LANDSCAPE USE AND ECONOMIC VALUE OF EURASIAN BEAVER (*CASTOR FIBER*) ON A LARGE FOREST IN SOUTHEAST NORWAY

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ABSTRACT

Though numerous studies of damage caused by beaver (*Castor canadensis* and *C. fiber*) to commercially managed forests have been conducted, few have incorporated the economic advantages beaver can create for forest owners. In Norway, hunting rights belong to the landowner, who in turn can obtain income from the further sale of hunting privileges to others. In this study we have measured 1) the proportion of the landscape affected by beaver, 2) the relative volume of commercially valuable timber destroyed and its potential value, 3) the costs involved in controlling beaver damage to forest stands and technical installations and 4) the income derived from the sale of beaver hunting privileges on a large (61,500 hectare) and intensively managed commercial forest in southeast Norway.

The field study was conducted in 1993 on 3469 hectares (6%) of the forest, divided into 648 managed stands. All waterways here were censused in July and 38 beaver colonies located of which 19 (50%) were active. Density of active colonies was 0.55 kolonies/km^2. The combined area affected by tree felling and impoundment from dam building was defined as the beaver "activity area". The total beaver activity area comprised 2.8% of the upland study area and 2.9% of the productive forest area. Present and recently impounded forest comprised 7% of the beavers total activity area and only 0.2% of the upland study area. Fifty-five percent of this inundated area was classified as bog and of little value for commercial tree production. Thus only 0.1% of the productive forest on the study area and been impounded. This low proportion of impounded area was due mainly to the beaver's use of already existing bodies of water and the mountainous topography of the region. Assuming that inundated forest is permanently removed from commercial production, then flooding by beaver, in the long run, should reduce this landowners income by about 0.1%.

No Norway spruce (*Picea abies*) or Scotch pine (*Pinus sylvestrus*) was found felled. Beaver removed 50% of the birch (*Betula pubescens*) and 60% of the aspen (*Populus tremula*) ≥10 cm diameter breast high (dbh) from 2.6% of the study area. This amounted to 1.3% of the harvestable broadleaves there. On 43% of the productive forest area within the beaver activity area, the forest management plan called for heavy thinning of most young birch and aspen to enhance conifer growth. Felling by beaver within these stands probably accomplished much of the same task, probably creating production benefits for the forester rather than damage.

Between 1970-93 the landowner paid trappers to remove problem animals and allowed employees and others to hunt beaver for free. After 1993, an increasing number of hunters have paid for the right to hunt beaver on this property. In 1998 the landowner paid 60,000 Norwegian crowns (about $7700 American dollars) to control beaver damage on the entire property, while income from the sale of beaver hunting rights amounted to 20,000 crowns.

Based on estimates of population density, it is predicted that about 10 times as many beaver could be harvested from the property on a sustained basis as were removed in 1998. With the present rapid increase in demand for beaver hunting, income from hunting may soon surpass the cost of controlling damage for this landowner. Due to initial high densities of broadleaves following clear-cutting, it was predicted that intensive forestry practices may actually enhance beaver density. At the landscape level, the presence of beaver is likely to increase biodiversity in commercial forests - a major goal of Norwegian forest management.

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1. INTRODUCTION

After having been extirpated from most of its previous range, the Eurasian beaver (*Castor fiber*) is rapidly returning to previously occupied habitats (Rosell and Parker, 1995; Nolet and Rosell, 1998). Much of this habitat is now being extensively managed by man for forestry, agriculture or residential purposes and conflicts with beaver are inevitable. Norwegian forest owners have traditionally viewed beaver as having only negative economic value (Barth, 1943; Ellefsen, 1980; Follum, 1988). Beaver can, however, provide a direct source of income to the landowner as well. In Norway, as in many other European countries, hunting rights belong to the landowner and may be temporarily sold to others. Furthermore, game meat and other wildlife products may be sold and income obtained from services such as guiding and cabin rental. This income may partially offset the costs of the damage beaver inflict. Both the damage caused and the assets provided will depend upon local ecological conditions, landscape forms, vegetation composition, management policy, patterns of land ownership and use, possession of hunting rights and traditional attitudes towards wildlife. What constitutes damage and assets will therefore be expected to vary considerably between countries and cultures.

