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Transfer of radiocaesium (^{137}Cs) to lynx (*Lynx lynx*) and brown bear (*Ursus arctos*) in Chernobyl affected areas in Sweden

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ABSTRACT

In this study, ^{137}Cs activity concentration was measured in 266 lynxes hunted in early spring during the years 2006-2011 in central and northern Sweden and in 161 bears hunted in the end of August until October during the years 2010 and 2011.

Highest activity concentrations of ^{137}Cs were observed in lynx and bear coming from counties with highest radiocaesium fallout after the Chernobyl accident. However, activity concentration of ^{137}Cs was higher in the animals of Norrbotten than in Värmland or Dalarna, where average deposition of the Chernobyl was at least threefold higher than that in Norrbotten.

Short-term study revealed no temporal trend of ^{137}Cs activity in the studied animals. Compilation of data obtained during this study with original data of 14 years study (1997-2003) conducted by Åhman et al. (2004) shown gradual decline of radiocaesium in lynx. However, the slope of decline varied substantially among the counties. Furthermore, the slope of decline tends to level off in the recent years for all counties.

No significant difference was observed in ^{137}Cs activity concentration between males and females of lynx and bear. Age class of lynx found to be a significant factor showing that adults tend to have higher activity concentration of ^{137}Cs than sub-adults. For age class of bear, the results were adverse; sub-adults had higher concentrations than adults did, although the difference was statistically insignificant.

Aggregated transfer factor (T_{ag}) was significantly lower in bear compared to lynx, while for both bear and lynx; T_{ag} values were significantly higher in Norrbotten than in rest of the counties. For lynx, T_{ag} values were also significantly higher in Västerbotten than in Dalarna, Gävleborg, Jämtland, Värmland or Västernorrland. Meantime for bear, Dalarna county have shown significantly higher T_{ag} than in Gävleborg, Jämtland, Västerbotten or Västernorrland.

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1. INTRODUCTION

Particular interest was given to ^{137}Cs (caesium-137) as the main anthropogenic environmental contaminant and human health threat, especially after the Chernobyl disaster in April 1986. Outside of post-Soviet territory, Sweden was the country that received the highest amounts of air born cesium, due to the current weather conditions at the time after the accident, mainly distributed over the central parts of Sweden.

Physiochemical properties of ^{137}Cs, reversibly binding to organic matter, facilitates its accumulation in the environment being an environmental issue for both natural and semi natural ecosystems. Moreover, a relatively long half-life of the element, 30.17 years, consolidates its persistence in these ecosystems. As a result, forest ecosystems are subject of high radiocaesium concentrations on all trophic levels. Several studies have been carried out to investigate governing factors of cesium transfer from soil-plants-mushrooms to game animals in natural ecosystems in order to clarify a trend of cesium accumulation in animals. The focus in these studies was mainly on such factors as radiocaesium deposition rate, diet of the animals or influence of individual habitat characteristics. Åhman et al. found in 2004 that high cesium variation in lynx, apart from mosaic cesium distribution, strongly related to season and diet of the animals on Chernobyl affected areas in Sweden. Skuterud et al. in 2004, on the other hand, focused on differences in cesium accumulation between females and males as well as between cubs and adults showing that adults tend to have higher activity concentrations than cubs. However, no significant difference where found between gender in this study. Moreover, both authors stated the importance of reindeer on radiocaesium concentration in lynx, showing that reindeer has a higher cesium concentration in winter than in summer.

No previous studies have been found concerning radiocaesium accumulation in brown bear *Ursus arctos.* However, some information is available for another omnivore, fox *(Vulpes vulpes L),* from a survey by Lowe and Horrill carried out in 1986-1987, which might be useful when analyzing the results in bear. Lowe and Horrill´s publication states that ^{137}Cs activity concentration in fox flesh is highly variable over time and space, from 24 to 4798 Bq kg^{-1} (f.w.). Main factors to this variation are sex, age, season and habitat area. Furthermore Lowe and Horrill found a significant difference ($P<0.001$) between male and female foxes, showing that males tend to accumulate radiocaesium to a higher extent than females (Lowe & Horrill, 1990). Therefore, in this paper we will investigate the same factors, affecting radiocaesium accumulation in fox, in bear to see if there are any similarities in ^{137}Cs accumulation.

Bear meat together with other products from natural ecosystems is often a part of human consumption in areas affected by the Chernobyl fallout. This can then act as a source of cesium exposure to humans in these areas. In order to prevent the population from increased risk of having adverse health effects from radiation, an upper limit of 1500 Bq/kg d.w. was set for products coming from forest ecosystems. This limit is five times higher than the limit, 300 Bq/kg d.w., set for products from agricultural areas field (Livsmedelsverket web, 2012). Even though food coming from forests appear quite rarely on our tables, certain groups of people such as hunters might be exposed to activity concentrations significantly higher than the upper limit of 1500 Bq kg^{-1}.

1.1 Aim

The aim of this study is to assess transfer and accumulation rates of ^{137}Cs in Lynx (*Lynx lynx)* and Brown Bear (*Ursus arctos*) in contaminated areas. In addition, we will try to find the role of gender, age and time on ^{137}Cs accumulation in lynx and bear. Finally, using T_{ag} values, we will examine a difference of ^{137}Cs activity concentrations in animals coming from the north of Sweden comparing to those of central Sweden.

Hypothesis:

- Expected decrease of ^{137}Cs in the studied animals with time.
- Significantly higher ^{137}Cs activity concentrations in lynx adults than in sub-adults.
- According to the previous studies, run on lynx and other game animals, gender is insignificant factor in radiocaesium accumulation.
- Lynx harvested in northernmost parts of Sweden have significantly higher T_{ag} values than in the rest of the counties.

2. BACKGROUND

2.1 Effects of radiation on humans

Effects of ionizing radiation on humans are associated with damage to DNA done by emitted particles or packets of energy from unstable nuclei. Despite the fact that human DNA has properties to recover, extensive damage may not be repaired causing production of an altered cell or its death. Therefore, the degree of adverse health effect depends on the dose of irradiation. Acute dose of irradiation, 3 gray or more, received by a part of the body part over a short period of time will probably cause noticeable damage to the part that was irradiated. Furthermore, lethal effects may appear after several months or less if, the whole body was exposed to radiation (International Atomic Energy Agency (IAEA), 2004 & Contemporary Physics Education Project (CPEP), 2003).

Low doses of radiation and its effects on humans are much more difficult to define due to absence of symptoms of irradiation. The symptoms will not be visible within a short time, however, in the end, it might contribute to the development of a cancer cell. Low doses are normally considered as doses below 10 mSv received annually, which is ten times higher than the average annual effective dose for an individual on earth (Hendee & Edwards, 1996).

2.2 Sources of radiation and background doses

The public often considers radiation as a fabricated environmental threat, which is partly true. However, radiation has always existed on earth in different forms. There are several natural sources on Earth, which in turn accounts for 80% of the total radiation that a human is exposed to (United States Environmental Protection Agency, 2007). Because of human activity, new and unstable (radioactive) elements have appeared that were previously not present on Earth.

Humanity is exposed to two main sources of radiation; natural and anthropogenic. Natural sources can be divided into terrestrial or cosmic depending on where radiation is originated. On the earth, prime radioactive elements are uranium (^{238}U, ^{235}U) and thorium (^{232}Th). Those elements are the prime sources of new elements that in turn are the source of alpha, beta and/or gamma radiation (*Appendix* 5). Protons, alpha-beta particles, or other high-energy particles emitted as a result of interaction between cosmic rays and atmospheric gases represent cosmic radiation. In natural sources of radiation, nuclear reactions appear spontaneously while in the other source of radiation, anthropogenic, all reactions are the result of human activity on earth (IAEA, 2004). This type of radioactivity is widely used for military, nuclear engineering, medical and other purposes due to its high potential energy possession. Strontium (^{90}Sr), iodine (^{131}I) and caesium (^{137}Cs) are the main products of fission of nuclear weapons and nuclear power in radioecology (Aakorg A., 2001). In turn, anthropogenic radiation consists of sub sources such as nuclear weapons testing, accidental release, controlled release, medical and research use. Nowadays, accidental release is the most dangerous and significant contribution of radiation into the environment with an example of the accidents in Chernobyl (1986) and Fukushima (2011). The role of nuclear weapons tests as environmental contaminator has decreased significantly since 1980, when the majority of the leading countries, with an exception of China, stopped testing bombs in the atmosphere Aakorg A., 2001).

In Sweden total annual dose for an individual amounts to around 4 mSv (*Fig.* 1). However, the dose might vary from human to human, depending on his/her activity features, as well as on geographical location within the country with an increase towards south-west of Sweden (Bergman et al., 1994**)**. For instance, people working at a nuclear power plant (NPP) receive relatively higher doses compared to the population in general. Average annual dose for a nuclear plant worker is about 2 mSv, not taking background radiation into account. Exceptions might occur in case of a single year exposure that can increase the dose up to 50 mSv. However, the average radiation dose from a NPP to the rest of the population, not involved in nuclear engineering or similar, fluctuates around 0.1 mSv year^{-1} (Vattenfall, 2010).

Another source of anthropogenic radiation is x-ray or other medical radiation related treatments, that according to Bergman et al (1994), accounts for about 15% (0.7-mSv year^{-1}) of the total annual dose. The natural sources, on the other hand, account for about 73% (3.5 mSv year^{-1} person^{-1}) with an absolute dominance of radon gas, accounting for ≈ 63% (3 mSv). In addition, people, consuming more products from natural ecosystems (mushrooms, game meat, fresh water fish etc.), can receive an extra dose of 1-2 mSv year^{-1} (Bergman et al., 1994).

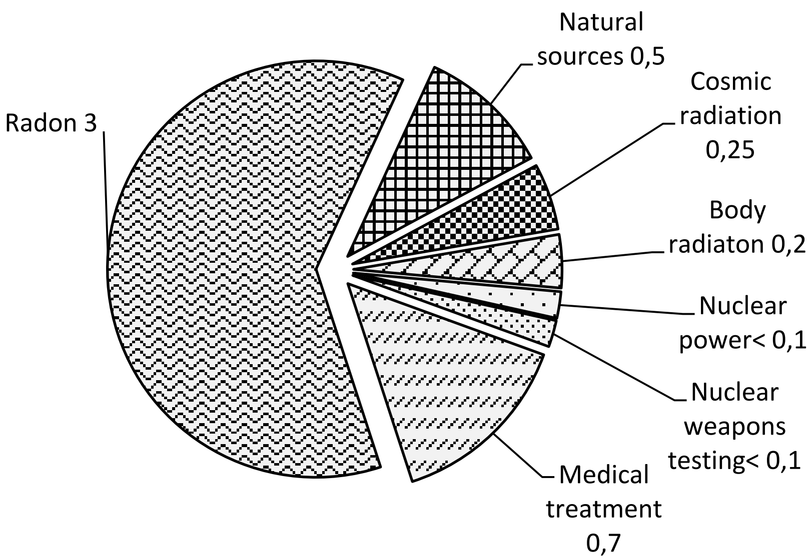


Fig.1 Dose contribution in mSv, from different sources of radiation, per year (Bergman et al., 1994)

2.3 Latest major nuclear accidents.

The most recent and significant, from any point of view, nuclear power plant accidents are thought to be Chernobyl in April 26th 1986 and Fukushima on March 11th 2011.

2.3.1 Chernobyl accident

On April 26 in 1986, two explosions appeared because of lack of “safety culture”, proper qualification and coordination of the staff. Moreover, “week”, from the security point of view, design of the reactor, destroyed reactor no. 4 at the Chernobyl Nuclear Power Station. Vast amounts of radionuclides burst into the atmosphere up to a height of 1 km. Heavy fuel particles fell down in the local area within a 30 km radius while lighter volatile particles, mainly noble gases, iodine and some cesium, were carried by winds up to great distances and were eventually brought down by different types of precipitation. Large emissions continued for about 10 days after the explosion, due to core melt down, but decreased significantly after another ten days when the graphite fire was finally extinguished (CPEP, 2003).

