social-ecological systems (SRC, 2007). The aim is to change how world community leaders and the general population perceives and evaluates their local social ecological system in a global political context (SRC, 2007). They hope to achieve this through innovative cooperation between the relevant parties, such as political development, industry and the public (SRC, 2007).

In 2009, SRC suggested a new way to work towards a global sustainability, presenting the work done by 28 different scientists, with the Executive Director for SRC Johan Rockstöm as lead author. The proposition consists of nine different categories, where each category represents a global environmental issue, each with their own boundary for safe operation for sustainability. The categories presented were as follows (Rockström et al., 2009):

- Climate change
- Ocean acidification
- Stratospheric ozone depletion
- Biogeochemistry – nitrogen and phosphorus cycle
- Global freshwater use
- Change in land use
- Biodiversity loss
- Atmospheric aerosol loading
- Chemical pollution

The first seven categories have each been given a specific boundary. However the last two categories, atmospheric aerosol loading and chemical pollution have not yet been given a boundary level. In Figure 2 the different categories are presented with their safe operating space (green area), the proposed planetary boundary (outer ring of green area) and how the status of the category is in present (red segments). As shown in the figure, three of the categories exceed their given boundary level. These three are climate change, nitrogen cycle and biodiversity loss.

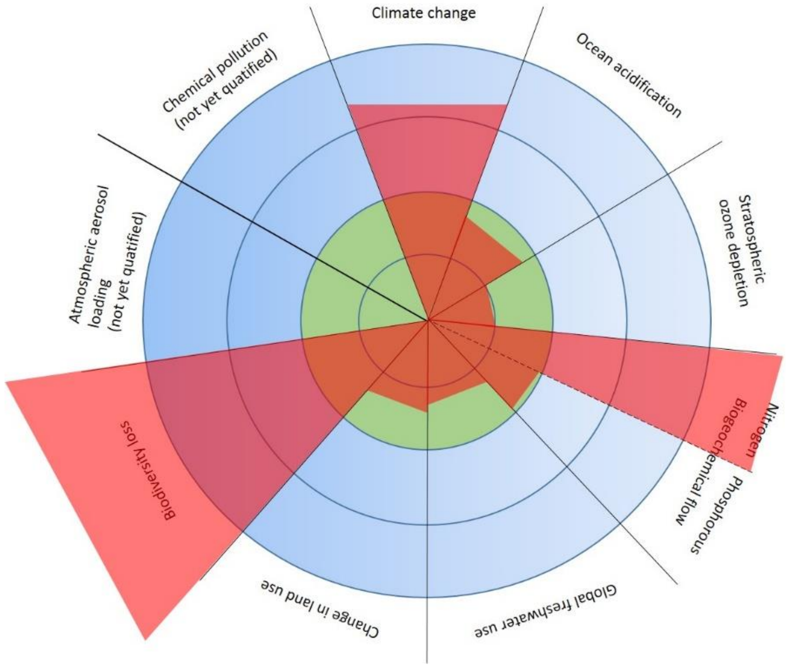

Figure 2: The nine planetary boundary categories. The green area is the safe operating space, with the boundary being the outer ring of the green area. The blue area is the zone of uncertainty. The level reached is indicated by the red segment. Three boundaries are beyond its given boundary level; Climate change, Biodiversity loss and the Nitrogen cycle (Biogeochemical flow). Figure is an adaptation of original figure by Rockström et al. (2009)

2.1.1 Resilience

The concept of *resilience* is an important factor in the Planetary Boundary framework. Holling (1973) introduced resilience as an ecological term, where he divided the behavior of an ecological system into two terms, resilience and stability. Resilience was defined as what determined the stability and persistence of an ecological system, by measuring the ability to absorb changes in the current state and the driving forces, with all their variables, and still persist (Holling, 1973).

Stability was defined as the ability of an ecological system to reach an equilibrium after a disturbance to the system (Holling, 1973). The term resilience differs between systems, and SRC offers this definition when talking about resilience in a global social-ecological perspective: "*The capacity of a system to deal with change and continue to develop; withstanding shocks and disturbances and using such events catalyze renewal and innovation"* (Moberg et al., 2007). When considering the term with regard to crossing planetary boundaries, it can be seen as going beyond what natural systems can deal with, creating irreversible global change (Moberg et al., 2007).

2.1.2 Safe operating space, zone of uncertainty and thresholds

The *safe operating space*, the green area in Figure 2, is where the negative effects of the categories level is not present, or not at a global scale impact (Rockström et al., 2009). When it reaches beyond the level of safe operating space and crosses the boundary, it enters the *zone of uncertainty*, as indicated by the blue area in Figure 2. The boundary is set at a level where one can be sure of safety for the global subsystems (Rockström et al., 2009). Because of the complex global systems, one cannot with a 100% certainty conclude that crossing the boundary will immediately cause changes to a system (Rockström et al., 2009). The insufficient knowledge of the dynamics of natural processes calls for a zone of uncertainty, where disruption will occur, but at an unknown exact level within the zone (Rockström et al., 2009).

Common for all the categories is the presence of *thresholds*. Thresholds can be defined as non-linear transitions, and in the case of Planetary Boundaries, caused by interactions between the human and the environmental systems (Lenton et al., 2008). The thresholds are events and/or changes that are not easily reversed, or contributing factors in disruption on global systems (Rockström et al., 2009). A threshold can also be referred to as a “tipping point” (Lenton et al., 2008, Schellnhuber, 2009). The effects of entering the zone of uncertainty differs between the categories, as shown in Figure 3, are therefore divided into two groups (Rockström et al., 2009).

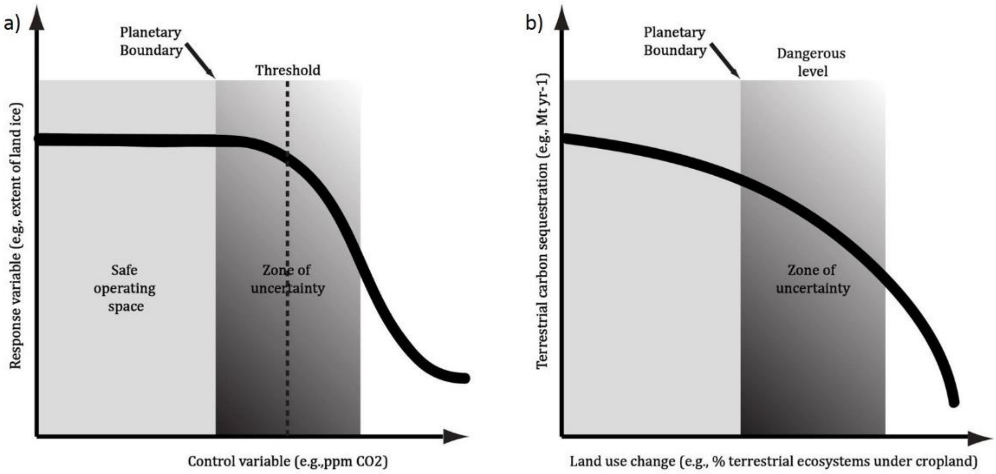

Figure 3: The different groups of planetary boundaries, with and without known threshold. Example from climate change a), has known planetary threshold, for example the increase of ppmCO2 will cause drop in extent of land ice, at threshold level, somewhere within the zone of uncertainty. Example from land use change b), has possible regional thresholds and act as a slow variable, for example the percentage of converted land to cropland will affect the amount of biological carbon storage, by metric (mt) per year (yr) (i.e. Mt yr^{-1}), which will have regional effects aggregating to global scale, in addition to further strain the category climate change. Figure is an adaptation of the original figure by Rockstöm et al. (2009)

The first group (Figure 3a) is where the process has a known *global scale thresholds*. The existing knowledge is usually insufficient to predict exact critical levels, and therefore the threshold is at an unknown level within the zone of uncertainty (Rockström et al., 2009). An example of such a global scale threshold at an unknown level, is the change from coral reefs to systems dominated by algae, caused by ocean acidification (Rockström et al., 2009). The ocean acidification boundary is defined as staying above 80% of the pre-industrial mean saturation of aragonite, with the threshold mentioned predicted to occur within a zone between 70-80% of pre-industrial concentration (Rockström et al., 2009).

In the second group (Figure 3b) there are no known global thresholds, but crossing the boundary will cause regional changes and/or have effects that impact the other categories (Rockström et al., 2009). This group of thresholds is called *slow variables* (Rockström et al., 2009). The slow variables are small scale changes, for example regional thresholds, which will aggregate an unwanted effect on a global scale (Rockström et al., 2009). An example from this type of regional threshold and slow variables is from the category land-system change, where crossing the boundary can cause regional changes in ecosystems at several locations (Rockström et al., 2009). In addition to this it will act as a slow variable to affecting regional carbon storage and regional loss of species, affecting the categories with global climate change and the global loss of biodiversity (Rockström et al., 2009).

2.1.3 The boundaries - Examples

The planetary boundaries for the different categories are based on values for preindustrial time, depending on the data available, and put in a modern context, with recent scientific findings (Rockström et al., 2009). For example, one of the boundaries for climate change is 350 ppm concentration of CO_2 in the atmosphere, whereas the global average concentration is reported to exceed 400 ppm by 2015-2016 (UNEP, 2013). The boundary is based on research done on polar ice sheets, which suggests a zone of uncertainty, within 350-550 ppm CO_2 in the atmosphere (Rockström et al., 2009). This is indicated by the category climate change being placed in the blue area of Figure 2.