In the Nordic countries of Norway, Sweden and Finland several studies have estimated the area of forest impounded by beaver (Landmark, 1972; Lavsund, 1977; Rajala, 1977; Lavsund, 1983, 1987; Härkönen 1999) or the volume of timber felled (Ellefsen, 1980; Follum 1988). Others have assessed the economic costs to landowners by beaver (Barth, 1943; Myrberget, 1967). None, however, have simultaneously measured both the economic costs and benefits that beaver can provide. In this study we have measured 1) the proportion of the landscape affected by beaver, 2) the proportion of saleable timber destroyed and its relative value, 3) the costs involved in controlling beaver damage to forest stands and technical installations and 4) the income derived from the sale of beaver hunting privileges on a large, privately owned forest in Norway. Finally, we predict the effect intensive forest management will have on future beaver density and briefly review the importance of beaver for multiple use forestry.

2. STUDY AREA

The study was conducted in Siljan and Kongsberg townships in Telemark and Buskerud Counties in southeast Norway on a large (61,500 hectare (ha)), intensively managed commercial forest belonging to the Fritzøe Skoger Company (59-60^{o}N, 9-10^{o}E). We arbitrarily chose 3,469 ha (6%) of the forest in 2 sub-sections (1883 and 1586 ha) as the study area (Haugen, Kristensen, Myrum and Kolsing, 1994). The area was deemed typical for the property as a whole with respect to topography, forest species composition and beaver density. The study area consists of 66% productive forest, 29% low productive forest and 5% lake surface. Productive forest is defined as stands showing an annual volume increase for Scotch pine *Pinus sylvestris* (hereafter pine), Norway spruce (*Picea abies*) (hereafter spruce) and broadleaves dominated by hairy birch (*Betula pubescens*) (hereafter birch) and aspen (*Populus tremula*) with traces of rowen (*Sorbus aucuparia*), gray alder (*Alnus incana*) and willow (*Salix* spp.), including bark, of ≥1.0 meter^3/ha/year. Production on low productive forest is <1.0 meter^3/ha/year. Twenty-eight percent of the low productive forest is peat bog and the remainder mostly thin-soiled rock outcrop. The study area is mostly forest-covered, contains no cultivated land and the topography is predominantly mountainous with altitudes ranging from 350-700 m a.s.l. It contains 39 lakes averaging 4.3 ha, 27,000 m of lake and impoundment shoreline and 15,050 m of stream length. Forest composition measured as standing volume was 75% spruce, 10% pine and 15% broadleaves.

Beaver returned to the region by natural immigration in the early 1960's after having been extirpated during the mid-19th century. They were first seen on the study area in 1965 and the population peaked about 25 years later.

3. METHODS

The study area consisted of 648 managed forest stands averaging 4.9±7.2 SD ha in size. Each stand of productive forest was categorized into one of 5 harvest classes: class 1 (H1) = recent clear-cut, either newly planted or in the initial stages of natural regeneration; class 2 (H2) = satisfactory regrowth of spruce, pine and birch but not yet of commercially harvestable dimension; class 3 (H3) = first thinning advisable, with thinned stock of saleable dimension (i.e. diameter breast high (dbh) ≥10 cm); class 4 (H4) = second thinning advisable and class 5 (H5) = final harvest recommended (Nedkvitne, Bjørnstad and Refsdal, 1990). The optimal final harvest age on the study area was 50-60 years for birch, 90-100 years for spruce and 110-120 years for pine. Clear-cutting was the usual final harvest form. The area distribution of harvest classes on the study area was 0%, 54%, 8%, 1% and 37% for classes H1 to H5 respectively, i.e. classes H2 and H5 were most strongly represented. Classes H2 and H3 usually contained high densities of young broadleaves in those stands where this group had not been reduced through thinning or use of defoliants. Stands in class H5 contained predominately mature spruce and/or pine though usually with some broadleaves.

Each stand was also classified with respect to site quality, i.e. the site's ability to produce spruce and pine, known as the H_{40}-system (Nedkvitne et al., 1990). The 6 site classes in order of increasing productivity were: "low productive" (see above), S8, S11, S14, S17 and S20. A site classified as S14 is of average productivity, and S14 indicates that the mean height of the 10 highest spruce trees in the stand is 14 m at age 40 years. The area distribution of site quality classes on the study area was 28%, 4%, 23%, 30% 14% and 1% for classes "low productive" to S20 respectively.