Core no. 4 in the reactor no. 4 contained about 40×10^{18} Bq of radioactive material. All inert gasses are thought to have been released which account for about $1.7\text{-}2 \times 10^{18}$ Bq (Boeker & Rienk van Grondelle, 2011).

Wind directions and local weather conditions defined the deposition of radionuclides such as ^{137}Cs and ^{134}Cs. Sweden received the highest fallout of radioactive matter in Europe. Deposition, on average, exceeded 37 KBq m^{-2} and was even higher in some parts of Gävle municipality reaching levels above 185 KBq m^{-2} (NEA, 2002).

2.3.2. Fukushima accident

The earthquake in the coastal area of Japan on March 11 in 2011 caused a tsunami that covered Fukushima Dai-ichi nuclear power station with its six water-boiling blocks, three of which were operating at the time. Even though the emergency cooling system was started right after the earthquake, it was soon put out of order by the following tsunami. Several explosions in the operating rooms of the working reactors, making it even harder to keep the situation under the control, aggravated the situation. As it was after the Chernobyl accident, the radionuclides of prime interest were again different isotopes of iodine and caesium (Walls & Livens, 2011).

According to “New Scientist” (2011) the levels of daily release of cesium and iodine from Fukushima, 50-60% and 74% respectively, are close to those released from Chernobyl. The main difference between these two major nuclear accidents was the extended fire on Chernobyl’s reactor block, which contributed to the continued release of radioactive materials into the atmosphere. At Fukushima, only volatile elements such as iodine and cesium were able to escape from the damaged reactors. The released amount from Fukushima was reported to be about $1.2\text{-}1.3 \times 10^{17}$ Bq day^{-1}, which was monitored by off shore monitor centers. The other difference between the nuclear plants is that Fukushima had 1760 tons of fresh and used nuclear fuel while Chernobyl had only 180 tons. In Chernobyl, the release ceased after 20 days, while at Fukushima the release lasted a much longer time (McKenzie, 2011).

2.3.3. Cesium fallout and distribution in Sweden after Chernobyl accident

A radioactive plum following the accident was taken by the winds, blowing north-west, and resulted in high levels of deposition in Scandinavia. When the cloud reached Sweden, wind direction switched to southward. Current weather conditions, at the time of cloud passage, characterized by low atmospheric pressure caused enhanced wash out by the rain. About 5% of the total cesium fallout from Chernobyl accident precipitated in Sweden. However, the distribution of cesium was uneven from the very beginning due to varying rainfall (Almond et al., 2009 & NEA, 2002). Further redistribution was facilitated by topography, presence or absence of snow on ground as well as type of vegetation it fell over. Where radioactive matter was deposited on snow-covered areas further redistribution was bound to happen due to subsequent snow melting where topography directed the water flow. Varying topography of a deposition area is as important on macro scale run off (square kilometers) as it is on micro scale run off (square meters).

A quite important role in radiocaesium redistribution, in addition to those mentioned above, plays the type and state of vegetation that intercept cesium radionuclides from the air. It was found that the retaining ability of coniferous trees is much higher than that of deciduous trees, due to a higher leaf area index (LAI). Additionally, at the time of deposition the LAI of deciduous trees had not reached full extension facilitating direct deposition on the understory. The main part of cesium that was intercepted by trees was soon lost due to physical weathering by wind or rain further redistributing the radiocaesium. The remaining part later fell down because of autumn defoliation, and only an insignificant amount was retained in the tree tissue (Bergman, 1994).

2.4 Forest ecosystems (boreal forests)

Boreal forests are the dominant biome in Fennoscandia. Ranging from latitude 56 to 69, boreal forests cover almost whole area of Sweden. The major species of trees in boreal forest are coniferous trees.

In general, forests are very complex natural ecosystems. Complexity is not only built on vegetation diversity, animal and other species presence, but also on their direct and indirect interactions. Multiple food chains and trophic levels with low human disturbance make this ecosystem quite different from any other. In fact, Europe is approximately by one third covered with forests (FAO, 2001). Unfortunately, some parts of this complex system favor the preservation of some radionuclides, having similar physiochemical properties as vital nutrients such as K and Ca (Bergman, 1994).

There are four main storeys in the boreal forest. Canopy of trees exposed to the sun or standing above other vegetation is called overstorey. Second level is the understorey - small trees with bushes, shrubs and herbs. The third storey is the organic layer, mainly consisting of mosses and different dead organic materials as an end product of living cycle (leaves, needles, wood residues etc.). Finally, soil, is the bottom layer of the forest where most of the microbial, chemical and physical processes are occurring. The process of humification is carried out with assistance of micro, meso and macro organisms such as microbes, worms, mites, fungi etc. All storeys in the forest are connected to each other and actively interact through the soil. The types of interaction in this ecosystem may range from mutualism to parasitism (Schell & Linkov, 2001).

2.4.1 Factors governing ^{137}Cs mobility in boreal forest soils and plants

The forms of ^{137}Cs in the forest soil might differ depending on its location. In a soil solution, ^{137}Cs may be as a free ion or in form of cesium hydroxide (CsOH). More often cesium binds reversibly having exchangeable state. Exchangeable state of ^{137}Cs is usually represented by binding to the negative site of the organic matter (OM) or its residuals. OM is decomposed by microbial and fungal activity gradually releasing cesium back to the media. Therefore, presence of the OM in boreal forests is one of the major key points of Cs mobility.

Irreversible binding to clay minerals is insignificant part of radiocaesium cycle in forests, which is simply due to the lack of clay minerals in forest soils. Irreversibly bound, ^{137}Cs can also be released with time by the processes of physical and chemical weathering of the soil. Rate of weathering in turn depends on several factors such as soil pH, redox potential, and physiochemical properties of the soil, presence of OM or microbial activity (Oughton and Salbu, 1994). More information on physiochemical properties of ^{137}Cs is given in *Appendix* 4. The other factor determining cesium mobility in the soil is presence of nutrients available for plants. It is widely known that forest soils are nutrient poor. Therefore, a plant lacking essential nutrients, such as K, uptake elements that have similar characteristics - ^{137}Cs. Uptake of ^{137}Cs by plants or fungi redistribute it above ground afterwards as a secondary contamination (Giannakopoulos et al., 2011). As a result, this facilitates long-term cesium cycling in the forest ecosystem.

Finally yet importantly, ^{137}Cs is cycling within a living fungal biomass, due to the similar properties with potassium, which represents significant part of radiocaesium in forest soil pool (Shaw, 2007).

2.4.2 Soil-plant-animal transfer of ^{137}Cs in forest ecosystem

Unless ^{137}Cs is irreversibly bound to clay minerals, it cycles from the soil to plant or tree and falls down by defoliation, after what ^{137}Cs is exchangeable bound to the humus. Again, plants uptake ^{137}Cs by same mechanisms as it does uptake potassium. Furthermore, more than 90% of the ^{137}Cs stays within upper 5 cm of the forest soil being available to the plants (Shaw and Bell, 2001). Olsen (1994) have observed enhanced radiocaesium uptake by fungi, which was reported by many other researchers. The levels of ^{137}Cs activity in fruit bodies of fungi compared to vascular plants may be up to 100 times higher. Uptake rates vary between different species of vascular plants as well as among fungal species (Olsen, 1994).

Contaminated vegetation, mushrooms and lichens are primary food for all herbivores and omnivores. Feeding on contaminated herbivores thus results in exposure also to carnivores. Contaminated herbivores will consequently affect humans, especially hunters, consuming meet of game animals.

There have been numerous studies to assess transfer factors from soil to plants, plants to animals. However, quite large uncertainty is related to the soil-plant-animal dynamics of radiocaesium and other radionuclides. Apart from the uneven distribution of ^{137}Cs, species and genera of plants and fungi play a major role in uptake of radionuclides. Consequently, there is no single transfer factor, which can be assigned for all plant and mushrooms species and genera. However range values were presented by Rolf A. Olsen showing that in acid soils of forest ecosystem transfer factor (T_f) , from soil to plants, varies from 0.08 to 0.3 $m^2\ kg^{-1}$ of dry weight (Olsen, 1994).

Aggregated transfer factor (T_{ag}) is another way to calculate transfer factors, and is simply the relation of ^{137}Cs activity concentration in meat (Bq) to the concentration per square meter of soil. Aggregated transfer factors for game animals, similar to soil-plant transfer factors, show strong temporal and spatial variation. Such aspects as animal diet, seasonality, density and homogeneity of radiocaesium deposition contribute dramatically to the end T_{ag} value. Karl J. Johanson observed factors of caesium transfer to moose and roe deer being 0.01-0.03 and 0.03-0.14 $m^2\ kg^{-1}$ respectively (Johanson, 1994). These T_{ag} values suggest that activity concentration of ^{137}Cs in meat of other game animal or birds will probably differ even more to that of moose and roe deer due to different habitat and diet utilization. Many authors have reported that roe deer having access to agricultural areas have much lower activity concentrations of ^{137}Cs than roe deer feeding only in forest areas (Johanson, 1994 & Karlen et al., 1990).

2.4.3 Cesium transfer and accumulation in lynx

Factors governing ^{137}Cs transfer to lynx are primarily those applied for herbivores, - seasonality, diet and ground deposition. Seasonality has direct and indirect effect on radiocaesium accumulation in the lynx body. Mushroom season, August–September, is a time when lynx has the highest ingestion rate of radiocaesium over the year due to roe deer feeding preferences on mushrooms (Karlen & Johanson, 1990). Mushrooms can also be consistent as a considerable part of other herbivores diet such as a reindeer that, in turn, will increase ^{137}Cs activity in lynx (Skuterud et al., 2009). Direct seasonal influence might be a change of the preys' habitat or its periodical migration that force lynx to switch to smaller and more available food. Changes in the diet, therefore, presume change in the ingestion rates of cesium (Odden et al., 2006). Odden et al. (2006) has also found the that amount of roe deer in lynx diet were higher in winter than in summer suggesting that it is easier for lynx to prey on groups of roe deer which cluster around supplemental feeding sites.

After a study carried out during 1996-2001, Åhman et al. (2004) presented data of aggregated transfer factors (T_{ag}) for Swedish lynx. In areas with absence or low density of reindeer T_{ag} values were lower than in areas of reindeer herding showing values between 0.16-0.28 and 0.48-1.1 m^2 kg^{-1} respectively. In addition, they found average value for concentration ratio (CR) between lynx and prey being 1.3 for roe deer and 2.6 for reindeer. These values assume higher levels of cesium in predator than in prey. More than that, the biological half-life of ^{137}Cs in predators, according to different literature sources, is longer than that in herbivores and might range from 22 to 35 days (Mohn and Teige, 1968 & Holleman and Luick, 1976). As a contrast, many herbivores have only 7 to18 days for summer and winter respectively (Holleman et al., 1971). Biological half-life is the time by which activity concentration of ^{137}Cs in body of an animal is reduced by half. To find this time it is necessary that the animal be supplied with non-contaminated food after activity concentration has been measured.

Other similar term that is used in this paper is effective ecological half-life of ^{137}Cs. The difference from the biological half-life is that effective ecological half-life counts for reduction of ^{137}Cs activity concentration caused by immobilization and self-decay of radiocaesium in the ecosystem.

2.4.4 Agricultural ecosystems in comparison to forest ecosystems.

The difference between these two ecosystems is vast in many aspects. Agricultural land is by far a less complex ecosystem than a forest. Agricultural land is continuously disturbed by human agricultural activities. As a result, an upper organic layer is absent, contrary to a forest ecosystem, which is why nuclides are distributed directly in the upper soil layer at time of deposition. In case of crops growing, at time of deposition, a majority of contaminants will be deposited on the plants, while the amount of intercepted nuclides depends on the leave area index (LAI). The remaining part of deposition will eventually be brought down to the soil by physical weathering or with plant residues. Lack of multilayers or storeys in agricultural ecosystem presumes reduced time of nuclide redistribution to soil from plant.