In addition to the amount of CO_2 in the atmosphere, the boundary is also based on the possible change in the energy balance of the earth, which is measured by the changes in radiative energy absorption of sunlight on the planet surface, in W m^{-2} (Ramaswamy et al., 2001, Rockström et al., 2009). By keeping below the level of 350 ppm CO_2, the thresholds for this category can be avoided. By going beyond this level, the thresholds loss of polar ice sheets, regional climate disruptions and loss of glacial freshwater supplies is predicted to occur within the zone of uncertainty (Rockström et al., 2009).

An example of a category that is based on different factors is the loss of biodiversity. The other categories, such as climate change, is based on physical and chemical properties, whereas loss of biodiversity is regarded as more complex (Samper, 2009). The boundary is set to be within 10 extinctions (E) per million species per year (MSY) (i.e. E/MSY), with 10-100 E/MSY set as the zone of uncertainty, and the current rate estimated to be over a 100 E/MSY (Rockström et al., 2009). In Figure 2, this is indicated by the red segment going beyond the blue area. The boundary has been estimated from fossil data stating that extinction rate for marine organisms is between 0.1 to 1 E/MSY (Pimm et al., 1995), and 0.3 E/MSY for mammals (Mace et al., 2005). Compared to the other categories, the loss of biodiversity boundary is based on ethical factors, in addition to the possible economic and environmental factors, making it more debatable than the other boundaries (Rockström et al., 2009).

2.1.4 Comments on the boundaries

Since the publishing of the article of Rockström et al. (2009), there have been different views on which parameters have been used to define the boundaries for the different categories (Bass, 2009, Samper, 2009, Schlesinger, 2009). For example, the parameter used to set the boundary for land use, is the percentage of total land shifted from natural state to agriculture and construction (Rockström et al., 2009). It is suggested that the percentage of land that is no longer usable, due to changes such as geochemistry, be used as parameters instead. This to have the focus on the amount of land used together with the possibility of food production, rather than percentage of total land in use (Bass, 2009).

Suggestions that the categories are too general have also been brought forward, for example the loss of biodiversity. It is stated that the category should be divided in to different boundary groups, because of the different rate of E/MSY for the different animal groups (Samper, 2009). Amphibians for example have a much higher E/MSY than birds (Samper, 2009).

Also, there have even been claims that rather than functioning as an incentive to work for a better environment, the boundaries actually give politicians room for allowing further pollution, as some of the boundaries are not yet reached (Schlesinger, 2009).

2.1.5 The boundary for Chemical Pollution

Rockstöm et al. (2009) started a line of thought on how to make a planetary boundary for chemicals, but concluded that it was not yet possible to compile the vast number of chemicals, and their interactions, in to one single planetary boundary. The authors still present two points on why chemicals deserve one of the nine categories. The first is the possible global impact on ecosystem functionality and human health the chemicals have shown, through alterations in for example physiological development.

The second reason is that chemicals have been placed in the group of planetary boundary categories acting as slow variables, meaning to contribute to combined negative effect with other planetary boundary categories (Rockström et al., 2009).

They also propose two possible measurements of chemical impact, concerning a possible planetary boundary. One has the focus of the global *reach* of the chemicals, including the long range transport possibility together with low level effects that might be lethal or sub lethal. The other focusing on the *effect* of chemicals, with aggregating all known effects, covering the most subtle effect on the most sensitive species (Rockström et al., 2009).

Persson et al. (2013) proposed three conditions, where all three have to be met simultaneously, for a chemical to pose a global threat:

1. The chemical or mixture of chemicals has a disruptive effect on a vital earth system.
2. The disruptive effect is not discovered until it is, or inevitably will become, a problem at a planetary scale.
3. The effects of the pollutant in the environment cannot be readily reversed.

Condition 1 is explained as being disruptive on a system, for example a biological system disruption that affects reproduction, and endangers the survival of a species. The loss of biodiversity is a global threat, and chemicals are described as severely impacting the diversity by threatening several species, without specifying how many would make up a global threat (Persson et al., 2013). The second condition is explained by the reasoning that there has to be known, or reason to believe that certain effects will occur at a global scale, for the society to be presented with a global threat (Persson et al., 2013). The third states that the effect should be of a scale and of the effect that it cannot be reversed in hindsight (Persson et al., 2013). Persson et al. (2013) thus combines the two categories of Rockström et al. (2009), chemical reach and effect, into three conditions that might be used in the selection of chemicals to be included into the boundary.

For the time being Rockström et al. (2009) presented chemicals as possibly having a great impact on human health and ecosystems. In addition to this they present possible effects of chemicals that increase the risk of pushing towards thresholds and disrupting the resilience for other categories through combined effects (Rockström et al., 2009). They stated that there is a large amount of evidence and knowledge of toxicity and reach of individual chemicals, but not on their collective effect and the global scale effects (Rockström et al., 2009).

2.2 DDT

In 1874, Othmar Zeidler synthesized for the first time 1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane (DDT) (Mrema et al., 2012). The chemical was rediscovered in 1939 by Paul Mueller, who through experimentation observed the effectiveness of the chemical against insects (Costa, 2013). The acute toxicity of DDT is low, so during the Second World War it was used in a large scale and applied to people directly to fight the spread of diseases spread by insects (vector), such as malaria, yellow fever and typhus (Manahan, 1989). In addition to the usage against these vector-borne diseases, DDT was effective in agricultural pest control (Costa, 2013).

In the 1960s approximately 400 000 tons of DDT was used annually until the ban of the chemical in the 1970s (Mrema et al., 2012). The sudden public awareness was partially caused by the publication of the book *The Silent Spring* by Rachel Carson in 1962, which was written as a warning of wide-scale pesticide usage, through the death of songbirds in an area (EPA, n.d.-b).

2.2.1 Chemical Properties

Technical DDT is a mixture of different isomers of dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) (WHO, 2011), with DDT being the universally used name for the insecticide (Costa, 2013). The structures of the different isomers are shown in Figure 4. The percentage of the different isomers may vary, due to the variations in manufacturing of DDT (WHO, 2011). Of the mixture, it is p,p'-DDT that functions as the insecticide (Costa, 2013).

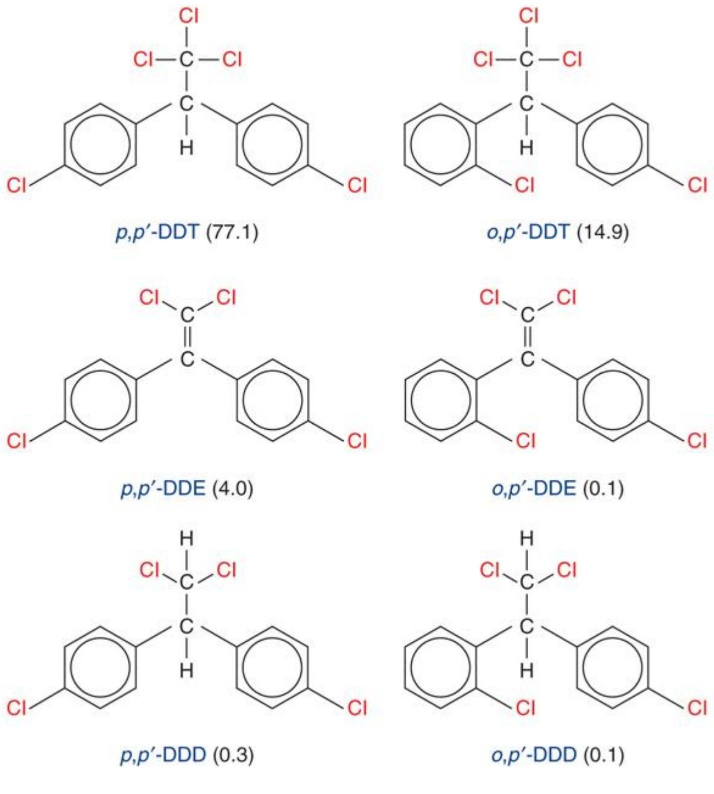

Figure 4: Structures of different isomers in technical DDT; p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE p,p'-DDD and o.p'-DDD. The parenthesis indicate the approximate percentage concentration of the indicated isomer in technical DDT (Costa, 2013).

DDT was an excellent chemical for insecticidal use because of several properties such as cheap manufacturing, chemical stability and persistence, low mammalian acute toxicity and of course the effective toxic effect on insects (Mrema et al., 2012). Some of these properties are also the reason for the negative effects of DDT. The low acute toxicity of the chemical caused a use without major concern, but biotransformation of DDT results in higher concentrations of DDE and DDD, which both have carcinogenic effects on mice (Costa, 2013).

In experimental studies, often pure samples of for example p,p'-DDE are used, whereas the natural exposure is through the mixture and further by biotransformation (WHO, 2011). There are several other possible toxic effects of DDT to humans and on different organisms, which will be discussed further on in the paper.