In June 1993 we censused all lakes and streams on the study area, on foot or by canoe, for all active and abandoned beaver colonies. Colonies containing fresh sign of beaver activity (e.g. newly browsed trees, forbs or aquatic vegetation; trails in use) were classified as active. We measured the area affected by tree-felling (hereafter felled area) at both active and abandoned colonies by plotting on a map the location of trees felled at the outer edge of each cut area and drawing a polygon between them. Within this area we classified the proportion of birch and aspen with dbh ≥10 cm (including bark) felled by beaver into 1 of 5 felling categories: 0%, <25%, 25-50%, 51-75%, >75% felled of that available. Median percentages for each felling category were thereafter defined as 0%, 13%, 39%, 64% and 88% respectively. By using the median value for each felling category, and weighing each value according to its frequency, the mean values for the proportion of birch and aspen ≥10 cm dbh removed from felled areas were calculated. The area presently and recently inundated by beaver (hereafter *inundated area*) was also mapped. On each inundated area the number of birch, spruce and pine ≥10 cm dbh killed was classified into 1 of 4 categories: 1-10 individuals killed, 11-100, 101-500 and 501-1000. The combination of felled and inundated areas for both active and abandoned colonies was defined as the beaver's *activity area*. On the map we measured the distance from the water's edge to the outer edge of felled areas at 80m intervals along a line perpendicular to the water's edge. A mean outer edge distance for each colony, and for all colonies combined, was then calculated.

Mapping was done on forest management plan maps (1:10,000) showing the borders of all forest stands. Shoreline and stream lengths were measured with a planometer and areas measured using area diagrams (Nedkvitne et al., 1990) with no adjustment for slope. All information on harvest class, site quality, stand age, forest species composition and stand areas were obtained from Fritzøe Skoger's forest management plan. Information about beaver population trends on the forest, the cost of damage control and income from hunting were obtained from company personnel.

Beaver can be legally trapped and hunted on the study area from 1 October to 30 April. Though beaver dams and lodges are protected by law, landowners can apply for permission to remove them, or to trap or shoot nuisance beaver during the closed season when the destruction of forest or technical installations merits control. As an indirect measure of the damage beaver were inflicting on the landowner we recorded the number of colonies hunted and trapped during 1990-93, as well as dams removed during 1988-93.

We used a Chi-square test to check for differences in the distribution of forest site quality classes and forest harvest classes on the study area, and within the beaver's total activity area. Mean values are shown with ± 1 standard deviation. An exchange rate of 7.8 Norwegian crowns per 1 US$ was used.

4. RESULTS

4.1. Landscape Use

We found 38 colonies on the study area of which 19 (50%) were active. The density of active colonies was 0.55 kolonies/km^2. The total activity area for all colonies combined was 91.9 ha or 2.8% of the upland study area, of which 65.3 ha (71%) was productive forest. This productive forest constituted 2.9% of the productive forest on the study area. Some form of dam building activity was found in 37 (97%) of the 38 colonies. However, only 12 (32%) colonies were established on impounded streams alone, the remaining having been situated primarily on existing bodies of water. Both present and recently impounded forest covered 6.4 ha or 0.17 ha/colony. This was 0.2% of the upland study area and 7% of the total activity area. The remaining activity area, the felled area, covered 85.5 ha which was 2.6% of the study area and 93% of the total activity area. Forty-six percent of the lake and impoundment shoreline and 35% of the total stream length on the study area fell within the beaver's total activity area. The mean outer edge distance for all colonies that trees were felled from the shoreline was 36±32 m.

The distributions of forest site quality classes on the study area and within the beaver's total activity area (Fig. 1) were significantly different (Chi-square test, $X^2 = 113.0$, 5 df, $P < 0.001$) with beaver favoring sites of average quality and selecting against low productive forest. The distributions of forest harvest classes on the study area and within the beaver's total activity area were also significantly different (Fig. 2)(Chi-square test, $X^2 = 204.8$, 3 df, $P < 0.001$) with beaver favoring the younger H2 harvest class while selecting against the mature forest of class H5.