Due to periodically improving of physiochemical properties of arable soils by cultivation and fertilization, agricultural ecosystems have higher nutrient levels than forest soils. Therefore, as long as ^{137}Cs is present in soil in cationic form, - higher pH, cation exchange capacity (CEC), clay content, mineral and oxide presence will decrease mobility of radiocaesium and in turn reduce uptake of nuclides by plants. Furthermore, cultivation of arable soils redistributes nuclides within the soil profile diluting the levels available for plant uptake. Because of ploughing, radionuclides migrate deeper in to the arable soil than they do in forest soil. From the report of Bunzl (1987), the migration of radiocaesium to one meter depth, in arable soils, is ranging from 150 to 4500 years. Variation of migration speed mainly depends on soil properties mentioned above. However, nuclides can be found down to 20 cm depth already after first soil cultivation (Shaw and Bell, 2001).

Unlike to the forest ecosystem, for agricultural field, several countermeasures can be applied in order to decrease radiocaesium availability to plants (Strebl et al., 2007).

2.5 Lynx *(Lynx lynx)*

Lynx is the third biggest predator in Sweden after wolf and bear. However, lynx is the second most common predator, not counting human, due to the low population of wolfs. Population of lynx in Sweden is estimated to be, according to several sources, around 1500 individuals, which is the largest population among Nordic countries. Wolf, as comparison, is present at a few hundred individuals (André et al., 2002; Swedish Wild Life, 2012).

Color of the lynx fur is varies from light to mild brown with gray tint. Body size is ranging from 15 to 30 kg with a trend of bigger males than females. Mating season starts by the end of the winter and last until mid-spring. It takes about 67-74 days before the female gives a birth, to normally 2-3 kittens. For the next 10 months, until the mating season, kittens stay with their mother reading weights of 9-14 kg. Two years after female kittens were born; they are ready to reproduce while the males usually need one more year to be sexually mature. Upper ages for lynx are approximately 17 years. Furthermore, according to the WWF, due to high mortality only half of the juveniles will become adult, despite the fact that lynx does not have any natural enemies; human hunting not considered (WWF, 2000).

2.5.1 Habitat

The distribution of the lynx is wide throughout the Central Europe including Nordic countries, Russia and central Asia while Western Europe seems to be the least populated by lynx. In Sweden, lynx is found in majority of counties, especially in the northern and central areas. Nowadays, there is an expanding trend of lynx population moving southward to its formerly colonized areas (Swedish Wild Life, 2012).

2.5.2 Home range

Lynx has an enormous home range, which may vary by a factor of 10 in different study areas of Europe being larger for males than for females. According to the WWF (2000), home ranges vary from 60 to 760 km^2. Other observation, made by researchers from Norway and Sweden, reported home ranges for males and females to vary from 600-1400 and 300-800 km^2 respectively (Linnell et al., 2001). Ivar Herfindal et al. (2005) found similar results - mean value for male 625 km^2 with standard deviation of 509 km^2 and for females 319 km^2 with 231 km^2 of standard deviation. Home ranges depend on prey density, prey composition and habitat type, e.g. increasing home range with decreasing prey density (Herfindal et al., 2004).

2.5.3 Diet

Lynx diet is quite dependable as well as variable. Density of the prey and its composition seems to be the major factors defining lynx prey choice. Lynx feeds on prey ranging from the size of a mouse to a moose. However, preferable prey is small to medium sized ungulates such as roe deer and chamois (Odden et al., 2006). Reindeers are bigger and not always possible for inexperienced juveniles to kill. Another source stated that reindeer was the most frequent food (90%), from both scats and skull analysis (Pedersen et al., 1999). The reason for that may probably be high density of reindeers due to herding. In addition, it was found that lynx kill approximately one ungulate every five days, when ungulates are the only available prey (Kwam & Johansson, 1998; Pedersen et al., 1999). This confirms the findings of Mohn and Teige (1968), saying that lynx needs about 2 kg of fresh meat daily (in fresh weight) or one average sized roe deer per 5 days. Other sources states similar findings saying that lynx need about one roe deer per week or around 60 per year (WWF, 2010).

When the density of preferable prey is decreasing lynx switch to smaller size catch such as hares, birds and/or rodents (Odden et al. 2006). However, it has not been found at what density lynx switch to smaller prey. As a small prey, hare, probably is most popular while among birds, black grouse *(Tetrao tetrix)* and capercaillie *(Tetrao urogallus)* were found to be the most preferable by lynx (Odden et al. 2006). One more thing that should be added to clarify lynx prey choice is how seasonality affects habits of both predator and prey. For prey, it is first of all migration during the summer or other seasons of the year decreasing its density. As a response, lynx increase it home range but do not follow migrating animals. That in turn forces lynx to switch to smaller available prey or, more unusually, kill of some encountered domestic or semi-domestic animals such as sheep, pigs etc. It is also known that lynx consume about 100% of the smaller prey while 20 to 50 % of killed ungulates might be left uneaten. Furthermore, it has been found that prey which lack defending instincts, is often killed as an accidental encounter and is in most cases left uneaten (Odden et al. 2006).

Despite the fact that diet of lynx is quite variable, the main preference of lynx are roe deer and reindeer, usually constituting more than 60% of the lynx diet (Skuterud et al. 2004).

2.6 Brown Bear *(Ursus arctos)*

Brown bear belong to the taxonomical group of carnivores. In addition, it is one of the biggest animals in Sweden along with moose. Males are heavier than females by a factor of 1.2-2.2 varying from 80 to 150 kg and 180-310 kg for females and males respectively (Schwarz et al. 2003). Highest bear weights are found during hibernation period, which is characterized by intensive feeding which can add up to 40% of extra weight. Hibernation lasts from October to April. After hibernation, in mid of May, does the mating season start, which continues until the beginning of July (Dahle and Swenson, 2003). Females become sexually mature at the age of 4-5 and at the age of 27 females undergo reproductive senescence (Schwarz et al. 2004). However, according to other sources (Swenson et al. 2001 and Zedrosser et al., 2006) both females and males become sexually mature at age of three. Normally 1-3 cubs are born in the period of mid-winter to the beginning of spring. Cubs separate from the mother after approximately 1 year even though 2.5 years has been observed as a highest limit in Scandinavia. Life expectancy is about 30 years at the most (Schwarz et al. 2003, Swenson et al. 2001).

The population trend of brown bear started to increase slowly from 1913 when it was no more allowed to hunt bear on Crown land. During the 1980’s the population grew from 15 to 49 individuals. By the year 2004 the population consisted of approximately 1635 to 2840 individuals having an annual increase of 4.7% (Scandinavian Brown Bear Research Project, 2004), which is in agreement with Kindberg (2010) that found an annual increasing trend between 1998 and 2007 to be 4.5%. However, estimated population of brown bear in Sweden, according to Kindberg (2010) varied from 2968 to 3667 individuals for the year 2008.

2.6.1 Habitat

Brown bear is the most common and widespread bear in the world found in different types of habitat such as tundra, different forest ecosystems and even deserts (Swenson et al. 2000). However, large populations are mostly found in eastern or northern Europe. Even though brown bear are spread throughout most of Sweden, they are normally not observed by humans due to their shy and secretive behavior.

2.6.2 Home range

Home range varies among individuals as well as between genders being larger for the males. Dahle and Swenson (2003) estimated home range for females to be around 200 km^2 while for adult males it was over 1000 km^2. In agreement to that, Dahle et al. (1998), reported home ranges of 400-500 km^2 for female and 1400-1500 km^2 for males. Furthermore, male ranges might be extended in case female absence in the area.

2.6.3 Diet

The brown bear is a typical omnivore, which is why diet may vary from small insects or berries to a moose. In diet preference of bear, a clear pattern of seasonality is evident. In the period just after hibernation, ungulates, mostly carrion, are the most frequent diet. During the summer , is the diet dominated by ants, forbs and ungulates as reindeer and moose, while in autumn, berries such as crowberry, bilberry etc., are the main food in Sweden. Quantitatively, berries account for about 50% of an annual diet, while up to 30% of the bear diet consists of ungulates. The rest of the diet comprises of insects, 14-22%, and graminoids, 12-18% (Dahle et al. 1998).

3. MATERIALS AND METHODS

3.1 Study Area

Main fallout of ^{137}Cs coming from CNPP took place in central parts of Sweden. Among the most affected counties are Gävleborg, Västerbotten, Västernorrland, Uppsala and northern part of Jämtland. Therefore, in this paper, focus will be brought to the samples taken from these counties. In addition, a couple of regions with low radiocaesium deposition were included in the study in order to compare trend of radiocaesium behavior in relation to those highly contaminated areas. The least contaminated counties in central Sweden include Dalarna, Värmland and southern parts of Jämtland (*Fig.* 2*)*. Data on depositions rate of ^{137}Cs in central and northern part of Sweden in 1986 is presented in *Appendix* 3 with decay correction to the later years.

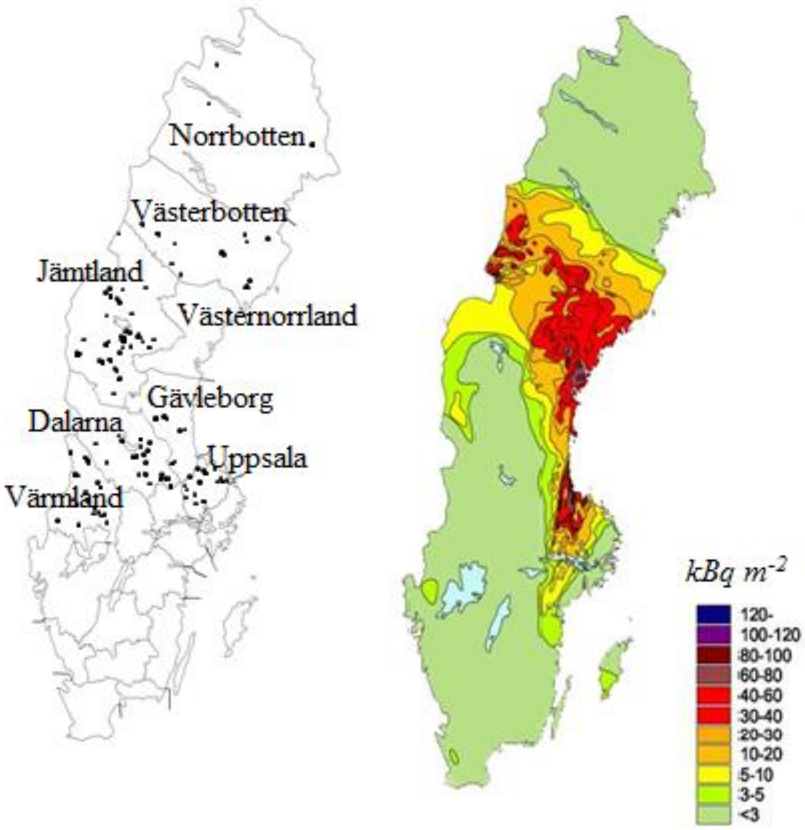


Fig.2 Investigated counties with harvested animals and fallout of ^{137}Cs in Sweden after Chernobyl accident in 1986 (kBq m^{-2}). Picture from SNA (http://www.sna.se/webbatlas/kartor/kopia/cesium_137_efter_tjernobyl_86.html)

3.2 Sampling

266 lynx samples were taken during hunting season from 2006 to 2012 while for bear 161 samples were taken in period of 2010 and 2011 (Table 1). Open season for hunting of lynx may slightly vary being beginning of the spring to April while for the brown bear it is in autumn. After the animals were shot, their bodies were registered by county board officials and sent to National Veterinary Institute (SVA) in Uppsala for further examination. Front-leg muscle samples were also sent to SLU in a plastic bag with an ID on it. The rest of the information, - sex, age, date it was taken on were obtained from SVA home page later on.