The stability and persistence of the chemical is also a concern, where low solubility and high lipophilic properties result in bioaccumulation in wildlife and in humans (Manahan, 1989, AMAP, 1998, Stockholm Convention, 2008b). In addition to accumulating in the exposed organism it will increase in concentration with each trophic level, through biomagnification (AMAP, 1998, Stockholm Convention, 2008b). Another concern to the persistence within some biota, is that DDT is distributed to all parts of the world, including the arctic, through atmospheric deposition and long range transport (AMAP, 1998, Stockholm Convention, 2008b, EPA, n.d.-a).

2.2.2 Acute toxicity

As previously mentioned the acute toxicity of DDT to humans is low, but set as moderate when the dose is given orally, with a LD_{50} at approximately 250 mg/kg and causing illness at 10 to 20 mg/kg oral doses (Costa, 2013). High exposure doses of DDT may cause spasms, decrease motorization, memory loss, hypersensitivity and personality change, which all indicate the Central Nervous System (CNS) as the primary goal for the toxicity (Manahan, 1989, Costa, 2013). Accidental intake of high doses of DDT, have caused severe neurological damages and even death, especially in children (Rogan and Chen, 2005, WHO, 2011, Roberts et al., 2012).

The chronic toxicity for humans will be the main concern in this paper, and will be dealt with in chapter 4.

2.2.3 Political Development

The "silent spring" brought the attention of DDT to the political community, as well as its metabolites, DDE and DDD and their effects on the environment (Mrema et al., 2012). This resulted in strict legislations on the use of DDT and other similar chemicals. The current use and production of these chemicals is a result of four major international political agreements, which are presented to show the development within internationals chemical policies.

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was in effect from 1992 (Basel Convention, 2011). The increase of dangerous waste made the need for stricter regulation on disposal and treatment of wastes. The Convention's goal is to reduce the amount of waste generated, environmentally-friendly management of the waste and to regulate the transboundary movement of the waste, where one could see an increase of transport from countries with expensive, but environmentally safe treatment, to developing countries with less regulation for treatment at a low cost (Basel Convention, 2011).

The Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters in Aarhus was signed 1998 and in effect from 2001. The Convention states the public's right to receive and access information on the environments state, measures taken and on the decisions made by the public authorities. It also grants the public the right to participate in the decision-making concerning the environment, as well as the right to challenge the decisions made as a representative for the environment, concerning breaches on environmental law (European Commission, n.d.-a).

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade was signed 1998 and in effect from February 2004. Through the Prior Informed Consent (PIC) procedure and the Information Exchange the Convention sets the boundaries for export and import of specific hazardous chemicals. Through the procedures agreed upon, the demand for updated information and the communication between parties, the convention contributes to safe and controlled export and import of chemicals (Rotterdam Convention, 2010). The member states agree that importers have to communicate about their own restrictions to the exporters, in addition to the the exporters updating the importer about the properties of the chemicals and the dangers of handling it (Rotterdam Convention, 2010).

The Stockholm Convention on Persistent Organic Pollutants (POP) was adopted in 2001 and in effect from May 2004. The conventions goal is to reduce the exposure of humans and environment to persistent, accumulative and wide spreading POPs. POPs that needs to be eliminated and where the production, import and export is prohibited are listed in Annex A in the Convention (Stockholm Convention, 2008a). Annex B, lists POPs that have restricted production, usage, import and export, including DDT (Stockholm Convention, 2008a). In addition to this the Convention has listed POPs in Annex C, where the goal is to reduce the release of unintentionally produced POPs (Stockholm Convention, 2008a). The Convention also sets goals for issues such as information, awareness and education for the public, information exchange between parties, research and development towards for example replacement chemicals (e.g. DDT), monitoring of the POPs in the environment and organisms (Stockholm Convention, 2008a).

Lastly, the establishment of Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) has been an important measure for the framework and legislations for chemicals in the European Union (EU) and the members of the European Economic Area (EEA) (Norwegian Environment Agency, 2007). REACH entered into force in 2007, and offers procedures for assessing hazard and properties for substances (ECHA, n.d.). The goal is to ensure safety for human health and minimize environmental impact, by making the producers and importers responsible for the registration of their substances (European Commission, n.d.-b). The European Chemical Agency (ECHA) receives the companies' registration, and evaluates their assessment and whether they are in compliance, with the power to restrict or ban the use of substances with unmanageable risk (ECHA, n.d.). It is expected that 30 000 substances will be registered with REACH by 2018 (Norwegian Environment Agency, 2007).

2.2.4 DDT in the Arctic

The clean environment in the Arctic has been and still is of special concern regarding the distribution of POPs, including DDT (AMAP, 2011). Because of the properties of POPs, there is a high level accumulation and magnification in the biota in Arctic food webs, even if the levels of contaminants in the Arctic is low compared to other areas (AMAP, 2011). The sources of POPs in the Arctic is for example through contaminants flowing with the sea currents, with migratory animals and largely by deposition by long range transport (AMAP, 1998).

DDT has been present in samples from several groups of arctic biota, including freshwater and saltwater fish, marine and terrestrial mammals, seabirds and aquatic invertebrates (Rigét et al., 2010). Some species have shown high levels of DDT over time, but since the ban in the 1970s a stable reduction during the last three decades has been observed in for example polar bears (*Ursus maritimus*) (Dietz et al., 2004, Dietz et al., 2013), humans (Chashchin et al., 2012), ivory gulls (*Pagophila eburnea*) (Braune et al., 2007) and species from all the previously mentioned groups of biota (Rigét et al., 2010). However, it is still important that this area is still under close monitoring concerning POPs, DDT included, especially because of the possible increase of deposition due to climate change (AMAP, 1998) indicated by some yearly variations in recent years (AMAP, 2009).

2.3 The chemical Cocktail and combined effects

Experimental exposure of chemicals is often done with pure samples of single chemicals (WHO, 2011), or with mixtures with known concentration and contaminants (Letcher et al., 2010). In the environment, the wildlife is exposed to a combination of many contaminants of different concentrations and through different exposure routes (AMAP, 2011). The toxic response may differ for the chemical, depending on the chemical is acting alone, or if it acting as a part of a *cocktail* of different chemicals (AMAP, 2011). The four main categories of possible combined effect are:

- *Additive* effect, where the sum of different chemicals equals the sum of each individual effect (Eaton and Gilbert, 2013). There is no interaction between the chemicals (AMAP, 2011).
- *Synergistic* effect, where the sum of different chemicals is much greater, then the effect of each individual chemical added together (Eaton and Gilbert, 2013).
- *Potentiation* is when one chemical does much greater damage, because of the combination with a different chemical, that does not have any effect itself (Eaton and Gilbert, 2013).

- *Antagonism* is when chemicals interferes with each other effect, or one chemical interferes with the effect of another, causing less effect than the chemical would initially (Eaton and Gilbert, 2013).

An example of studies on how to predict the effects of a realistic chemical cocktail, is a study done on sledge dogs (*Canis familiaris*), who were fed with "naturally" contaminated fodder, minke whale (*Balaenoptera acutorostrata*) blubber, with concentrations of POPs (Sonne et al., 2007, Sonne et al., 2008). The sledge dogs were used to indicate the possible effect on polar bears, where there were different indication of possible effects on for example the liver and kidneys (Sonne et al., 2007, Sonne et al., 2008).

In addition to POPs, levels of mercury, radioactivity and climate change can have combined effects with DDT as well (AMAP, 2009, 2011). It is expected that the climate will, through causing physiological responses to stress, seasonal change and abiotic factors, change for example the degree of accumulation and the toxicity of chemicals (AMAP, 2011). There are several theoretical outcomes proposed for how these environmental changes might impact the exposure to chemicals and their combined effects (Letcher et al., 2010, AMAP, 2011). Keeping all this in mind, the combined effect of contaminants is still not clear, and there is a need for more research in this field (Letcher et al., 2010, AMAP, 2011).

2.4 Malaria Control

DDT has since its discovery been used effectively in pest control, both in agricultural use, but also in the battle against malaria (WHO, 2014). Malaria is a vector transmitted disease, a so-called vector-borne disease, where the female of approximately 60 species within the genus *Anophelus* is functioning as a vector for the parasite (Walker, 2002). It is estimated by the World Health Organization that 85% of the deaths, diseases and disabilities caused by malaria was in the African region, with South East Asia and the East Mediterranean area being the second and third (WHO, 2014).

Regarding the fight against malaria, there are several methods in use;

- Environmental modification/manipulations by altering the environment where the vector lives or reproduce, where the goal is to reduce contact between the vectors and humans (WHO, 2014).
- Biological control through the introduction of species, such as larvivorous fish or invertebrate predators for instance, to the environment of the vector (WHO, 2014).
- Chemical treatment by special spraying of areas, the use of larvicides or through indoor residual spraying (IRS) (WHO, 2014), or by insecticide-treated nets (ITN), such as the long-lasting insecticidal nets (LLIN) (WHO, 2007).

The use of DDT is estimated to have been a reported use of 4000-5000 metric tons of DDT between the years 2000-2009, where IRS is the main method where DDT still is in use (van den Berg, 2009). DDT is sprayed on the surfaces of the inside of people's homes or nets, to affect the female mosquitos while they rest after draining blood from a human (WHO, 2007, 2014). By doing so, the mosquito dies due to the toxic effect of DDT and will not be able to further spread the disease (WHO, 2014). It has been speculated whether IRS is having a negative effect on the environment, but with the fugacity of DDT and its persistence, it is suggested that up to 80% of the applied DDT to walls, will end up in the environment after a period of six months (Walker, 2002).