4.2 Tree Felling

Neither spruce nor pine was found felled by beaver on the study area. Figure 3 shows the number of colonies in which birch and aspen were absent, and the proportion of birch and aspen ≥10 cm dbh removed within the felled areas. Birch ≥10 cm dbh was present in all colonies but aspen in only 24 (63%). The most common felling category recorded for birch was 26-50% and the mean proportion felled was 50%. For aspen the most common felling category was > 75% and the mean proportion felled 60% suggesting a preference for aspen. Assuming that beaver were felling 50% of the harvestable broadleaves on 2.6% of the study area, and that broadleaf composition was equal within felled areas and the remainder of the study area, then beaver had felled an estimated $0.5 \bullet 0.026 \bullet 100 = 1.3\%$ of the harvestable broadleaves on the study area. Foresters, however, are primarily interested in growth on productive forest. As 15% of the productive forest volume was broadleaves (essentially birch and aspen), and approximately 50% of this was cut by beaver on felled areas, then beaver were felling about $0.15 \bullet 0.50 \bullet 100 = 7.5\%$ of the standing volume of commercially interesting tree species on productive forest within their activity area. The activity area contained 2.9% of the productive forest on the entire study area. Therefore beaver had felled $0.029 \bullet 0.075 \bullet 100 = 0.2\%$ of the standing volume within productive forest on the study area.

4.3 Inundated Forest

The number of colonies containing inundated birch, aspen and spruce ≥ 10cm dbh is shown in Figure 4. Only 6 (16%) contained inundated broadleaves while the comparative number for spruce was 16 (42%). No pine ≥ 10 cm dbh was found inundated. Fifty-five percent of the area impounded was classified as bog and therefore of little commercial value for forest production. As 0.2% of the study area was presently or recently impounded, then $0.45 \bullet 0.2 = 0.1\%$ of the productive forest on the study area had been affected by flooding. The most common forest site quality class on inundated productive forest was S14, as was the case for the remainder of the study area (Fig.1). Assuming that the quality of productive forest inundated by beaver is similar to that on the rest of the study area, and that inundated forest is permanently removed from commercial production, then flooding by beaver, in the long run, should reduce this landowners income by about 0.1%.

4.4 Trapping, Hunting and Dam Removal

Only 3 (8%) of the 38 colonies had been trapped during the open seasons of 1991-93 while 28 (74%) had been hunted on at least once during the same period. No nuisance animals had been removed by trapping or hunting outside of the open season. In 6 (16%) of the colonies, dams had been removed at least once during the past 5 years.

4.5 Cost of Damage Control and Income from Beaver Hunting

The hunting and trapping of beaver on the forest began around 1970 and was initially free of charge in an attempt to control damage. Nuisance beaver were also occasionally trapped by company personnel. No systematic records of the cost of this early control, however, were kept. In 1993 the first hunting licenses for beaver on the forest were sold. Since then, interest in beaver hunting has gradually increased. In 1998 a detailed account of both the cost of controlling beaver damage to technical installations such as logging roads, culverts, drainage ditches, dikes, etc. and the income from the sale of hunting licenses was calculated for the first time for the entire forest. A total of 60,000 Norwegian crowns (≈ 7700 US dollars) was used to control beaver damage of which 36,000 was wages, 15,000 the cost of renting equipment for dam removal, 5,000 for dynamite and 4,000 for travel expenses. In comparison, 20,000 crowns were earned from the sale of beaver hunting that year and 21 animals were shot.

5. DISCUSSION

5.1 Landscape Affected by Beaver

The proportion of the landscape previously and presently affected by beaver felling and impoundment defines the area on which economic loss for foresters can potentially occur. The size of this proportion, in turn, will depend upon the stage of beaver population development and the quality and quantity of potential habitat on the area in question. Hartman (1994) working in similar boreal forest habitat in neighboring Sweden found that maximum colony density peaked 25-35 years following reintroduction. The present study was conducted about 30 years following the first beaver sightings in the area. As both harvest pressure and measures to control nuisance individuals have been light during this time, it seems likely that the population on the study area was near peak density around the time the study was conducted. The proportion of the landscape affected by beaver activity presumably could peak after the population itself as resources become depleted and more marginal habitats eventually are utilized. Johnston and Naiman (1990a), however, reported that 90% of the final inundated area of boreal forest in northern Minnesota was impounded during the first half of a four decade period of beaver colonization. Thus the figures reported here for forest area inundated and felled on by beaver should be near the maximum that can be expected for the study area in the long run.