Table 1. Numbers of annually harvested animals (lynx and bear) in northern and central Sweden in the period of 2006-2011.

Animal/Year	2006	2007	2008	2009	2010	2011
	Number of samples each year					
Lynx	42	23	26	13	75	87
Bear					34	127
Total					Lynx	266
					Bear	161

To prepare samples a 60 ml (Cerbo 60) plastic container was used (*Fig*. 3). The meat samples were cut into smaller pieces to fill container up till 90-100%. Moreover, activity concentration of ^{137}Cs does accumulate equally in all muscle tissue. Muscle tissue accumulates about 10-50% higher activity concentration of radiocaesium than organs and other tissues (Åhman et al., 2004). Therefore, thorough separation of other than muscles tissue (e.g. hair, fat, glands and tendons) is required to decrease measuring error. After filling, the containers were labeled on the lid with basic data (code, year, county, sex, date of sampling and net weight), and afterwards kept frozen until the measuring day.

Fig.3 (a) Obtained muscle sample of lynx from SVA with an ID; (b) example of prepared sample.

3.3 Gamma spectroscopy

Meat samples were analyzed for ^{137}Cs activity concentration through gamma spectroscopy using a High Purity Germanium detector - HPGe (*Fig*. 4). HPGe belongs to semiconductor detectors that are based on a solid-state device made by highly refining the element germanium and growing it into a crystal. Attachment of negative and positive contacts creates an electronic diode that can transform energy of gamma ray into the similar current with extremely close values (Miglierini, 2004).

The detector must be kept under cryogenic temperatures (<150℃). Therefore, regular refill of liquid nitrogen is required in order to avoid damage on the detector. HPGe is shielded with led walls of 20-25 cm in order to prevent influence of background radiation. Furthermore, detectors undergo weekly calibration as well as monthly adjustment to a background radiation in order to reduce errors. Time for analyze may vary, however, after three hours, samples were checked and in case of high uncertainty, > 5%, measurement continued.

Apex software was the tool handling the detection process. This program recalculates activity concentration of ^{137}Cs in the meat to the date the animal was shot. In addition, software was set to give activity concentration values per kilo.

Fig.4 Gamma detectors used for ^{137}Cs measurement in the animals.

3.4 Data analyzes

Number of samples is varying between the counties as well as years, which is why not all of them are considered as representatives of a county or a year. Thus, counties with highest number of samples were chosen. Due to the large variation, data were $\log_{10}$ transformed before statistical analyses that were performed in Minitab 16. Major focus was made on general linear model (GML). Log ^{137}Cs activity concentrations in lynx and bear were used in GLM versus year; county; gender and age class to test whether there was a significant effect by any of these factors on ^{137}Cs activity concentration in the animals. The animals were categorized into corresponding groups (adult, sub-adult and male female). Age group of sub-adult was considered to be ≤ 2 years while adult >2 years for lynx. Bear has different age groups being >3 years for adults and below as a sub-adult.

Similar to ^{137}Cs activity concentration, T_{ag} values were used in GLM against year; county; gender and age class to estimate significance of these factors on transfer of ^{137}Cs to the animals. T_{ag} values were calculated for each of the animals by dividing ^{137}Cs activity concentration in muscle with average ground deposition of the county an animal was shot. Original data on levels of radiocaesium ground deposition in 1986 was obtained from Åhman el al 2004.

For a long-term of 14 years, which is a combination of data from current study and the study conducted by Åhman el al 2004, linear regression was performed for each of the counties in order to estimate effective ecological half-life of ^{137}Cs. For data obtained during this study, one-way analysis of variance (ANOVA) was used to find which of the years is significantly different from the others. In all cases, 95% confidence interval was chosen. In addition, post hoc with pair wise comparison was performed using Tukey’s method. Descriptive statistics we are looking for are p-value, r-square, confidence interval (CI), mean, standard deviation (St.dev) etc.

4. RESULTS

4.1 Lynx

Activity concentration of ^{137}Cs in lynx varied from 11 Bq kg^{-1} (Jämtland, 2011) to 6750 Bq kg^{-1} (Västernorrland, 2011). In general, highest activity concentrations of ^{137}Cs are found in lynx from the areas most affected by the Chernobyl fallout: Västerbotten, Västernorrland, Northeast of Jämtland, Gävleborg and Uppsala. Lynx samples originating from Värmland and Dalarna showed the lowest average values (*Fig.* 5*)*. More data with corresponding number of samples, minimum and maximum values are presented in *Appendix* 1. It is, however, evident from the data analysis that animals coming from the same county with relatively homogeneous ground deposition areas have substantial variation of radiocaesium levels. That, in turn, suggests presence of other factors influencing levels ^{137}Cs activity concentration in lynx.

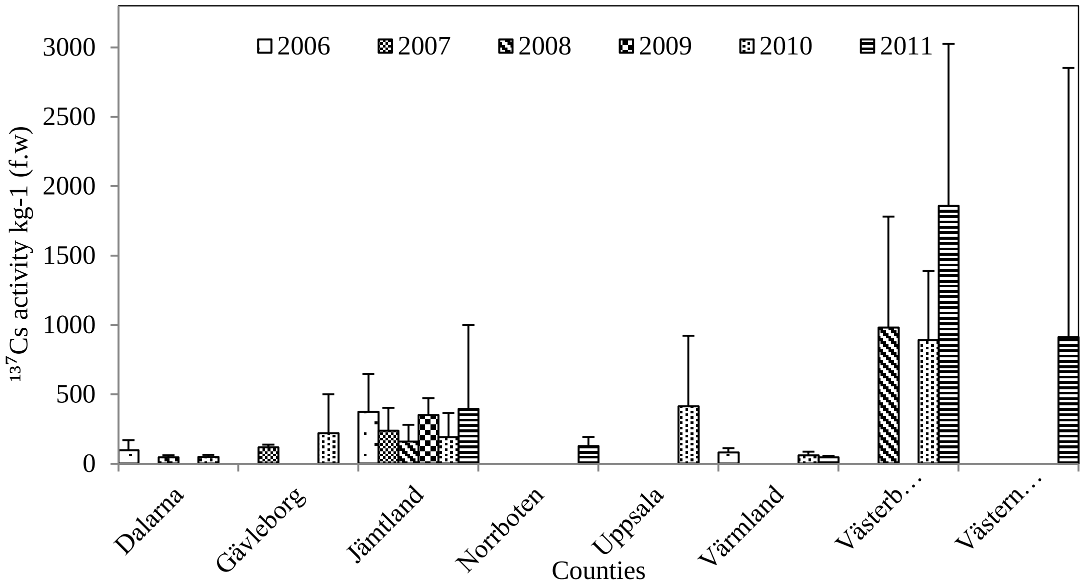


Fig.5 Lynx average ^{137}Cs activity concentrations (Bq kg^{-1}), with standard deviation, in counties of central Sweden during 2006-2011.

Factors influencing 137Cs activity concentration in lynx.

Two-way analysis of variance using general linear model was carried out to study influence of such factors as county, year, age class and gender on levels of ^{137}Cs activity concentration in the lynx. Simulation of these factors against log activity concentration of ^{137}Cs revealed that county and age class have a significant effect on levels of ^{137}Cs in the lynx (P<0.0005; P=0.002). Further analysis of age class showed that adults had significantly higher activity concentration of ^{137}Cs than sub-adults. Year and gender were found to be insignificant factors (P=0.051; P=0.49). Despite the fact that year analysis showed probability nearly fitting CI of 95%, H_0-hypothesis yet cannot be rejected because the error is still greater than 5%.

Temporal behavior of ^{137}Cs in lynx.

No statistically significant trend of ^{137}Cs activity concentration in lynx was observed in any of the counties using linear regression. Similar results were obtained by general linear model that again confirmed year to be insignificant factor (*P*=0.051). Additionally, in majority of the counties, due to low R-values (<0.20), one-way analyses of variance were used instead in order to find which years differ from each other. Jämtland county (*Fig.* 6*)* with a largest sample size of 109 (2006-2011) is a good example of trend absence (*R*=0.054, *P*=0.66).

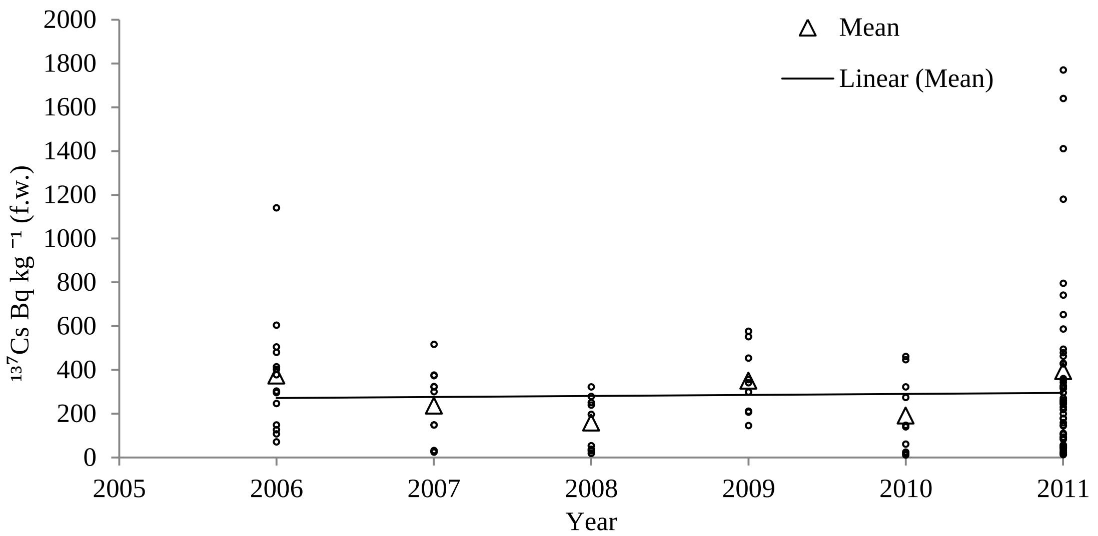


Fig. 6 ^{137}Cs activity concentrations (Bq kg^{-1}) in lynx meat in Jämtland county during 2006-2011 with a number of samples 14, 11, 9, 10, 10 and 55 respectively where each dot represent one sample.

Significant difference between the years was only observed in Dalarna county (Fig. 7), which has relatively lowest initial ground deposition among the counties investigated. Analysis of variance has shown that at least one of the years significantly differs from the others (*P*=0.022). Performing post hoc test with pair wise comparison using Tukey's method we found that activity concentration of ^{137}Cs in 2006 is significantly lower than in 2010, 46 and 76 Bq kg^{-1} f.w. respectively.