2.4.1 Mosquito immunity to DDT

The first case of DDT resistance in insects was reported in 1947, where two mosquito species showed increased tolerance towards the chemical (Brown, 1986). Since then there have been reported over 100 species of mosquitos that show resistance to different kinds of insecticides, especially DDT, where 50 of the species are in the genus *Anopheles,* the most common malaria vector (WHO, 1992). The WHO defines resistance as: "*an inherited characteristic that imparts an increased tolerance to a pesticide, or group of pesticides, such that the resistant individuals survive a concentration of the compound(s) that would normally be lethal to the species"* (WHO, 1992).

An example of high level resistance is a recent study done in Ethiopia by Asale et al. (2014), where experimental huts were sprayed with different insecticides. The result showed low effects of DDT, among other insecticides, that indicate a high level of resistance in the area (Asale et al., 2014). Different levels of resistance is reported from all areas with malaria (WHO, 1992). The likely mechanism for resistance is thought to be ether a result of metabolic mechanism or through genetic mutation (Hemingway and Ranson, 2000, WHO, 2007). With an increase of enzyme activity of modified enzymes, it is thought that insects can increase the detoxification of the pesticide, which is categorized as a metabolic mechanism (Hemingway and Ranson, 2000, WHO, 2007). The other possibility for resistance is the specific genetic mutation called kdr (knockdown resistance), where the sensitivity of the voltage gated sodium channels, that is effected by DDT, decreases (Hemingway and Ranson, 2000, WHO, 2007). The increase in resistance is serious, and will have effects on how vector management is done, the cost of it, the effectiveness of chemical control, and an increase of resistance would possibly increase the number of malaria infections in the population (WHO, 1992).

3 METHOD

In this paper a literature review has been conducted. Typical for a review is presenting literature with the goal of making suggestions for further research and/or development of new theoretical ideas. (Writing@CSU, n.d.). The intention behind a review, is to help the reader understand and make sense of the available literature, by making connections between different theories and studies, and presenting the significance of the theory (Presbyterian College Biology Department, 2013).

3.1 Literature search

The theory presented in this paper is theory from public reports, articles and research made available through the licenses at the Norwegian University of Science and Technology (NTNU) and the literature available at the university libraries. The search was mainly conducted on the Internet on different databases. The four major databases used were Google Scholar (scholar.google.no/), Web of Science (webofknowledge.com), Scopus (scopus.com) and the Chemical Abstract Services (CAS) SciFinder (scifinder.cas.org).

Most of the searches were conducted equally in the four different databases, with a different number of results. An example of searches and results is made in Table 1. As indicated by the table, the searches gave different amounts of results and it shows the procedure of getting manageable results within a subject. SciFinders results differs in some of the searches, because when there was a high number of search words used, SciFinder presented results with different combinations of the key words.

The reasoning for selecting four search engines was to get a wide perspective of the literature available, due to the different amounts of hits and relevance. According to Storleer (2014), by personal communication, Google Scholar is the search engine that stands out the most from the other three. By receiving all metadata from the publishers, the search will be conducted on a full text search, with no human evaluation on what the important aspect of the published text is. This is indicated by the number of results of searches in Google Scholar compared to the other engines chosen in Table 1. The three remaining search engines receive articles from publishers, where the company responsible has specialists within the subject, that evaluate and select the important aspects of a text and set keywords, which makes the searches more accurate and more relevant than a full text search (Storleer, 2014).

The articles that were not available through the licenses of NTNU were sought out through other search engines and through the library search engine BIBSYS. Not all possible relevant literature was possible to obtain.

Table 1: Examples of searches made in different search engines, and the number of results per engine

Topic	Search Engine	Search words	Result
Planetary boundaries	Web of Science	Planetary + boundaries + chemicals	329
	Google Scholar		31 300
	Scopus		383
	SciFinder		161
	Web of Science	Planetary + boundaries + chemicals + Rockström	1
	Google Scholar		1 390
	Scopus		0
	SciFinder		168
Eggshell thinning	Web of Science	Eggshell + thickness + population + effect + DDT	25
	Google Scholar		2 940
	Scopus		17
	SciFinder		3/11/28
Pollinators	Scopus	DDT + pollinator + effects + population	0
		Malaria + control + impact + insect + population	229
		DDT + insect + diversity	7
Human health	Google Scholar	Human + health + effects + organochlorine + pesticides	38 600
		Human + toxicity + DDT + development + malaria + control	13 000
		Human + toxicity + DDT + breast + cancer + young + women + malaria + control	2 400
Reptiles	Web of Science	Reptile + toxic + response + DDT + population + effect	0
	Google Scholar		5 400
	Scopus		0
	SciFinder		3

3.2 Process

Establishing an overview of the framework and the chemical was done to have a basic understanding, before the process of finding relevant literature. Both periods of the process, the theoretical background and the findings are results of literature searches.

Depending on the amount of literature, and the quality of their results, the different segments of findings were made. Excluding certain groups of exposed groups of biota was necessary for this review, due to the time aspect of the work period. Selection of the included groups of biota were done based on the previously known association between DDT and toxicity, and by the amount of literature obtained on the subject. For example an assessment on Amphibians was started, but due to very few relevant results and literature, it was decided not to be included.

As mentioned previously the different engines were used similarly, but due to the different relevance and amount of results, Google Scholar was mostly used for searches when looking for specific texts and authors. In addition Google Scholar was sometimes used for a general search when only basic knowledge was known on the subject, to randomly pick a few articles before specifying the searches.

Adjustments to the search words were needed during the search, when the number of results was too high to manage. For example in Table 1 where one search in Scopus, on the topic of pollinators, gave zero results, the adjustment of search words gave 229 results. 229 articles were too many to manage, so another adjustment gave seven results. Through logical thinking and several attempts, search words were chosen, to conduct searches that gave the most relevant results, where specifying the searches also gave more manageable numbers of results. In Scopus, Web of Knowledge and SciFinder, results under 20-30 were preferred, where half could be selected as more relevant based on the title, and then some were selected for further reading based on the abstract and the keywords.

In an attempt to have both political and scientific statements not only scientific papers were used. Political reviews and assessments, for example the United States Environment Protection Agency (EPA), the World Health Organization (WHO), the Millennium Ecosystem Assessment and similar were used to highlight political importance and general consensus in the political sphere.

Lastly the primary sources was preferred, but not always possible to obtain. In addition to this reviews were used to some extent, where assessments and conclusions were already made for different subjects. In these cases attempts were made to be able to cite both the original research and the review, where the assessment was not of a large scale data analysis.

3.3 Reliability and Validity

The reliability of this review is dependent on the quality of the search engines used and the amount of available relevant literature. The person dependent aspects such as selection of keywords and the selection of literature made from the results will also have an impact on the reliability. Several searches were conducted, and they were adjusted depending on the amount of results. The same searches were conducted on four different search engines, and most of the results were available ether through NTNUs licenses or through the university libraries. With the amount of literature available and the measures taken to find as relevant literature as possible increases the reliability of the method used.

Throughout the study, several biota is reviewed, and attempts have been made to find literature that explores different causative reasoning for effects on a species or groups investigated. A wide specter within the different groups of biota has been included, to increase the validity of the study. More groups could have been included, but after consideration, they were excluded, due to the literature available and the time perspective of writing the review.

The discussion and conclusion in this review is based on personal interpretation of the literature assessed in this review. It is made through an attempt of presenting a thorough and a wide-specter analysis as possible of underlying theory of the framework and the chemical as an introduction to the topic, together with the toxic responses to the chemical as a result of the literature review. When further discussed and concluded, previously presented literature is used, and any new statements should be validated by a reference to literature.

4 RESULTS – LITERATURE REVIEW

It has been mentioned already that DDT and its congers might have toxic effects on different groups of biota. In this segment some groups have been chosen to make an assessment of the possible effects. The groups have been chosen on the basis of available data. The groups presented are birds, insects, reptiles, fish and humans, in that order. The data presented is the information that was seemingly most relevant, towards the goal of producing possible thresholds for a planetary boundary for DDT and evaluate its global impact.

4.1 Birds

Eggshells and the reduction of their thickness is an effect that is natural to consider when examining the effect of DDT on birds. The correlation between eggshell thickness and the level of DDE is very strong, and has been shown in many studies since the 1960s (Hickey and Anderson, 1968, Wiemeyer et al., 1988, Fry, 1995, Helander et al., 2002). Of the different groups of birds the level of eggshell thinning differs at the same concentration of DDE. Newton (1979) claims that raptors are the most sensitive group of birds to chemicals and that they are more exposed then others due to their position at the top of the food chain. This is supported by others as well (Hickey and Anderson, 1968, Nygård et al., 2001). Less sensitive are the gamebirds and fish eating birds (Newton, 1979, Nygård et al., 2001), followed by the songbirds being the least sensitive and the least exposed group of birds (Newton, 1979).

It has been suggested that it is not the level of thinning that has the major impact on bird populations due to DDT exposure, but the reduced egg size (Snyder and Meretsky, 2003). This however was disclaimed later in a different study, on the same species, the California condor (*Gymnogyps californianus*), where it is claimed that the previous study by Snyder and Meretsky (2003) did not have any data to support this conclusion (Burnett et al., 2013). In addition to this Burnett et al. (2013) propose that the loss of water during incubation is the reason for low reproductive success instead of breakage, where breakage was only associated with levels at 50% reduced thickness. The study however, used a very small sample size, and the use of artificial incubation was high, due to the species' small population (Burnett et al., 2013).