Present and recently impounded forest covered only 0.2% of the study area and 7% of the beaver's activity area. This was not due to low colony density, as 0.55 active colonies/km^2 is typical for well established populations in Scandinavia (Simonsen, 1973; Frendin, 1979; Kortner, 1989; Hartman, 1994). The low area of impoundment appears to be mainly due to 1) the frequent use of already existing bodies of water as the prime site for colony establishment and 2) the mountainous topography of the study area. Though 97% of all colonies showed some sign of dam-building activity, most of this consisted of only minor impoundments. Lavsund (1987) reported that 0.5% of the forest in Jämtland County, Sweden, a somewhat flatter landscape, had been impounded by beaver at peak density. In contrast, 13% of a 250 km^2 region of relatively flat boreal forest in Minnesota, USA, with a beaver density of about 1 colony/km^2, was eventually impounded by beaver (Johnston and Naiman 1990a, b). This is double the colony density but 65 times the relative area impounded compared to the present study. Likewise, Härkönen (1999) reported a mean size of 2.2 ha for forest area impounded or seriously waterlogged by North American beaver on a relatively flat, lowland area in southeast Finland. This is 13 times greater than the average impounded area for colonies in this study. Some of this difference could conceivably be due to interspecies variation in dam building intensity (Danilov, 1983). The small size of resulting impoundments on the study area may, in part, explain why beaver chose so frequently to establish colonies on existing bodies of water, as these would provide an access to food supplies not possible on the small, beaver induced impoundments. Based on the above, we predict that the cumulative proportion of the landscape impounded by beaver in hilly and mountainous terrain in the Nordic countries will rarely exceed 0.5%, when measured on a scale of thousands of ha.

5.2 Economic Consequences of Inundation and Felling for Forest Production

The predicted income loss of 0.1% due to impoundment of productive forest will be correct if 1) all previously used sites are continually reimpounded, 2) the recolonization cycle for beaver is shorter than the forest harvest cycle and 3) the mean quality of impounded and nonimpounded productive forest is similar. Beaver alternately occupy, abandon and reoccupy sites in response to e.g. fluctuating food resources and population density. Though studies are lacking, the length of this cycle is probably considerably shorter than the harvest rotation times for birch, spruce and pine of 60-120 years, and probably shorter even than the age of first commercial thinning of about 25-30 years. Indeed, our result from the present study showing that beaver prefer to colonize young forest of preharvestable age supports this view. Therefore, unless site occupation by beaver is in some way prevented through damage control or harvesting, most suitable dam sites are likely to be reimpounded long before the commercially important tree species there have reached harvestable age. Hence a good estimate of income loss due to impoundment from beaver will be

$$L = (A/B)\ I$$

where L is income loss due to inundation on productive forest, A = area of productive forest previously and presently inundated; B = total area of productive forest; I = expected income from sale of timber on area B. Area A, and thus L, will increase until the area impounded by beaver has reached a maximum.

The validity of the above equation is based on the assumption that the mean quality of productive forest inundated by beaver is not significantly different from the mean quality of all productive forest. Because the total area of productive forest impounded by beaver in this study was so small (2.9 ha) no meaningful statistical comparisons between these two classes were possible. However, the most common site quality class was the same for both impounded and nonimpounded productive forest suggesting similar quality. Though timber harvesting is less common and not encouraged on unproductive forest (Hÿtonen, 1995), landowners with a high proportion of unproductive forest could incorporate its value also into the equation.

Fifty-five percent of the forest impounded by beaver was unproductive bog compared to 8% for the entire study area. Lavsund (1977) and Härkönen (1999) also found a relatively high proportion of bog on areas impounded by beaver in Nordic boreal forest. Only 16% of the colonies in our study contained inundated broadleaves of commercial value. In contrast, Härkönen (1999) found that birch occurred more often than expected on impounded areas and comprised 47% of the trees on damaged areas, possibly reflecting better site suitability for birch than conifers in the flat riparian habitats common in Finland. Though trees killed by impoundment can act as breeding sites for bark beetles (Scolytidae), with the subsequent risk of infecting surrounding healthy forest (Saarenmaa, 1978), no instance of this was observed on our study area.

The study area (3469 ha) had only one owner. The mean size of privately owned productive forest tracts (larger than 2.5 ha) in Norway, however, is only 47 ha (Nedkvitne et al., 1990). Consequently, on the average, 74 different forest proprietors would have owned an area equal to the size of the study area, instead of one. While a single large landowner would likely tolerate having 0.1 % of a large, productive forest impounded, several small landowners experiencing considerably greater damage would be more likely to complain to local wildlife authorities. In southeast Finland, mean forest property size was smaller (34 ha) while the mean size of impounded areas was 13 times larger (Härkönen, 1999) than on our study area. This may explain why Finnish foresters seem to be more concerned about beaver damage than Norwegians (Härkönen, 1999). Mean property size is therefore an important determinant of damage extent and incidence.