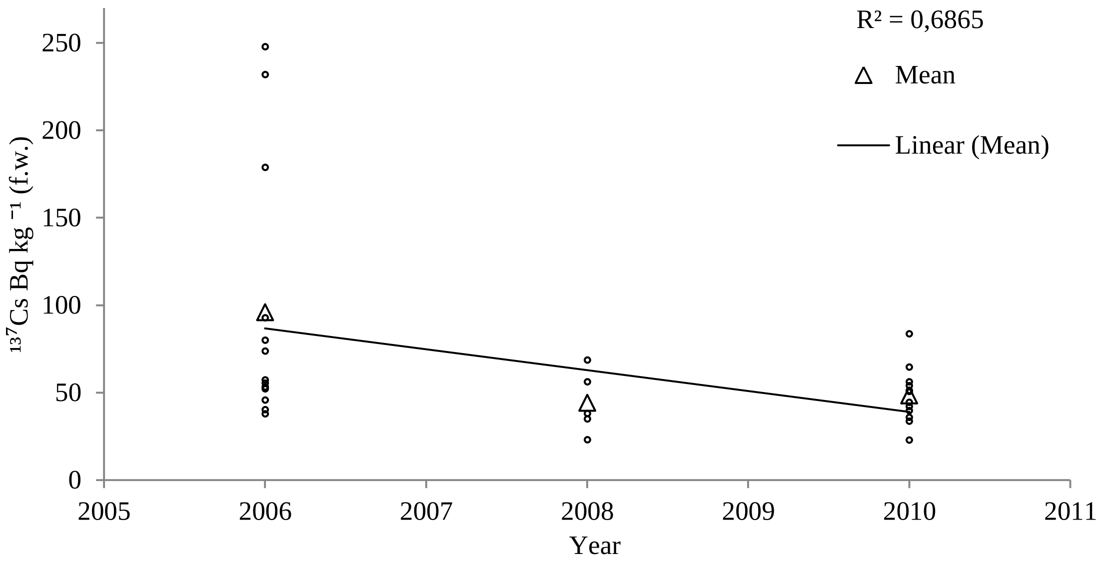


Fig.7 ^{137}Cs activity concentrations (Bq kg^{-1}) in lynx meat in Dalarna county during 2006-2011 with a number of samples 13, 5, and 12 for 2006, 2008 and 2010 respectively.

Despite the absence of a short-term trend in all of the counties, long-term plot showed that there is a significant declining trend over the 14 years, starting from 1997. Data obtained from the previous studies, conducted by Åhman et al. 2004, was compiled with data from current work. Performing regression, five out of six counties, Gävleborg, Jämtland, Norrbotten, Värmland and Västerbotten, showed statistically significant decline of ^{137}Cs concentration in lynx muscles (P<0.05) during the period of 14 years. However, slopes of decrease vary within the counties having different ecological half-life. Following corresponding linear regression equations, for both Jämtland and Västerbotten, ecological half-life was estimated to be 7 years. Värmland and Gävleborg have shown even shorter ecological half-life of 4 years. Norrbotten, unlike the rest of counties had longest half-life of 12 years, although number of samples for this county was the smallest.

Exception was Västernorrland, where we did not observe any significant trend during the 14 years. It is important to mention that this county had extremely high data variation ranging from 90 to more than 15000 Bq kg^{-1} f.w.. Additionally, larger sample size was obtained for the latest years of 2010 and 2011.

The most consistent data set, for the period of 14 years was available for Jämtland, 362 + 109 samples. R-value of 0.80 and P-value <0.005) gives reasonable evidence of veracity of the slope of ^{137}Cs in lynx in this county (*Fig. 8*).

Absence, for the short term, of declining radiocaesium trend suggests that decrease of ^{137}Cs in lynx is leveling off.

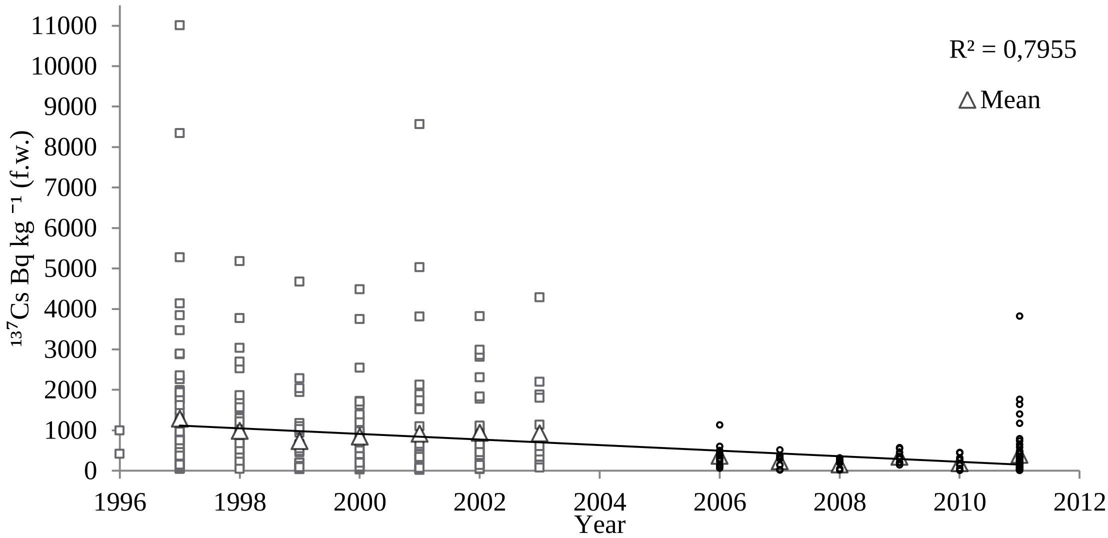


Fig.8 Concentrations of ^{137}Cs (Bq kg^{-1}) in lynx muscle over 14 years, 1997-2011, in Jämtland county. Line is a fitted average linear regression. Data from 1997-2003 was obtained from a previous study by Åhman et al. 2004.

Aggregated transfer factor

Similar to log activity concentrations, T_{ag} values were used in general linear model versus year, county, gender and age class in order to investigate their effect on transfer rate of ^{137}Cs to the animals. Results revealed that county and age class have a significant effect on the ^{137}Cs transfer rates (P<0.0005; P=0.048). Obtained T_{ag} values were significantly higher in Norrbotten and Västerbotten than in the other counties, although significantly different from each. For the rest of the counties T_{ag} values did not differ significantly among each other.

The other significant factor was found to be age class. Transfer rates of ^{137}Cs, or T_{ag} values were significantly higher for adults than for sub-adults. Year and gender were insignificant regarding transfer rate (P=0.123; P=0.062). However, T_{ag} values obtained during this study were significantly lower than the values reported by Åhman et al., (2004). Range of T_{ag} values with means for the years 2010-2011 is presented in table 2.

Table 2. Aggregated transfer factor ranges for lynx with mean values during 2010-2011, where n- number of samples

County	2010			2011		
	T_{ag} range	T_{ag} mean	n	T_{ag} range	T_{ag} mean	n
Gävleborg	0.005-0.1	0.025	8	-	-	
Jämtland	0.002-0.08	0.034	10	0.003-0.7	0.075	55
Norrbotten	0.25-0.39	0.35	3	0.14-0.6	0.37	8
Värmland	0.03-0.12	0.054	20	0.03-0.05	0.04	6
Västerbotten	0.04-0.18	0.09	6	0.03-0.4	0.2	10
Västernorrland	0.03-0.1	0.06	2	0.004-0.33	0.04	11

4.2 Bear

Measurements have shown that brown bear tend to have significantly lower values of ^{137}Cs activity concentration than lynx (P<0.005). Furthermore, variation of activity concentration is noticeably lower for bear comparing to that of lynx. Similar to lynx, highest radiocaesium activity concentrations were found in animals coming from the areas most affected by Chernobyl's fallout such as Västerbotten and Västernorrland *(Fig.* 9*)*. However, highest activity concentration of ^{137}Cs in brown bear is yet by threefold lower than in lynx. Total number of samples for these two years is not equal being 34 in 2010 and 129 for 2011. More information on ^{137}Cs activity concentrations in bears is presented in *Appendix* 2.

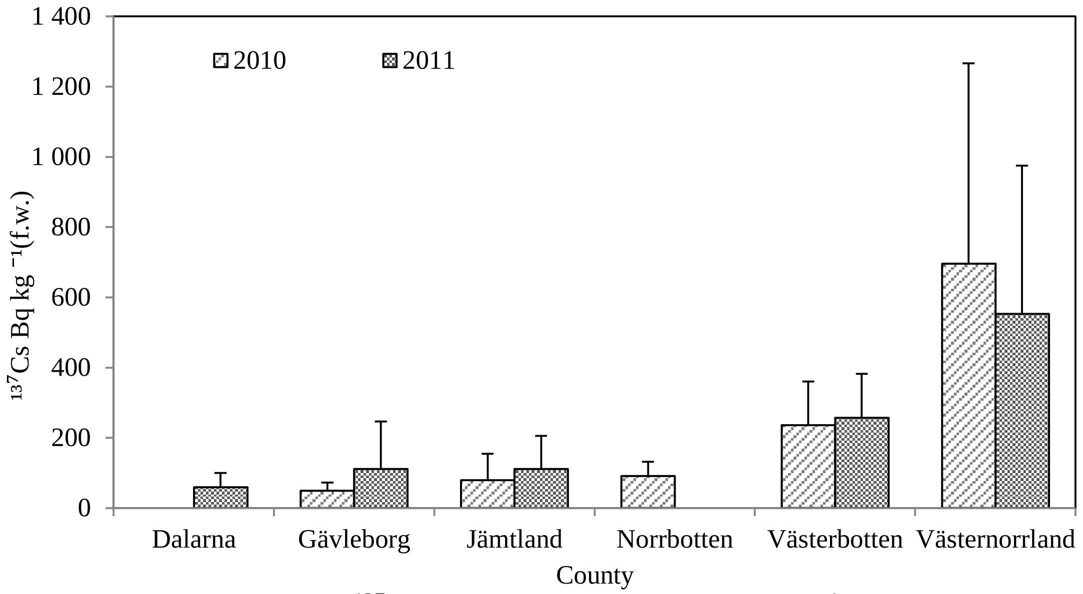


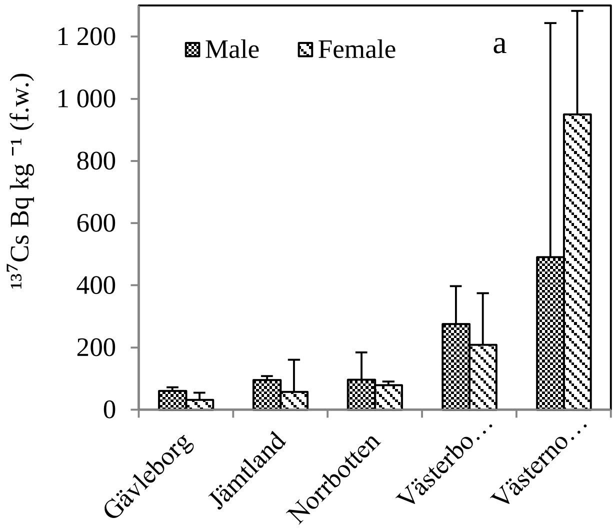
Fig.9 Brown bear average ^{137}Cs activity concentrations (Bq kg^{-1}) with standard deviation in counties of central Sweden 2006-2011.

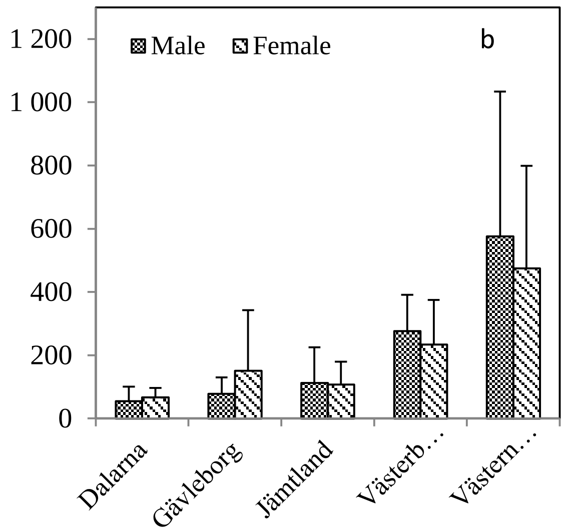
Factors influencing ^{137}Cs activity concentration in brown bear

Using the same linear model, we plotted log activity of ^{137}Cs in muscles against year, county, gender and age class. Similar to the lynx results, county factor was significant regarding levels of radiocaesium in bear (P<0.005). Västernorrland and Västerbotten significantly deviate from the other counties. Data analysis of age class has shown that, unlike to the lynx results, bear adults tend to have lower activity concentration of ^{137}Cs than sub-adults. However, the results were statistically insignificant (P=0.17). Similar insignificant results were obtained for "year" showing that in 2010 activity concentration of ^{137}Cs in bears was higher than in 2011.