Even with the difference between bird species there has been suggested a mean percentage of 16-18% reduction of eggshell thickness, where a stable reduction of the population can be observed for birds in general (Newton, 1979). Thislevel of reduction was estimated after comparing different populations and species over time (Newton, 1979). This has been supported by later studies, where near complete reproductive failure was observed, and others with a level of reproduction not capable of keeping a stable population, for example the brown pelican (*Pelecanus occidentalis*) at 15% reduction of thickness (Blus, 1982), 17% in osprey (*Pandion haliaetus*) (Johnson et al., 1975) and 15% in bald eagles (*Haliaeetus leucocephalus*) (Wiemeyer et al., 1993).

Comparisons of DDE concentrations in eggs and the percentage of eggshell thickness reduction has been made to investigate the correlation, but the results have large variations between species. The brown pelican being at the critical level, where reproduction was being substantially affected, was estimated to be 3 ppm DDE, and near complete reproductive failure at 4 ppm (Blus, 1982). The latter value was correlated to the reduction of eggshell thickness by 15% (Blus, 1982). For osprey 8.5 ppm DDE was associated with a 17% reduction of thickness (Johnson et al., 1975), but a different study also suggested a 20% reduction at 8.7 ppm (Wiemeyer et al., 1988). The Peregrine falcon (*Falco peregrinus*) had a concentration at 20 ppm associated with 20% reduction (Peakall et al., 1975) and the bald eagle, stated as being the least sensitive of raptorial birds, a 15% reduction at 16 ppm DDE (Wiemeyer et al., 1993).

In bird populations in the areas where DDT has been restricted since the 1970s, it is possible to see the resilience of some bird species and populations. In several more recent studies, where development of levels of DDE in eggs and the eggshell thickness over time has been studied, there is a clear improvement from decade to decade, in both the eggshell thickness, reduced DDE levels and then also the population of different bird species (Newton et al., 1999, Nygård, 1999, Nygård et al., 2001, Huber et al., 2014). An example of is the merlin (*Falco columbarius*) in both Norway (Nygård, 1999) and in Great Britain (Newton et al., 1999) where the species has shown great improvements in recent years.

On the other hand, even if the populations do improve, Hellander (2002) points out that the white-tailed sea eagle (*Haliateetus albicilla*) needed 10 years after the ban of DDT to show any signs of improvements, and in 15 more years it still had not reached the level that it had shown prior to the introduction of DDT. How much damage has been done should also be considered when looking at the resilience of a species, for example the ivory gull, where one has seen an 80% population decline from the 1980s to the 2000s in Arctic Canada (Grant Gilchrist and Mallory, 2005).

Even with a decline of DDT concentration in the Canadian Arctic, to levels below the threshold of reduced reproductive success indications (Braune et al., 2007), reports from the Russian and Svalbard Arctic still showed eggshell thickness reduced to 17% (Miljeteig et al., 2012). The mean reduction of eggshell thickness in this study was 13% (Miljeteig et al., 2012). The ivory gull has shown some of the highest levels of environmental contaminants (Miljeteig et al., 2009), whereas several of the levels are associated with lethal and sublethal effects (Braune et al., 2007, Miljeteig et al., 2009). In addition to the chemical exposure the loss of preferred types of habitat and climate change might cause additional stress and population decline (Grant Gilchrist and Mallory, 2005, Miljeteig et al., 2009). Whether the impact of DDT alone is still causing present reproductive success is not clear, due to the lower levels in recent years (Braune et al., 2007), and by not being able to separate the effect of DDT from other chemicals (Miljeteig et al., 2012). However the effect of the combined effect with other chemicals and the climatic changes can still cause DDT to have a significant impact on populations of birds (AMAP, 2009, Letcher et al., 2010, AMAP, 2011).

4.2 Insects

The role of insects as pollinators is important, and the loss of essential pollinator species would cause major ecological changes and impact food production (Abrol, 2012). For legumes and fruits different kinds of insects are required for sufficient pollinations (Abrol, 2012, Everly, 2013). With that in mind, the previous use of insecticides may have had an impact on the diversity during the years used in agriculture (Walker, 2002). Several studies show residues of DDT in insects (Johansen, 1977, Romaniuk et al., 2004, Abrol, 2012, Everly, 2013) and in the honey collected by honey bees (*Apis* spp.) (Sarfraz Khan et al., 2004, Choudhary and Sharma, 2008, Rodríguez López et al., 2014).

When discussing pollinators, the population of domesticated bees and wild bees is an important aspect, as the loss of their populations, would have a large impact on global food production (Schierow et al., 2012). At present, the loss of bees is a reality (EPA, 2012), and it is therefore important to find out, whether the use of pesticides, is the sole reason to the reduction of bee populations, or if it is a combined effect of chemicals and/or changes in the surroundings (Schierow et al., 2012). As for DDT, it has been suggested that the lethal dose for the honey bee *A. mellifera* is 12-27 µg/bee (Vetter and Roberts, 2007), but indications are that this level might be higher to other species (Romaniuk et al., 2004, Sarfraz Khan et al., 2004), due to low toxicity of DDT to honey bees (Johansen, 1977, Roberts et al., 1982). Still studies show residues of DDT in bees from different regions of the world, that indicates a chronic exposure for honey bees (Al-Rifai and Akeel, 1997, Blasco et al., 2003, Sarfraz Khan et al., 2004, Wang et al., 2010, Rodríguez López et al., 2014).

Another interest in keeping a divers insect fauna is the ecology of pests. Predators in the cereal field are especially important to the yield of cereal crops (Sunderland and Vickerman, 1980, Ahmad et al., 1987). The reduction of predators has shown the effect of a large number of pests, especially aphids (*Aphididae*) damaging the crops (Vickerman and Sunderland, 1977). A study conducted in Nigeria, on farmland plots sprayed at different times with DDT, showed that the more treated with DDT the larger the reduction in the numbers of lycosid spiders (*Lycosidae*) and crickets (*Gryllidae*) after the first year (Critchley et al., 1980). And after four years, also ant (*Formicidae*) and millipede (*Diplopoda*) populations showed large reductions (Critchley et al., 1980).

4.3 Reptiles

After a sudden decline in a population of alligators (*Alligatoridae mississippiensis*) in the lake Apopka in Florida after a major spill of pesticides, effects of pesticides on reptiles were given some focus (Guillette et al., 1994). Effects such as elevated levels of estradiol in females, dislocation of testis and reduced penis size in males has been reported, most likely caused by endocrine disruption caused by pesticides (Guillette et al., 1994, Guillette et al., 1996). DDT has for a long time been made out to be the most likely toxicant to cause the reduction of the alligator population in Lake Apopka, but the presence of more documented endocrine disruption chemicals (EDC) indicates that DDT might have been given an unfair label in this specific incidence (Semenza et al., 1997).

Regarding reptiles as a group, there seems to be s consensus regarding their vulnerability to environmental pollutants (Sabourin et al., 1984, Skaare et al., 1991, Khan and Law, 2005), and that they have the potential to be a good indicator of the presence of EDCs (Crain and Guillette Jr, 1998) and general chemical pollution (Fleet and Plapp Jr, 1978, Hopkins, 2000). Reptiles are often on the top of the food chains in their habitat, which poses the likelihood of bioaccumulation of pollutants (Sabourin et al., 1984, Skaare et al., 1991). Despite this, reptiles is the least studied group of vertebrates concerning ecotoxicology (Hopkins, 2000, Rainwater et al., 2005, Weir et al., 2013).

It has been speculated in similar effects among reptiles and birds regarding eggshell thickness and pesticide exposure, but there does not seem to be any correlation between thickness and population decrease (Hall et al., 1979, Heinz et al., 1991).

4.4 Fish

The present and the previous use of DDT can also still impact the state of water quality and the environment for freshwater and saltwater fish, for example runoffs from old deposits (Connor et al., 2007) or by drifts from spraying (Frank et al., 1990).

The change in aquatic environments can affect fish in different ways, for example the direct effect like lethality, reproduction changes and behavioral changes or through reduction in invertebrates considered to be fish food (Pimentel and Greiner, 1997). Hellawell (1988) presents reasons to why fish are especially vulnerable to organochlorine pesticides, such as DDT. In comparison to other insecticides the organochlorines show a *strong* potential of entering freshwater resources, being *highly* toxic to the aquatic environment, with a *prolonged* persistence in the aquatic environment and with a *strong* bioaccumulation factor (Hellawell, 1988). Where DDT is no longer in use, it is predicted that the concentration of runoff will decrease, but a results from a study from San Francisco Bay predicts that the level would not be considered clean before 25 years after the study was conducted in 2007 (Connor et al., 2007).