While dead and dying trees on impounded forest usually have little or no commercial value, the economic consequences of broadleaf felling are more difficult to calculate, as both costs and benefits are involved. Costs include the loss of saleable timber, though some of this may be salvaged. Felling broadleaves on bogs can also have the negative effect of reducing water loss through transpiration, thereby increasing soil water content and reducing the growth rate of e.g. conifers present. Felling broadleaves in young production stands where frost damage to young conifers is expected, and where an over story of broadleaves has been established to protect them, could lead to increased frost damage ((Nedkvitne et al., 1990). Girdling of larger trees by beaver on nonimpounded forest can also lead to considerable damage (Toole and Krinard, 1967; Bullock and Arner, 1985) but was rarely observed in this study.

Benefits include the positive effect that thinning by beaver may have on the improved growth of commercially valuable species present, particularly spruce and pine. Donkor and Fryxell (1999) found that conifers increased in relative dominance to broadleaves in the presence of beaver in Canadian boreal forest. In stands where spruce and pine are the expected prime harvest species, young birch is often heavily thinned by mechanical means or removed with defoliants. Indeed, on our study area the forest management plan stipulated that broadleaves were to be thinned on 43% of the productive forest, and 72% of this area had already been thinned at the time of the study. In stands where the management plan calls for thinning of birch, felling by beaver will presumably rarely constitute serious damage, and may even lighten the foresters thinning chore thereby leading to better production of conifers.

On sites where the production of saw log quality birch is the prime objective, the lowest quality stems will usually be thinned to obtain an optimal density for saw log production. Beaver are central place foragers (McGinley and Witham, 1985; Basey, Jenkins and Busher, 1988), removing less birch as the distance from the lodge and water’s edge increases. This form of “thinning” most likely will produce different end results of birch volume and quality than stands thinned by man. In most Norwegian forests, spruce or pine are the natural climax species (Larsson, Kielland-Lund and Søgnen, 1994) suggesting that broadleaf thinning by beaver may enhance growth conditions for conifers, shorten the climax cycle, and lead to a higher volume harvest of spruce and pine.

For the forester, the essential question is how felling by beaver affects the production of mature-age birch, spruce and pine on forest managed by intensive methods. To our knowledge, no data of this type exists, as beaver populations have only recently begun to peak on most of their former range, and because most intensively managed forests in the Nordic countries are too young to have reached harvest age following initial clear cutting. Thus the long-term effect of beaver on intensively managed forests is presently unknown.

The mean proportion of birch ≥ 10 cm dbh removed by beaver within felled areas in our study area was estimated at 50%, which was only about 1.3% of the commercially harvestable birch on the entire study area. As beaver have been present on the study area for only about 30 years this may be a minimum value. Johansen (1999), however, reported similar results finding that beaver had felled 52% of the available birch and 64% of the aspen within felled areas in boreal forest in southeast Norway, and where beaver had been present for about 40 years (Rosell and Aarvak, 1997).

The cost of felling by beaver is closely coupled to the market value of birch. From 1985-92 the mean value of birch saw logs sold by the Fritzøe Skoger Company increased from 69% to 98% of the mean value for spruce, while the mean value for birch chips remained stable near 83% of the value for spruce. However, as only 3% of the birch harvested on the forest is of saw log quality, birch on the whole is of lower value and its production therefore not likely to be favored by Norwegian foresters, except on those few sites where birch grows best. In summary, the economic costs and benefits of broadleaf felling by beaver in boreal forest have yet to be measured adequately, though we suspect that the benefits to Nordic forest owners will often outweigh the costs.

5.3 Cost of Damage Control and Benefits from Hunting

In 1998 the income from the sale of hunting rights amounted to one third of the cost of controlling beaver. We estimated that the sustainable harvest of beaver on the forest could be about 10 times the take in 1998. Thus the potential for increased income from the sale of beaver hunting is considerable, and an increased harvest should have the added benefit of reducing damage. At present, the interest in spring beaver hunting in Norway is increasing. In fact, some tour operators selling guided hunts are having difficulty finding landowner organizations with large enough units of suitable habitat to meet the demand. The market value of beaver meat is also increasing. Hunters can presently obtain around US$6.40/kg for the sale of whole carcasses (meat with bone) to local restaurants and butcher shops. Recently, choicer cuts of beaver meat were advertised for sale in a local shop for US$12.60/kg. In comparison, hunters from the same area for the past few years have been selling whole carcasses of moose (*Alces alces*) for US$ 8.80/kg (Vasdal, 1999).