Gender, has one more time shown its insignificance (P=0.68) on level of radiocaesium in bear. Male and female comparison is presented in fig.10.

Due to the absence of sufficient data for bear, analysis of temporal behavior of ^{137}Cs in bear was limited.





n= 5, 9, 6, 5, 9 n= 29, 34, 30, 19, 17

Fig.10 Mean ^{137}Cs activity concentrations (Bq kg^{-1}) in males and female brown bear, with standard deviation, in counties of central Sweden, (a) 2010 and (b) 2011, where "n" is number of samples per county.

Aggregated transfer factor

Data analysis revealed that county as factor has a significant effect on transfer rates of radiocaesium to the bear ($P<0.005$). Norrbotten had significantly higher T_{ag} values, with a mean of 0.27, than the rest of the counties. Additionally, significantly higher T_{ag} values were found in Dalarna (0.05) than in Gävleborg, Jämtland, Västerbotten and Västernorrland, although still significantly lower than in Norrbotten. Means as well as range for each county are presented in table 3.

Table 3. Mean aggregated transfer factors for brown bear in central Sweden 2010-2011 with standard deviation, where n- number of samples.

County	2010			2011		
	T_{ag} range	Mean-St.dev	n	T_{ag} range	Mean-St.dev	n
Dalarna	-	-		0.02-0.18	0.05±0.033	29
Gävleborg	0.003-0.007	0.006±0.003	5	0.004-0.07	0.01±0.016	34
Jämtland	0.007-0.05	0.014±0.013	9	0.004-0.09	0.02±0.017	30
Norrbotten	0.05-0.42	0.27 ±0.111	5	-	-	
Västerbotten	0.008-0.04	0.024±0.013	9	0.008-0.06	0.026±0.013	19
Västernorrland	0.004-0.1	0.033±0.027	6	0.002-0.06	0.026±0.020	17

5. DISCUSSION

5.1 Lynx

Factors governing variability (or accumulation) of ^{137}Cs activity concentration in lynx.

Activity concentration of ^{137}Cs in lynx muscle tissue is varying widely, from 11 to 6750 Bq kg^{-1} fresh weight (f.w.), within as well as among counties. Heterogeneous deposition and further redistribution has created highly variable levels of radiocaesium in lynx. According to the study by Skuterud et al in 2004, only the ground deposition itself from Chernobyl contributed to about 80% of the variability leaving approximately 20% for the other factors affecting accumulation of ^{137}Cs in lynx. Among this 20%, age and diet are probably significant factors while home range and gender evidently have insignificant effect. However, varying home ranges of Eurasian lynx, 600-1400 and 300-800 km^2 for males and females respectively, cause large variation of ^{137}Cs in them (Linnell et al., 2001). Furthermore, an increase in lynx sub-adult and male mobility during mating season, which is end of winter-middle of spring, coincides with hunting season, and in turn, may increase variability of ^{137}Cs among individuals (Skuterud et al., 2004). From *Appendix* 1 we can see that in the most affected counties activity concentration of radiocaesium can be as low as in least affected ones.

Based on previous studies, diet of lynx is an important factor affecting ^{137}Cs accumulation in their muscle tissue, even though stomach content was not examined in this study. Prevalent diet of lynx in Central Sweden is roe deer while in Västerbotten, Västernorrland, north-west of Jämtland, diet may also consist of reindeer due to herding areas. The northernmost county – Norrbotten has substantial reindeer herding areas, which is why, lynx preference switches towards reindeer, as it was reported in recent studies (Pedersen et al., 1999). ^{137}Cs activity concentration in roe deer and reindeer vary over the year. During winter, reindeer tend to have highest radiocaesium activity concentrations, due to lichen consumption, and relatively lower levels in summer. In roe deer, activity concentration reaches its peak in autumn, during the mushrooms season, while it is relatively low in wintertime (Skuterud et al., 2009; Skuterud, 2004 & Johanson et al., 1998). However, it has been pointed out in several studies that importance of lichen on accumulation of radiocaesium in reindeer has decreased significantly since the Chernobyl disaster. ^{137}Cs is gradually leaving the body of lichens by mechanical removal of rain, wind or grazing, with a half-life range of 3-6 years (Skuterud et al., 2009). Furthermore, growth of fresh lichen slowly dilutes activity concentration of ^{137}Cs in it. Because lichens absorb nutrients and water directly from the air, decline in activity of ^{137}Cs concentration is inevitable, provided no air born radiocaesium fallout is present at a time. In agreement to that, Åhman et al. (2001) observed higher effective ecological half-life for roe deer comparing to reindeer, 17 and 5 years respectively. Therefore, in a long term, decline of radiocaesium activity concentration in lichens will put plants, if not yet, on a position of equal or higher in radiocaesium content (Skuterud et al., 2009).

Mushrooms, as opposed to lichens, have an enormous internal uptake area, mycelia, that are able to reach radiocaesium not available for plants. In addition, many studies have shown that activity concentration in mushroom is not decreasing as readily as in lichens (Zibold et al., 2000). Consequently, activity concentration of ^{137}Cs in roe deer has longer ecological half-life than in reindeer as it was mentioned above.

Density of the prey has direct as well as indirect effects on home range and diet of the lynx. Dense population of prey reduce lynx effort to find the food while sparse availability force lynx to increase home range and ingestion variability of radiocaesium activity concentrations (Odden et al., 2006). On the other hand, low density of prey, although clear boundary is not known, increases importance of smaller animals and birds such as hare, capercaillie or black grouse (Odden, 2006). Additionally, ^{137}Cs activity concentration in those animals and birds are expected to be considerably lower due to the feeding preferences and habitat areas (Johanson, 1994).

Apart from lynx diet, a significant factor affecting accumulation of ^{137}Cs in their body is due to the diet and habitat area of their prey. Animals feeding on the mineral soil have low activity concentrations of radiocaesium comparing to those feeding on peats. Therefore, rabbits that can constitute significant portion of lynx diet, yet difficult to define approximate percentage due to the fast and complete consumption, ever ingest substantial amounts of radiocaesium. The reason for that is that hare's food grows on mineral soils (Lowe & Horrill, 1990; Odden et al., 2006). In addition, many animals that lynx prey on have access to arable land where activity concentrations of ^{137}Cs in plants are significantly lower than in natural ecosystems (Åhman et al., 2004).

Seasonal shift in the roe deer and reindeer diet towards dwarf-shrubs and lichens has an indirect effect on cesium accumulation in lynx. Due to the low content of essential nutrients, mainly potassium, in lichens and shrubs during the winter, excretion of potassium-like element -^{137}Cs is slowed down increasing retention of the element in their body and in turn activity concentration of the ^{137}Cs per body of the prey. Reindeer, as reported by Holleman et al. 1971, has longer retention time in winter being 18 days while 7 days in summer. Roe deer had similar biological half-life of 10 days in summer, while no information found for wintertime (Kiefer et al., 1996). From the variation point of view, prolonged retention of radiocaesium in lynx's body, probably, would partly decrease variability among individuals although higher average activity concentrations are expected. Retention of radiocaesium in lynx, as in all predators, is longer than in herbivores. Mohn and Teige (1968) found biological half-life of lynx to be 35 days while for wolverine and coyote, Holleman and Luick (1976), reported half-life retention of 25 days. Similarly to herbivores, ^{137}Cs variability in lynx is expected to be lower than if the biological retention time was shorter (Skuterud et al., 2004).

Temporal trend

Despite the decreasing long-trend of ^{137}Cs in lynx in all counties, ecological half-life are not equal for every county (Västerbotten 8 years, Gävleborg and Värmland 3.5 and 5 respectively). Longest ecological half-life was observed in Norrbotten – 13 years. Explanation to such observation is seasonal ^{137}Cs activity variation in prey. Harvest of lynx during the six years was done during early spring when roe deer tend to have lowest activity concentration of ^{137}Cs. Reindeer; however, at this time of the year has peak of ^{137}Cs activity concentration due to the lichen consumption. Therefore, lynx that preyed on roe deer will have lower concentrations and faster decline of ^{137}Cs than lynx that preyed on reindeer. All that presumes that season of the year has an effect on levels of ^{137}Cs activity concentrations in both prey and predator. However, we did not have data from other than spring seasons, and therefore, were not able to test for significance. Furthermore, absence of short-term slope imply that decline of ^{137}Cs has probably settling (*Fig*.8) mainly depending on physical decay. That, in turn, casts doubt on effective half-life obtained in this study. Thus, gradual increase of ecological half-life is expected for all counties. One explanation for this observation is that downward movement of radiocaesium in boreal forest ecosystems is limited due to abundant presence of organic material. Moreover, similar properties with potassium makes radiocaesium circulate between soil-plant-animal persisting in the environment.

Age and gender

As we mentioned above, in this study we did not find significant difference in radiocaesium accumulation of males and females. Skuterud et al. (2004) reported similar results saying that gender is not a significant factor affecting activity concentration of radiocaesium in lynx. However, Lowe and Horrill, (1990), observed higher ^{137}Cs activity concentration in fox males than in females, even though data was insufficient to test for significance. In addition, Howe and Horrill specified that males of mammals tend to accumulate radiocaesium to a higher degree than female. However, they did not justify their finding. One possible reason for having higher activity concentration of ^{137}Cs in male than in females is higher body weight of males over females, and therefore, higher consumption rates of meat. Additionally, it was reported that males prey on larger animals than females although difference was statistically insignificant (Odden et al., 2006). Consumption of smaller prey, such as hare, birds etc., gives relatively low radiocaesium ingestion, which would explain lower levels of ^{137}Cs in females. However, two studies, including this, found strong evidence that gender is not significant factor of ^{137}Cs accumulation.

According to our results, adults have significantly higher activity concentration of radiocaesium than sub-adults, which agrees also with study run by Skuterud et al. (2004). However, Skuterud et al. (2004) did not suggest reasons behind the results. However, from the literature review, we could suggest that significantly higher activity concentration of ^{137}Cs in adults is probably due to a higher efficiency of adults to prey on bigger animals. Such animals as roe deer or reindeer have higher concentrations of radiocaesium comparing to smaller preys as hare, grouse etc. Furthermore, the first year of life kittens follow their mother, which is why there diet is strongly dependent on their mothers prey. Odden et al. found in 2006, although results were not significant, that adult females tend to eat smaller prey than males, which assume lower activity concentrations of ^{137}Cs ingestion for kittens. Second year of the kittens’ life is probably associated with gaining of hunting experience, which similarly presumes that main part of their diet is based on smaller prey. Finally and yet importantly, we would expect lower activity concentrations of ^{137}Cs in sub-adults due to the faster metabolic processes in their body and therefore faster excretion of radiocaesium. However, it would also be quite logical to expect relatively high activity concentrations in sub-adults due to the intensive growth of their body, and therefore, higher relation of meat consumption to their body weight. Karl J. Johanson (1994) drew a similar hypothesis, explaining higher observed radiocaesium values in moose calves to be due to the metabolism characteristics of young. However, faster excretion of radiocaesium and prevalence of smaller prey in diet of sub-adults, are probably more significant than what relation of ingestion to the body weight is.

Aggregated transfer factor

Observed high T_{ag} values for the county of Norrbotten as well as Västerbotten can be explained by herding areas of reindeer. Furthermore, season of the lynx hunting coincide with a relatively high activity concentration of radiocaesium in their body (lowest in summer time) especially in northern part of Sweden where snow lays until late spring. That presumes lichens to be the dominant food for reindeer. Despite the fact that activity concentration of the ^{137}Cs in lichens is decreasing relatively fast (half-life of 3-6 years), lichens are probably still the main source of radiocaesium during the winter season.