The International Programme on Chemical Safety (IPCS) stated in 1989 in their report on Environmental Health Criteria that DDT is highly toxic to fish, with the 96 hour LC_{50} ranging between 1.5 to 56 µg/L for different species (IPCS, 1989), where Hellawell (1988) claims a range from 1 to 30 µg/L. From the literature there seems to be a wide difference of DDT toxicity between fish species, even within the same genera (Schoenthal, 1963, Macek, 1968). With the difficulty with a large gap between species sensitivity, the United States Environment Protection Agency (EPA) defined levels of acceptable concentrations in freshwater and saltwater (EPA, 1980). The average concentration of DDT defined as chronic exposure to fish is 0.001 µg/L DDT for both freshwater and saltwater fish (Train, 1979), and the acute exposure is set to not exceed 1.1 µg/L for freshwater and 0.13 µg/L for saltwater (EPA, 1980). Both the acute and the chronic concentrations are levels set by EPA, which aquatic environment can be exposed to without showing results that are unacceptable (EPA, n.d.-c).

Conservation of fish numbers, the diversity of fish and keeping the concentration of chemicals within what is safe for consumption is important for the environment, the economy and the human health aspect (Pimentel and Greiner, 1997, Kaur et al., 2008).

4.5 Humans

Humans have, as possibly all other organisms been exposed to DDT through for example direct exposure or by eating contaminated fish, seafood, or crops (Turusov et al., 2002, EPA, n.d.-a). Even from a young age, we are being exposed to DDT by transfer from the mother through breast milk (EPA, n.d.-a). This is a critical concern because of the possible effect DDT might have on humans, which includes it being a possible carcinogen, causing developmental defects, reducing reproductive success, being immunotoxic and neurotoxic (Hodgson and Levi, 1996, Longnecker et al., 1997, Rogan and Chen, 2005, Beard, 2006, Eskenazi et al., 2009, Mrema et al., 2013).

EPA classifies DDT as a *probable human carcinogen* (EPA, 1988). This classification was based on several animal studies, where elevation of tumors in the liver of mice could be observed (EPA, 1988). The elevation of cancerous tumors in mice is well documented, and shows a clear association between levels of DDT and liver damages and cancer, but the association is not proven in epidemiological studies (Rogan and Chen, 2005, Eskenazi et al., 2009).

Breast cancer is one of the most tested forms of cancer in association with DDT (Beard, 2006). In several recent reviews it seems to be the consensus that there is little evidence of DDT having any causative association with breast cancer (Rogan and Chen, 2005, Beard, 2006, Cohn, 2011). It should however be noted that some studies do show an association, especially when looking at early age exposure of DDT (Cohn, 2011). Examples of studies that show a stronger association is where young girls exposed to high concentrations before the age of 14 were examined (Cohn et al., 2007), and the examination of girls exposed *pre menarche* and *in utero* (Eskenazi et al., 2009). Another study show an increase in breast cancer when exposed to mixtures of several organochlorine pesticides and other POPs (Mathur et al., 2002), which nether proves nor disclaims DDTs possible effects, but might suggest a combined effect.

Pancreatic cancer, testicular cancer and leukemia are other examples of types of cancer that has been studied, both in animal studies and with epidemiology studies, where there has been no conclusive indications that DDT is carcinogenic (Longnecker et al., 1997, Beard, 2006, Eskenazi et al., 2009). A study on non-human primates found tumors in some of their specimens, but could not conclude any carcinogenic effect either (Takayama et al., 1999). It seems as even though it has been widely studied that there are no clear indications of carcinogenic effects on humans (Rogan and Chen, 2005), without being able to exclude that DDT might be harmful (Jaga and Dharmani, 2003).

Animal studies also indicate the potential of pesticides having developmental toxicity (Hodgson and Levi, 1996, ATSDR, 2002, Roberts et al., 2012). Suggested effects DDT might have on human development is for example effects on neurophysiological development, on mental development and effects like reduced growth (Beard, 2006, Eskenazi et al., 2009, Roberts et al., 2012). With the exposure of DDT beginning with maternal transfer in the womb (Vizcaino et al., 2014), continuing through breastfeeding (Kochubovski, 2012) and further on through diet (IPCS, 1995) the development of young children could be especially critical (Roberts et al., 2012). The animal studies show a strong biological plausibility for developmental toxicity, but the studies on populations of humans only show weak association, conflicting findings in similar studies and are unable to conclude for specific toxicity (Rogan and Chen, 2005, Eskenazi et al., 2009, Roberts et al., 2012).

Just as developmental toxicity, both animal and epidemiological studies indicate that DDT might cause effects on reproduction both on females and on males, but also here there are conflicting findings, making it difficult to conclude (Rogan and Chen, 2005, Beard, 2006). The possible effects on males include reduction in penis size, damage to the reproductive tract, low sperm count, low semen volume, reduced semen mobility and testicular cancer, but without any conclusive results (Hodgson and Levi, 1996, Longnecker et al., 1997, Rogan and Chen, 2005, Aneck-Hahn et al., 2007). It is suggested that the wide possible reproductive effects on males is caused by an androgen receptor antagonism effect of DDT (Kelce et al., 1995, Longnecker et al., 1997).

Longnecker (2001) conducted a study on data from children born between 1959 and 1966, where data on preterm birth, low birth weight and concentration of DDE was available. The study indicate an elevation, especially for preterm birth, associated with DDE concentration (Longnecker et al., 2001). The association with low birth weight was not as consistent (Longnecker et al., 2001). Furthermore there are other reviews where a possible association is found between DDT concentration in the mother and shortening of lactation time (Longnecker et al., 1997, Rogan and Chen, 2005). Reproduction effects on females such as shortening of lactation, preterm births and reduction of birth weight all contribute to an increase of infant mortality (Longnecker et al., 1997, Eskenazi et al., 2009, Vizcaino et al., 2014).

Immune systems effects and increased risk of diabetes is mentioned in some of the reviews, but also here are they unable to draw any conclusion to as to whether it is caused by DDT or not (Rogan and Chen, 2005, Eskenazi et al., 2009). The most common factor in the different reviews on DDT and human toxicity is that there is need for more specific research with high quality (Hodgson and Levi, 1996, Beard, 2006, Mrema et al., 2013). Other reviews also draw the conclusion that DDT and its metabolites are relatively safe for humans with little or no evidence of them being harmful to man (Jaga and Dharmani, 2003, Ahmed et al., 2005).

Despite several concluding that DDT is not harmful, there are reluctance to disclaim the possible effect on humans entirely (Jaga and Dharmani, 2003). Especially concerning special groups of people, where the effects might be more devastating than in for the regular population. Regarding the possible immunotoxic effects people with HIV/AIDS might be a group of people with an additional risk, keeping in mind the high level of HIV/AIDS in the areas where DDT is still used in IRS (Eskenazi et al., 2009). Pregnant women and children in areas with IRS are most likely also more susceptible than others (Longnecker et al., 1997, Longnecker et al., 2001, Beard, 2006).

In an assessment for human health issues for IRS workers by the World Health Organization (WHO) (2011) it was concluded that there was little or no danger associated with the general public in IRS areas. Their concerns were with women before and during pregnancy living in IRS treated houses and the IRS workers (WHO, 2011). Nor here were they able to draw any conclusion, but drew the attention to the need for more research and focus towards male and female reproductive effects and developmental effects (WHO, 2011). They did see a possible indication of an increase of cancer for IRS workers, but excluded it as a major concern, as the numbers were very low (WHO, 2011).

5 RESULTS – POSSIBLE PLANETARY BOUNDARY LEVELS AND THRESHOLDS

The team behind the article *Planetary Boundaries: Exploring the Safe Operating Space for Humanity* (Rockström et al., 2009) states that it is not possible at this time to define a planetary boundary for chemicals. Persson et al. (2013) still see the current need for one to be made, for society to take action. One can clearly see the result after the Stockholm Convention, concerning the improvement of the state of pollution of some POPs (Mrema et al., 2013). That does not call for a drastic move for a premature planetary boundary, but justifies the attempt made in this thesis. In the previous chapter, theories from different papers have been presented, and will further on be used to assess the planetary effect of DDT and make an attempt to draw out possible thresholds and boundary levels that indicate effects beyond global resilience. These levels set will indicate a threshold where the effect pose as an unacceptable impact on an ecosystem or human health. It has been necessary to draw some conclusions, beyond what might be common in natural science, to try to compile a product that is understandable, presentable and usable in a political and nonscientific sphere.

5.1 Birds

The possible loss of bird species due to population decline as a result of DDT toxicity is a threshold that can be included as an irreversible change. In the theory presented, there are two possible indications of critical threat to bird populations. Even with being early in stating a 16-18% reduction as cause for population decline, Newtons (1973) hypothesis has been demonstrated in similar studies later on. If such a level of eggshell reduction is found in a species in an area, it would be possible to predict a decline in the population of that bird species, and will therefore be included as a boundary level.

Raptorial birds are presented in the literature as the most exposed and the most sensitive group of birds, with the bald eagle seemingly the least sensitive to DDT. If the 16-18% reduction is taken into account, together with the total concentration of DDE in the egg, one could place a boundary at a 16 ppm DDE. At this level it is most likely to have a population effect on raptorial birds, due to the low sensitivity of the bald eagle. This is a less accurate indicator, but because of the difference in species it might pose as a worst case scenario for some raptorial birds and just as an indicator of population decline in species that are less sensitive. If investigating a species, where one already have more concrete indicator, this should be used to more clearly see the scale of the hazard.