As the price for beaver fur is presently very low, and permission to remove nuisance animals and their dams outside the hunting season is easy to obtain, dead trapping of beaver in Norway functions primarily as a means of nuisance animal control. Thus the level of both in and off-season trapping, and dam removal, are good indirect measures of the landowner's perceived damage from beaver. As very few colonies had been trapped, few dams removed and no nuisance animals had been killed on the study area during recent years, we interpreted this to mean that damage, at least on this part of the forest, was considered negligible by the landowner. This may be partly do to the relative inaccessibility of the study area, with resulting high cost of control. In contrast, Härkönen (1999) found that in Finland, where impoundments averaged much larger, forest owners were more active in attempting to control beaver damage.

One key factor influencing the value of beaver to landowners is the relative accessibility of good hunting areas during spring break-up, when most hunting occurs. This is usually in April, when travel by foot on melting snow and by vehicle on muddy roads can be difficult and limiting for hunter access. Beaver habitats at higher elevations, or situated far from major population centers, will also be less attractive to hunters.

In summary, the interest in beaver hunting and the market value for beaver meat are increasing, which in turn should increase the value of beaver to the landowner relative to other forest products. This should lead to increased harvests, reduced damage, a higher damage tolerance and better acceptance of beaver among landowners.

5.4 Effect of Intensive Forestry on Beaver

Much has been written about how beaver affect forestry, but how will intensive forest management affect beaver density and production in the long run? Results from this study on Eurasian beaver and Härkönen's (1999) study of North American beaver in Finland suggest that beaver favor pre-thinning and thinning age stands containing a large component of young to middle aged birch and aspen. This pattern of regrowth is primarily the result of clear-cut practices (Solbraa, 1996). As long as broadleaves in the younger age class stands are not excessively thinned or removed with defoliants, modern clear-cut forestry may actually increase beaver density relative to those harvest forms where older trees are selectively cut, or even to natural regeneration cycles. The proportion of preferred broadleaves within about 50 m of the waters edge seems to be a key factor determining beaver density. The observation that beaver favored the younger class H2 over final harvest class H5 supports this contention, as the volume proportion of broadleaves in Telemark County in classes H2, H3, H4 and H5 were respectively 37%, 23%, 23% and 13% (Tomter, 1991). Thus broadleaf content is both greatest and youngest in H2 and least and oldest in H5.

Though less attractive to beaver, final harvest age stands were nevertheless colonized to some extent in the present study, and seemingly even more so in Finland (Härkönen, 1999). As long as final harvest age stands contain some broadleaves, particularly near the water's edge, beaver may colonize them. As of 1990, 36% of the productive forest area in Telemark County was in class H5 (Tomter, 1991). The management of broadleaves in riparian habitats within this class will therefore likely influence beaver densities. The long term goal in Norway is to maintain, and preferably increase, the proportion of broadleaves in all age classes where this is compatible with production goals (Solbraa, 1996). We suggest the riparian zone be given special attention in this respect. If this goal is attained, we predict that intensive, clear-cut forestry will enhance beaver density.

5.5 Beaver, Biodiversity and Multiple Use Forestry

Beaver originally occurred throughout much of Eurasia and following near extirpation are rapidly returning to previous habitats (Rosell and Parker, 1995; Nolet and Rosell 1998; Rosell and Pedersen, 1999). As ecosystem engineers, beaver create impoundments and fell trees, creating major disturbances in ecological succession processes (Pastor and Naiman, 1992; Pollock, Naiman, Erikson, Johnston, Pastor and Pinay, 1995). At the local level, this can have both positive and negative effects on local biodiversity (Jones, Lawton and Shachak 1997). At the landscape level, however, beaver activity will likely have significant effects on biodiversity, and their return must be viewed as an important step in the process of Eurasian ecosystem restoration.