The reason for adults to have higher transfer rate of radiocaesium than sub-adults is probably similar to why adults tend to have significantly higher levels of ^{137}Cs, preferences to a bigger prey such as reindeer.

Åhman et al. (2004), suggested that slower decline of ^{137}Cs in the county of Norrbotten, comparing to the counties of central Sweden, is due to the fallout from tests of nuclear weapons. However, atmospheric tests of nuclear weapons ceased by the 1980 in the whole world, although underground testing is still being carried out. Therefore, explaining relatively high activity concentrations in the animals of northern Sweden we may conclude that we probably underestimated the importance of lichens' half-life. Additionally, there must be a source of ^{137}Cs, other than from Chernobyl, that provide relatively high levels of ^{137}Cs in reindeer and therefore in lynx. In agreement to that, Hanson W.C., (1967) reported biological half-life in Alaskan lichens of 13 years, which would explain todays levels of radiocaesium in reindeer and/or lynx of Sweden's Northernmost county.

Finally, though importantly, it would be reasonable to expect high or even higher activity concentrations of ^{137}Cs in lynx feeding on roe deer in the period from end of summer to the middle of autumn than lynx feeding on roe deer in wintertime due to the mushroom season.

5.2 Bear

Factors governing ^{137}Cs concentration in brown bear

In this study, we observed that concentration in brown bear in Sweden is varying within as well as among counties. The factors governing concentration of ^{137}Cs in bear are similar to those for lynx: diet, ground deposition, seasonality and home ranges. Among the factors that have possible effect on radiocaesium accumulation in bear are gender and age class.

Deposition appears to be the most significant factor effecting radiocaesium level in bears. Due to the large home ranges, up to 1500 km^2 or higher, concentration of ^{137}Cs in food consumed by the bears is ranging significantly. Home range might be extended in mating season or in areas with low population of females. However, as we mentioned above, probably there is no significant difference between home range of 500 or 1500 km^2, since varying deposition might be as wide within square kilometers as it is within hundreds or thousands square kilometers.

Diet of brown bear in Sweden is tightly linked to the season of the year. Need of high-energy food after denning sets bear preferences towards ungulates, mostly carrion (Dahle et al., 1998). Therefore, it would be rational to expect quite high doses of radiocaesium in bears in areas of reindeer herding. Likewise, relatively lower concentrations are expected in central Sweden where no herding areas of reindeer are. Lowest concentrations of radiocaesium in bears, according to the diet, would probably be in summer when bears gradually switch to ants and forbs, remaining ungulates to be a part of their diet. Although ungulates are still included in bear's diet, concentrations of ^{137}Cs in them are probably the lowest that can be observed over the year, due to the low activity concentration in ungulates in the beginning of summer (Skuterud et al., 2009; Skuterud, 2004 & Johanson et al., 1998). During autumn, berries dominate in the bear diet. Among the most important species are crowberry (*Empetrum nigrum)* and bilberry (*Vaccinium myrtillus)*. Uptake of radiocaesium by these plants varies depending on soil properties and nutrient status with the soil plant transfer factor ranging from 0.002 to 0.02 (Fesenko et al., 2000). Therefore, ^{137}Cs activity concentration in these berries is probably lower than in ungulates that are more preferable as prey in spring. Furthermore, by the time berry-plant start giving fruits, significant part of the available radiocaesium will be taken by other plants, decreasing pool of available ^{137}Cs for crowberry and bilberry. However, prior hibernation bears gain up to 40% of extra weight that they receive from carbohydrate-rich berries. To obtain such increase of body weight, bears need to eat significantly more of berries than if they were eating flesh, which in turn would probably contribute to the increase of ^{137}Cs concentration in their body. Moreover, while most of ^{137}Cs accumulates in muscles, increase in weight is based on fat storage, which would increase radiocaesium activity concentration in muscles.

Hypothetical ecological and biological half-life.

Despite the fact that absence of continuous data in this study did not allow us to estimate approximate ecological half-life, knowledge, extracted from the studies carried out on lynx and their prey will be useful predicting ecological and biological half-life for bears.

The diet of brown bear in spring is dominated by ungulates, which quite certainly raise biological half-life to number of days observed for carnivores (20-30 days). In summer period, when preferences of bear's diet laying towards forbs and berries, with further dominance of berries in autumn, biological half-life will probably shorten to 7-20 days as it is for the most of herbivores.

Concentration of ^{137}Cs in bears will certainly decrease as it is decreasing in plants and animals. However, the slope of decrease is unknown. Furthermore, the decrease might be slower in the north of Sweden where significantly higher T_{ag} values were observed for bears.

Age and Gander

From fig. 10, we may notice that males have higher number of mean concentrations than females. However, as we mentioned above, statistically, there is a strong evidence to believe that the difference is insignificant, and might be explained by random variation or other factors.

Insignificantly higher activity concentration of ^{137}Cs could be explained by herbivore diet preferences of the bear. In agreement, as it was stated above, Karl J. Johanson (1994) found that moose calves had higher concentration than adults did, which agrees with our findings. However, if bears are more carnivores in the North we may expect different distribution of ^{137}Cs within the age groups due to the relatively higher ingestions of ^{137}Cs being carnivore (especially if prey is reindeer). That, in turn, might have an effect on the results since we are testing age factor for the whole Sweden. Therefore, continuation of the studies on radiocaesium accumulations in bears is necessary with deeper analyzes of central and north Sweden samples.

Aggregated transfer factor

Aggregated transfer factors for bears, observed in this study, are similar to those found for herbivores such as moose and roe deer. Relatively low transfer factors are probably due to the time of the year bears were hunted. Bears from both 2010 and 2011 were harvested in the period of mid-August to mid-September. At this time of the year, diet of the bear in Sweden, is dominated by berries (Dahle et al., 1998). Therefore, it is quite logical to expect relatively low T_{ag} values. However, the county of Norrbotten shows values that significantly deviate from the other counties (Table 3). One explanation for that is probably different diet of the bears inhabiting northernmost areas. Persson et al. (2001) concluded from their study, run in Russia, that brown bear is more carnivorous in the north. In spring and autumn, ungulates constitute for more than 70% of the bear diet, while in autumn, berries is the main food constituting for about 50%. Despite the facts that in autumn berries dominate in a bear's diet, ungulates can still be significant part of their diet constituting up to 30%. The most important ungulates contributing to the diet of brown bear are reindeer and moose (Persson et al., 2001). Consumption of ungulates would in turn assume ingestion of higher concentrations of ^{137}Cs due to the season of the mushrooms. Furthermore, in end of October, Norrbotten county probably cannot be characterized by abundant presence of vascular plants, which presume increasing portion of lichens consumption by reindeer. However, reasons for significantly higher T_{ag} values in Dalarna comparing Gävleborg, Jämtland, Västerbotten and Västernorrland cannot be explained in this study.

Comparison of ^{137}Cs accumulation in bear and lynx.

In general, ^{137}Cs activity concentration in bears follows similar pattern as that in lynx being higher in counties with higher average deposition of radiocaesium (*Fig*. 11). However, bear tend to have lower levels of radiocaesium than lynx. Despite the fact that bears have individuals with high concentration of ^{137}Cs (>500 Bq kg^{-1} in Västernorrland in both years) it hardly ever exceeded 500 Bq kg^{-1}. Furthermore, ranges of values in bears are significantly lower than in lynx. Yet, maximum values in bear coming from the same area or region can be twenty fold higher comparing to minimum observed in the same county. From the data analysis, it is evident that heterogeneous deposition of ^{137}Cs is a major reason for such variation, although such factors as age class or gender might also have an effect on levels of ^{137}Cs.

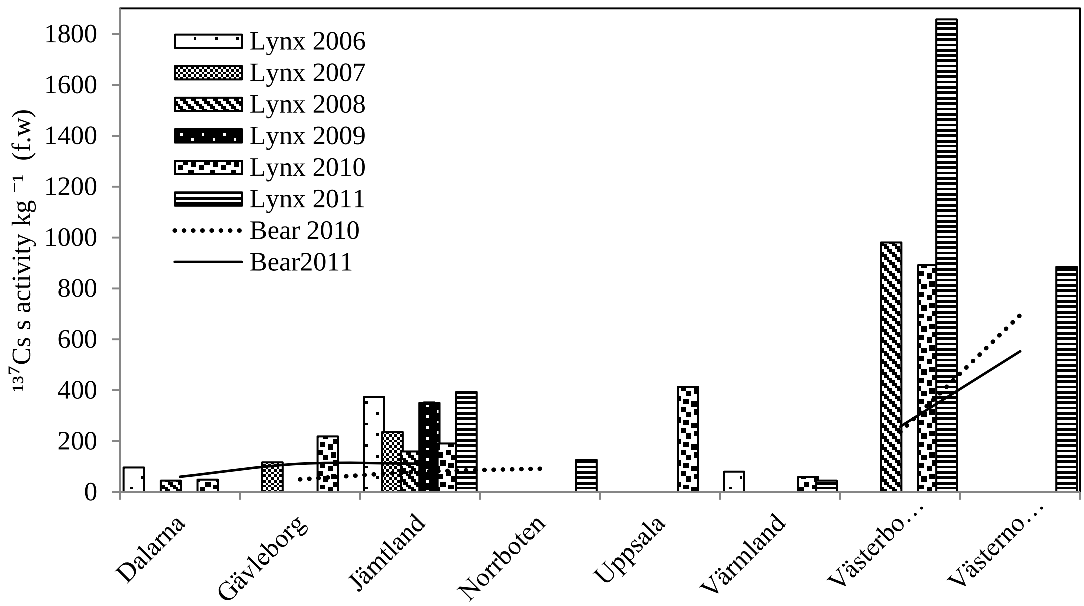


Fig. 11 Comparison of levels of ^{137}Cs (Bq kg^{-1} f.w.) activity concentration in lynx and bear.

The dominating vegetation diet of bears in autumn, which coincide with hunting period, can explain lower activity concentrations as well as lower variation than in lynx. Thus, T_{ag} values are lower for bears than for lynx, although they might near to those of lynx in a period of spring.

Similar home ranges for bear and lynx, 200-1500 km^2, might suggest that mobility have relatively low influence on ^{137}Cs accumulation comparing to the diets of the animals.

6. CONCLUSIONS AND SUGGESTIONS

This study has shown how complex and unpredictable natural system is in relation to ^{137}Cs retention. Decline of radiocaesium in the forest ecosystem is continuous; however, significant amount of evidence, including this study, pointing out that slope of decrease is leveling off. That, in turn, would mean that in future most of ^{137}Cs loss would be due to the physical decay of the element.

Relatively high activity concentrations of ^{137}Cs and T_{ag} values in Norrbotten suggest that lichens and reindeer are still significant sources of radiocaesium in autumn-spring period. However, deposition of Chernobyl's ^{137}Cs alone, in the north Sweden, would probably not give such high activity concentrations in animals. That implies that part of the former fallout from the NW tests is still available for the animals or there is an unknown to us source of air born radiocaesium contaminating higher altitudes of the earth. These uncertainties might be a topic for further research.

Variation of the data was the most limiting factor in this study that blurs over possible influence of the gender and age on ^{137}Cs accumulation. Presumably, dominant part of the variation is caused by heterogeneous nature of the Chernobyl's deposition, which is why it is important to count for deposition on smaller than county scale. Then, analyzing role of individual's features (gender and probably year) on radiocaesium accumulation will be evident due to reduced data variation.

From the results of lynx and bear that have similar home ranges it may be concluded that diet of the animals is more important for the activity concentration of ^{137}Cs in their body than home ranges. Additionally, difference between home ranges of 500 km^2 and 1500 km^2 has probably similar effect on ^{137}Cs activity concentration in animals, since heterogeneous distribution is already present at scale of square meters.