5.2 Insects

The literature shows that the diversity of insects is important. The effects of their loss include examples such as reduced crop yield, change in crop ecology and loss of biodiversity. Most importantly insect diversity is important in many ecological systems. It is mentioned that DDT exposed areas have reduced diversity of different insect species. It is on the other hand not certain how indoor residual spraying will affect nearby areas, or how the previous treatment of fields has affected the diversity, but could still be included as a possible threshold.

Insects are necessary for the pollination of different crops, such as legumes (Everly, 2013). There is a special focus on the sudden drop in numbers of honey bees, where the total collapse of their populations would be catastrophic for the environment and for agriculture. What role DDT plays in the decrease of honey bees is not certain, but the concentrations in honey indicate a chronic exposure to the chemical, so the possible contribution of DDT in a chemical cocktail effect cannot be excluded.

As for a boundary with a specific concentration level, or a specific level of exposure, there was not any clear indication in the literature reviewed. Therefore, the level of where to place a possible threshold would be highly speculative, even if the impact would be very harmful on a global scale. However, the impact would be major, so the possible effect should be included as a precaution.

5.3 Reptiles

Despite the focus alligators received after the spill of pesticides in Lake Apopka, the amount of literature found for this review was not sufficient for a planetary boundary level. It seems that the general consensus among researchers and review writers that there at the time being is not enough results to say much about the toxic effects of pesticides, such as DDT, have on reptiles (Gibbons et al., 2000, Hopkins, 2000, Rainwater et al., 2005, Weir et al., 2013). There are several implications of different effects, although not enough to make a specific boundary of chemical concentration and population effects. Therefore it would not be possible to include any threshold for reptiles in this review.

5.4 Fish

According to the literature old deposits of DDT still have a strong chance of ending up in ether freshwater or saltwater, in addition to the present concentrations in water. Reduction in fish diversity caused by DDT, just like insects, will affect the boundary for loss of biodiversity and will impact several ecological systems as well as food production. DDT is highly toxic to fish and will persist in aquatic environments for a long time, and is therefore an important aspect to include in this assessment.

The species differences have a wide specter of concentrations and it is very difficult to find a common boundary for fish in general. With the possible effects of DDT toxicity in aquatic environments it seems to use the levels set by EPA as safe levels for fish. EPA has operated with levels where chronic exposure is set to 0.001 µg/L for both saltwater and freshwater, and 1.1 µg/L for freshwater and 0.13 µg/L for saltwater for acute exposure, which could all be included as possible boundary levels.

5.5 Humans

Human studies include several aspects that makes it difficult to draw any clear conclusion. Also the possible errors due to under-reporting, lifestyle and social aspects must be taken into account. Lastly humans tend to have a long life span, which makes long term effects such as cancer difficult to predict and difficult to include in a time dependent study. Considering the specific effects of DDT and epidemiological studies, it is difficult to separate between the effects of exposure to a specific pesticide, and what are combined effects of several chemicals.

In the literature collected in this review, there are several mentioning the need for further research on the possible toxic responses, and no conclusive dangers for humans and DDT exposure. The World Health Organization (WHO) still has a concern, regarding developmental toxicity and certain reproductive effects for both males and females. No levels posing a possible boundary has been obtained at this time, but there are some groups that receives an additional concern, as they are in a more susceptible or more exposed, which include:

- IRS workers
- Women in child bearing age and pregnant, especially those living in IRS treated homes
- Children
- Girls under the age of 14, concerning breast cancer
- People with HIV/AIDS living in IRS treated homes

5.6 Summary of Possible Boundaries

In Table 2, the various possible boundary levels and thresholds for the different groups of biota are presented. Where levels for a possible boundary could not be presented, additional concerns are presented. The additional concerns are present, to keep in mind additional effects without known cause and effect, where DDT might play a role. In addition to this, aspects of what poses as a threat to sustainable development is presented by the social, economic and environmental risks. The likelihood presented is a subjective evaluation of the boundaries and additional concerns are likely or not, based on the literature reviewed.

Table 2: Summary of the possible boundary levels and thresholds for the different groups of biota reviewed. Additional concerns represent possible effects of DDT for groups where no possible boundary could be presented. Risks to the spheres society, economy and environment is possible threats to sustainable development.

Group	Boundary	Additional concerns	Social, Economic or Environmental risk	Threshold	Likelihood of predicted impact
Birds	16-18% eggshell thickness reduction		Possible loss of birds important for consumption Ecological impact	Loss of bird species	Probable
Birds	16 ppm		Ecological impact	Loss of species of raptorial birds	Probable
Insects		Contribute to collapse of honey bees	Major impact on food production Major ecological impact	Major loss in pollination, and loss of species	Speculative
Insects		Reduction insect diversity	Possible reduction of crop yield	Loss of insect species	Low
Fish	Long time exposure in 0.001 µg/L		Ecological impact Fish no longer suitable for consumption	Loss of fish species	Low
Fish	Acute exposure of 1.1 µg/L in freshwater		Local ecological and economic impact	Loss of fish species	Low
Fish	Acute exposure of 0.13 µg/L in saltwater		Local ecological and economic impact	Loss of fish species	Low
Humans		Sensitive groups	Increased strain on health sector Loss of human life and reduced reproduction	Loss of human life	Inconclusive

6 DISCUSSION

This section of the paper has been divided into two segments, where the initial questions will be discussed. The two major segments are whether a chemical boundary is possible, and by which parameters, and whether the historic and current use of DDT is at a sustainable level of which the planet is resilient to. Following the discussion, chapter 7 will be concluding and presenting the final findings on whether DDT has breached a planetary boundary level of tolerance.

6.1 The framework/Criteria for Chemical boundary

When considering the possibility for a global boundary for chemicals, and when considering it to be done by chemical data analysis and assessment, it needs some criteria. As mentioned earlier the REACH programme, is conducting an assessment of 30 000 chemicals. For a common global chemical boundary, 30 000, including new chemicals, will be too many to assess into a single boundary. Even if splitting the boundary into different categories, such as the biogeochemistry category, it would still pose as a near impossible task. Persson's (2013) criteria for the chemical boundary should be included, because the literature assessed indicates that stating a chemical as a planetary threat is not done lightly. The criteria that should be considered are:

- The chemical should have a global distribution
- The chemical must show toxic effects that pose a risk to the environment, economy or society
- The chemical must have an effect that is irreversible

In production and use, it is likely to see effects of chemicals in the nearby area. Local spills, exposure and distribution would less likely pose a planetary effect, by causing extinction of species or have large population effects on humans. Therefore chemicals that are persistent and transported over a large area should be prioritized. If the risk is in a specific area, for example an area of great ecological importance or similar, this would call for special evaluation.

The toxic effect should be well documented, but chemicals that show indications and are associated with a possible planetary risks should also be included, as a lack of cause and effect relationship, should not be interpreted as a lack of risk (van Den Berg, 2010). Concerning the possible economic impact, it is not primarily addressed as a pure cost, but also the socio-economic aspect such as reduced yield in food production and increased strain on the health sector. Lastly the effect should have an impact that is irreversible, with specific thresholds where for example populations or species go extinct and long lasting effects causing extensive loss of human life.

An assessment of which chemicals or groups of chemicals that should be included, and the assessment of the chemical toxicity and possible reach, is highly time consuming, speculative and very dependent of quality research. This makes it unpractical, possibly costly and not ideal. However, it might have more positive return than just the possible boundary. With the assessments one will obtain a great overview of the possible toxic effects, and one could possibly better predict the possible effects of similar and new chemicals with similar chemistry. Cooperation would also be preferable, for example the data collected from REACH, in addition to research done by individual scientists and institutions, to avoid assessing only data from importers and the production company. Therefore the method should not be discharged due to time and cost, but be considered for assessing the global impact of chemicals, through a planetary boundary.

6.2 Planetary boundary for DDT

After the “Silent Spring”, the spread to the Arctic and the indication of toxicity to humans, DDT is still used in certain countries, with the exception of vector control in the Stockholm Convention. The use has been massively reduced from the 1970s to present day (Jaga and Dharmani, 2003, EPA, n.d.-b), and the research to find a cause and effect for DDT and toxicity in different species continues. Considering the drop in use and production, and the decreasing levels in species, it is difficult to say whether the current use will have a global scale effect. The debate on whether to continue the use of DDT in the control of vector-borne disease is continuous (Bouwman et al., 2011). The possible dangers of using DDT must be weighed up against the health benefits gained from vector-borne disease control (Roberts and Tren, 2010), and at the same time not concluding that the lack of cause and effect relationship is the same as no risk (van Den Berg, 2010).

In order to summarize the review an attempt will be made to decide whether the usage of DDT has gone beyond a planetary boundary, with effects deemed irreversible, or if there is still a possibility for a sustainable use of DDT in the control of vector-borne diseases. This will be done based on resulting thresholds and boundaries from this review, with regard to the review’s reliability and validity. Keeping in mind that there are only some groups of biota included in this assessment. Groups such as amphibians, aquatic invertebrates, plants and other mammals, could have been included, but indications in the literature available suggest that would not have made a big difference to the results.

With the literature reviewed it is DDTs effect on birds that stands out as the most concrete. The indications of population effect at the specific level of 16 ppm DDT in eggs of raptorial birds, and the 16-18% of eggshell thinning for birds in general, seems likely for a planetary boundary for the threshold, loss of bird species. Furthermore, when discussing the present impact of DDT, it is important to keep in mind the zone of uncertainty. The boundary is just an indication of population decrease, which would indicate a possibility of reversibility through population resilience. This means that it is still possible for the species population to regain a stable population, and the loss of bird species threshold can still be avoided.

Some species has shown resilience towards the effects of DDT after the concentration decline (Newton et al., 1999, Nygård, 1999, Nygåard and Gjershaug, 2001), but other species are still showing difficulty with regaining a stable population (Grant Gilchrist and Mallory, 2005, Miljeteig et al., 2009, Miljeteig et al., 2012). It will be dependent on the state of the species and the state of the surrounding environment, at what exact level the threshold will occur, or whether the irreversible loss can be avoided. No literature reviewed indicated any biodiversity loss caused by DDT at present.

The collapse of the honeybees is a dramatic scenario (Abrol, 2012), but the role of DDT is only speculative, and no conclusions or strong indications of its role could be made, nor could it be excluded. If DDT were to be proven to contribute to the honey bee population collapse, this would cause DDT impact to exceed the boundary of global resilience.

The international agreements that prevent DDT in agricultural use reduce the plausibility of reduction of insect diversity as a possible outcome. Also, one should not exclude the possible effect DDT has had previously on which species now dominate in crop areas, and the possible loss of important pest managing species during the use of DDT before the 1970s.

The boundary suggested for fish might be relevant mostly for smaller freshwater bodies and for coastal areas, especially closed in areas like fjords and closed off sea areas, due to lower levels of dilution of the chemical (Vethaak et al., 2005). Because of this the likelihood is defined as low, where no literature reviewed indicated high levels of DDT in aquatic environments that might pose as a global threat. The safety of species in areas with IRS should still be especially considered.

Human studies reviewed showed to have few conclusive results on the toxicity of DDT, which made it difficult to assess any levels of possible thresholds. However this should not be interpreted as DDT being safe for humans (van den Berg et al., 2012). There are still associations and indications that suggest a risk for human health, and especially within the field of developmental toxicity and reproductive toxicity (WHO, 2011). In addition to this there are different groups that might be more vulnerable than others and therefore need closer attention concerning DDT (WHO, 2011). It was not possible to produce any specific boundary that would seem appropriate at this time, due to the lack of association between cause and effect, and concentration and effect.

Until now the focus has mainly been on the direct effect of DDT on human health and biodiversity, but the additional effects it might have through combination with other categories should also be included. Global warming can possibly contribute to, especially for the Arctic species, increased intake, redistribution and toxicity, in addition to an increase in the level of long range transport deposition (Noyes et al., 2009). This also includes non-Arctic species in general, who can be affected by climate change, in addition to other changes such as loss of habitat (Rockström et al., 2009).

Different chemicals might also impact the resulting toxic effect of DDT. Through the cocktail-effect the chemicals have the potential to have a much higher toxic effect, than initially thought (Sonne et al., 2007, Letcher et al., 2010, AMAP, 2011). With this unknown factor it is difficult to say whether a boundary has been passed or not, as it no longer depends only on the level of a single chemical, but several chemicals and the various combinations of them.

With all the mentioned factors, could DDT be placed in the framework of the Planetary Boundaries, by using the criteria made?

Considering it said that DDT possibly could be detected in all living groups of biota (Turusov et al., 2002) and the studies that show detectable levels of DDT in the Arctic (AMAP, 2009), it would indicate a global distribution of the chemical. In addition to the mentioned toxic effects, where exposure to DDT could have an irreversible toxic impact on global biodiversity, and at the same time impact global food production and human health. With this DDT fulfills the criteria set in chapter 6.1, for a chemical that could be included in a planetary boundary.

Determining whether the current effects are at an irreversible global level or not is still difficult to say. It could be safe to say that DDT is longer in the space of safe operations, due to its distribution, proven effects and possible effects. With that in mind it can be said that DDT has crossed the boundary, but is more accurately in the zone of uncertainty.

Illustrated in Figure 5, this assumption is put in the context of Rockstöm et al. (2009). The category for chemical pollution is still unknown, but an own segment for DDT has been included. As indicated by the red segment for DDT, it is slightly above the planetary boundary, within the zone of uncertainty. This assumption is made on the indication that it is still unknown whether the levels of DDT used have had a large enough effect to have "tipped over" any known thresholds. The inconclusive literature on combined effects of DDT toxicity with other chemicals and environmental changes will, together with missing answers to human toxicity and honey bee populations determine whether sustainable DDT use is possible or if the levels are beyond global resilience.

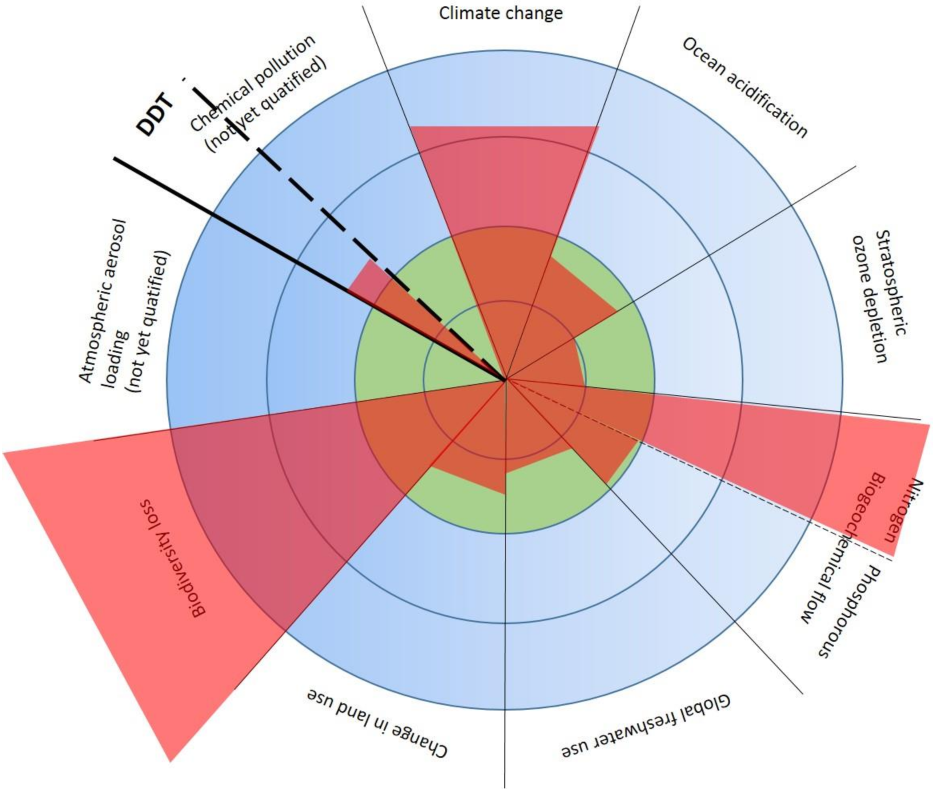

Figure 5: Planetary Boundary for DDT added to the original figure, with all nine categories of planetary boundaries. The green area is the safe operation space. The blue area is the zone of uncertainty. The red indicate the categories impact. The category chemical pollution is divided, to express that this level is an indication for DDT only. DDT is no longer within the safe operating space, green area, and is placed slightly beyond the boundary, beyond the outer green ring. Figure is adapted and developed from original figure by Rockstöm et al. (2009).

7 CONCLUSIONS

It is difficult to make any solid conclusions with many factors being inconclusive and speculative. The possible combined effect of several chemicals and other planetary boundary categories should be further investigated and monitored. Because of the lack of literature indicating present decline in populations due to mainly DDT, it cannot be concluded that DDT use is beyond a level of resilience, but indications are that several groups are still in risk of being affected. With the criteria it can be said that DDT is a threat on a planetary scale, and with its widespread occurrence and possible effects, it is clear that it is not within the space of safe operation, as indicated in Figure 5.

It is not however suggested to abolish the use of DDT as a mean in vector disease control, as the possible toxic effects should be evaluated up against the health benefits of the use in control of vector diseases. It should be mentioned that it is recommended that use of DDT would be only applied when and where most needed, and that other possibilities should be considered before engaging in IRS treatment of houses. The increase of immunity towards DDT makes it even more essential to further evaluate whether to make a shift in chemical treatment, to find an option with well-known toxic properties, or towards an increase of biological and environmental control, without causing large scale damage to the ecosystem.

As the Planetary Boundary framework indicates DDT *might* pose as a threat to sustainable development, and DDT and other chemical pollutants should be further investigated. Even with depleting levels and restoration of populations the previous use of DDT can still prove to have large scale effects.

Whether this result can be transferred to other chemicals or groups of chemicals can be further investigated. An attempt to conduct a planetary boundary for all chemical pollution could be made, by using the criteria the amount of chemicals to include could be reduced. Further development of the boundary for chemical pollution is recommended, to help the public and society to understand and to take action. The boundary could for example be divided into three segments;

- Chemicals with effects beyond resilience
- Chemicals with currently unknown effects, but indications of planetary threat (as for DDT)
- Chemicals within the space of safe operation

If presented with these three groups, a chemical appendix could be included to the framework, describing which chemicals are included and why. This is a suggestion for further investigation, to rethink how the boundary for chemical pollution could be made, as currently no literature reviewed has managed to assess one so far.

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