Finally, it is quite evident that the most significant factors affecting ^{137}Cs level in lynx are habitat area, defined by presence of herding reindeer, age class and deposition rate of ^{137}Cs.

For bear, seasonality, which is closely linked to bear's diet, along with radiocaesium deposition habitat area, are likely to be governing factors determining activity concentration of ^{137}Cs in it.

Conclusively, all the hypotheses that were stated in this study, with exception of short-term decline of radiocaesium, are confirmed.

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9. APPENDIX

Appendix 1

Average ^{137}Cs activity concentrations in lynx in counties of central Sweden 2006-2011, where St.dev is standard deviation; n-number of samples.

Year/County	Mean-St.dev	Range	n
2006			
Dalarna	96 ±74	38-248	13
Gävleborg	172 ±134	76-371	4
Jämtland	373 ±273	71-1140	14
Värmland	80 ±31	48-135	6
Västerbotten	319 ± 40	290-347	2
2007			
Västerbotten	1776±972	708-2610	3
Gävleborg	116 ±22	90-148	6
Jämtland	236 ±168	24-517	11
Uppsala	1590±721	1080-2100	2
2008			
Dalarna	44 ±18	23-68,8	5
Gävleborg	112 ±88	57-243	4
Jämtland	159 ±122	18-323	9
Västerbotten	980 ±800	282-2560	7
2009			
Jämtland	350 ±144	146-577	10
Västerbotten	631 ±90	567-695	2
2010			
Dalarna	48,3 ±16	23-83,8	12
Gävleborg	218 ±282	43-860	8
Jämtland	191 ±175	11-461	10
Norrbotten	118 ±23	92-132	3
Uppsala	413 ±509	39-1800	14
Värmland	59 ±29	30-133	20
Västerbotten	891 ±499	371-1830	6
Västernorrland	1369±1147	558-2180	2
2011			
Västerbotten	1857±1169	279-3930	10
Jämtland	394 ±608	13-3 830	55
Norrbotten	126 ±66	46-244	8
Värmland	44 ±12	28-56	6
Västernorrland	910 ±1943	90-6 750	11

Appendix 2

Mean ^{137}Cs activity concentrations in brown bears in counties of central and northern Sweden 2006-2011with standard deviation (St.dev); n-number of samples and range

Year/County	Mean-St.dev	Range	n
2010			
Dalarna	-	-	-
Gävleborg	49 ± 24	24-85	5
Jämtland	79 ± 76	38-279	9
Norrbotten	91 ± 41	18-141	6
Västerbotten	235 ± 125	77-393	5
Västernorrland	695 ± 571	90-2020	9
2011			
Dalarna	59 ± 41	22-225	29
Gävleborg	110 ±136	29-680	34
Jämtland	110 ± 96	23-488	30
Norrbotten	-	-	-
Västerbotten	256 ± 126	77-547	19
Västernorrland	553 ± 423	48-1 280	17

Appendix 3

Mean ground depositions of ^{137}Cs (Bq m^{-2}) in the April 1986, obtained from original data by Åhman et al., 2004 with further decay correction to April 2006 and 2011

COUNTY	Mean depositions of ^{137}Cs on 1986-04-26	Decay corrected depositions of ^{137}Cs to 2006-04-26	Decay corrected depositions of ^{137}Cs to 2011-04-26
Dalarna	2173	1369	1220
Gävleborg	14966	9428	8400
Jämtland	9803	6176	5502
Norrbotten	590	372	331
Uppsala	22262	14024	12494
Värmland	1873	1180	1051
Västerbotten	17267	10878	9691
Västernorrland	36349	22898	20400

Appendix 4

Physiochemical properties of ^{137}Cs and ^{134}Cs

^{137}Cs is a soft, malleable metal with silvery gold tint. At a temperature of 28^{o}C this metal has liquid physical form while boiling temperature is at 678.5 ^{o}C. Naturally occurring cesium is found as non-radioactive ^{133}Cs.

^{137}Cs is the most common radioactive isotope of the cesium group as well as the most electropositive and alkaline element. It has anthropogenic origin when heavy elements as uranium and plutonium undergo fission after capturing of neutrons in NPP and/or NW. While uranium-238, naturally existing on earth, with half-life of 4.47 billion years, half-life of ^{137}Cs disintegrates by half in only 30.17 years. Decay of cesium is accompanied by emission of beta particles as well as gamma rays (*Fig. 11*). In 94.4% of the cases, the decay of ^{137}Cs ends up with formation of intermediate form of ^{137m}Ba, which has a half-life of 2.55 minutes. The other 5% of decay do not form this intermediate element but directly ends up with formation of stable isotope ^{137}Ba. The time gap of 2.55 minutes, when unstable ^{137m}Ba transforms into ^{137}Ba is the only time when gamma rays are emitted (US EPA, 2012).

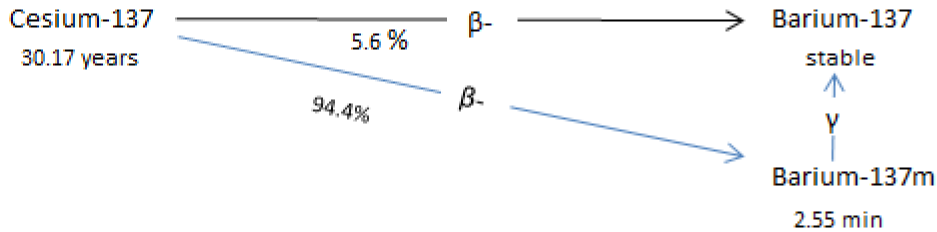

Fig. 11 Two ways of ^{137}Cs decay with a formation of stable isotope ^{137}Ba.

Electrons might also be emitted as a result of internal interaction between excited atomic nuclei and one of the electrons residing in low orbitals causing emission of a high-energy electron. Despite the fact that an electron is emitted the charge of the atom does not change which therefore means that it is not a beta decay.

^{137}Cs is highly reactive and readily oxidized having solubility in water. Furthermore, the chemical properties of ^{137}Cs are similar to those of potassium making it able to cycle easily in nature. Due to this ^{137}Cs is an important environment contaminator, where activity from 1 gram of ^{137}Cs is equal to approximately to 3.215 terabecquerel or 3.215 $^{x}10^{12}$ (US EPA, 2012 & Okumura, 2003).

^{134}Cs is an isotope with an atomic number of 55 and mass number 134, which is only formed as a product of chain reaction in nuclear reactors or after explosion of NW. Furthermore, cesium-134 created not by beta emission but direct fission of uranium-235 or plutonium-239, or by neutron capture of non-radioactive cesium-133. As an environmental contaminator, cesium-134 plays much lower role than 137 isotopes due to its significantly shorter half-life of approximately 2 years. However, shorter time of disintegration suggest higher activity that makes it one of the most harmful elements after nuclear accidents. The activity of 1 g of ^{134}Cs is close to 4,7$^{x}10^{13}$Bq which is 15 times higher than the activity of ^{137}Cs (Chemeurope.com, 2012).

Appendix 5

Radioactive emission and units

Emission of alpha and beta particles and/or energy appears as a result of nuclei transformation. In order to assign properties of a certain nuclei its disintegration must be quantified. Therefore, a number of units have been put to characterize or quantify the decay of unstable atoms. While the disintegration is represented by transformation per minute or second (Bq), the emitted particles possess certain energy capacities which are usually expressed in electron volts (eV).

Alpha (α) radiation

Positively charged particles consisting of 2 protons and 2 neutrons, which is nuclei of helium, usually appears after decay of the heaviest radionuclides such as ^{238}U, ^{226}Ra, ^{210}Po (*Equation* 1*)*. Alpha particles is relatively heavy which is why their mobility and penetration is limited to a distance of 1-2 cm through the air and/or thickness of paper sheet. However, alpha particles can be a serious threat to a human health in case of inhalation or ingestion (US EPA, 2007 & IAEA, 2004).

$$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{Th} + \alpha$$

Equation 1. Emission of alpha particles from uranium-238 with production of thorium-234.

Beta (β) radiation

Beta particles are a fast moving electrons or positrons and are therefore much lower in mass, which presumes higher penetration ability. However, the top layer of skin, clothes, glass or plastic but not a paper sheet can stop beta particles. In the same way as (α)-particles, (β) can do most harm when ingested and/or inhaled. Furthermore, some of the high-energy (β) emitters can penetrate the skin causing radiation damage. Some examples of (β)-emitters are ^{3}H, ^{14}C and ^{90}Sr (US EPA, 2007 & IAEA, 2004).

Beta decay is a type of radiation in which electrons or positrons are emitted due to the week interaction, also known as weak nuclear force that is one of the four fundamental forces (gravitational, electromagnetic and strong) in nature. Depending on what particle is emitted, positron or electron, beta decay can thus be beta plus (β^+) or beta minus (β^-) decay. As a result, beta decay promote nucleus conversion into next lower (β^+) or higher (β^-) level of the periodic table as shown in equation 2.

$$^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + e^{+} + \nu_{\mathrm{e}} \rightarrow (\beta^{+}\text{ decay})$$
$$^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^{-} + \bar{\nu}_{\mathrm{e}} \rightarrow (\beta^{-}\text{ decay})$$

Equation 2. Examples of (β^+) and (β^-) decay of ^{22}Na and ^{137}Cs respectively, where e^- is an electron; $\boldsymbol{\nu}_e$ - electron neutrino and $\bar{\nu}_e$ - electron antineutrino.

Unlike (β^-) decay, (β^+) can only appear with presence of external energy that is required to convert a proton into a neutron, positron and neutrino into kinetic energy of these particles. The energy is coming from differences in binding energies of mother and daughter nucleus being less for the mother nucleus (Aarkrog A., 2001)

Gamma (γ) radiation

Gamma radiation consists of photons, high-energy packets, emitted from unstable nuclei. Very short wavelength and high frequency provide much higher penetration ability compared to that of alpha and beta particles. Penetrating living organism gamma rays induce damage to the cells and/or DNA. As a result of penetration, neutral atoms become charged or ionized, while the process itself is ionization. Acute doses of gamma radiation leave no chance for DNA to repair itself. Therefore, due to its penetrability, it is not necessary to inhale or ingest sources of gamma radiation to be irradiated. (IAEA, 2004)

Naturally occurring gamma radiation is represented by emission from ^{40}K. In addition, gamma radiation reaches the earth originally coming from the hottest places of our galaxy or a supernova (star explosion). Anthropogenic sources of gamma radiation are ^{60}Co, ^{137}Cs etc. (US EPA, 2007).

Units of radiation and radiation doses

Marie Curie, who is the prime finder of naturally radioactive elements, firstly defined radioactivity as corresponding to the emission of one gram of radium-226. Nowadays, one curie (Ci) has been estimated to be equal to 3.7×10^{10} decays per second. However, curie units were replaced by the International System of Units with Bq, which is equal to one decay per second (CPEP, 2003).

To measure radiation relating to the human health other than Bq units must be used. The reason for this is to quantify the risk of negative response in a living cell to a radioactive exposure. Major units for dose measurement are *rad, gray, Sievert and rem,* which nowadays are being changed by SI from rad to gray and rem to Sievert respectively. Gray (Gy) is the amount of energy received per unit of living matter (J/kg). Sievert (Si), previously known as *rem*, counts for the loss of energy by atomic particles traveled over the unit of distance using a *quality factor Q* (e.g. Q=1 for the electron and 20 for alpha particles). Furthermore, a weighting factor is used in case of partial irradiation of a living organism in order to get effective dose (CPEP, 2003).

High doses of radiation are usually expressed in gray units that do not account for distance traveled by atom particles. Moreover, for electrons and gamma rays 1 Gy corresponds to 1 Sv (CPEP, 2003).