Multiple use is a central goal of Norwegian forest management and foresters are strongly encouraged to enhance biodiversity in their forests through various management schemes (Hytönen, 1995; Solbraa, 1996). Though the proportion of the landscape affected by beaver in this study was small, their effect on Nordic biodiversity may nonetheless be important (Rosell and Parker 1996). Beaver also represent a potential source of income for many landowners through the sale of hunting rights, guiding and other services, as well as through the sale of nonconsumptive tourism (Rosell and Parker, 1995). Foresters should therefore increasingly view beaver as a welcome and revitalizing element in today's often sterile forest environment, rather than simply as a nuisance. In time, they must learn how to define and limit the real damage beaver sometimes incur and accept them again as a desirable and key segment of our ecological heritage.

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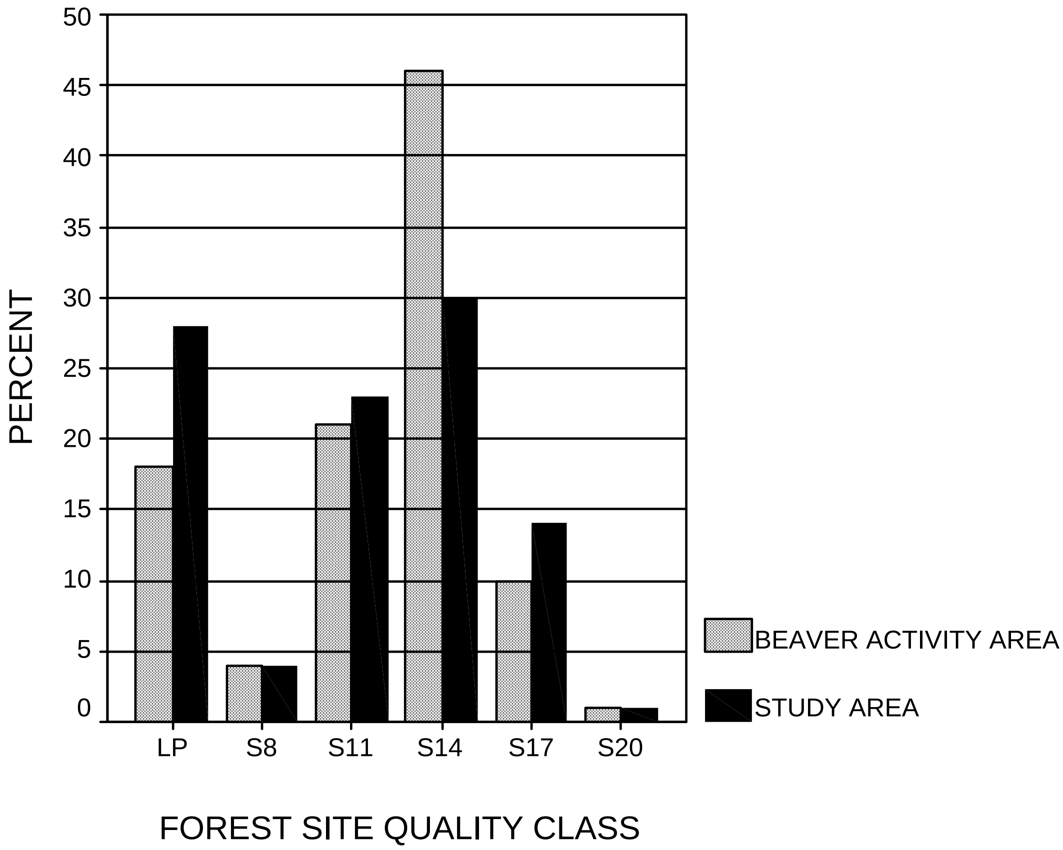
Figure texts

Figure 1. Distributions of forest site quality classes on the study area and on the beaver activity area (area felled on and inundated by beaver). Forest site quality classes are arranged in order of increasing site quality. Area is measured in hectares. The distributions were significantly different (Chi-square test, $X^2 = 113.02$, 5 df, $P < 0.001$).

Figure 2. Distributions of forest harvest classes on productive forest on the study area and on the beaver activity area (area felled on and inundated by beaver). Area is measured in hectares. See Methods for description of forest harvest classes. The distributions were significantly different (Chi-square test, $X^2 = 204.8$, 3 df, $P < 0.001$).

Figure 3. The number of colonies where birch and aspen were absent, and the proportion of birch and aspen ≥ 10 cm dbh (diameter breast high) cut down within the area of forest felled on by beaver (felled area) on 38 colonies.

Figure 4. The combined number of birch and aspen and the number of spruce ≥ 10 cm dbh (diameter breast high) killed from inundation by beaver in 38 colonies.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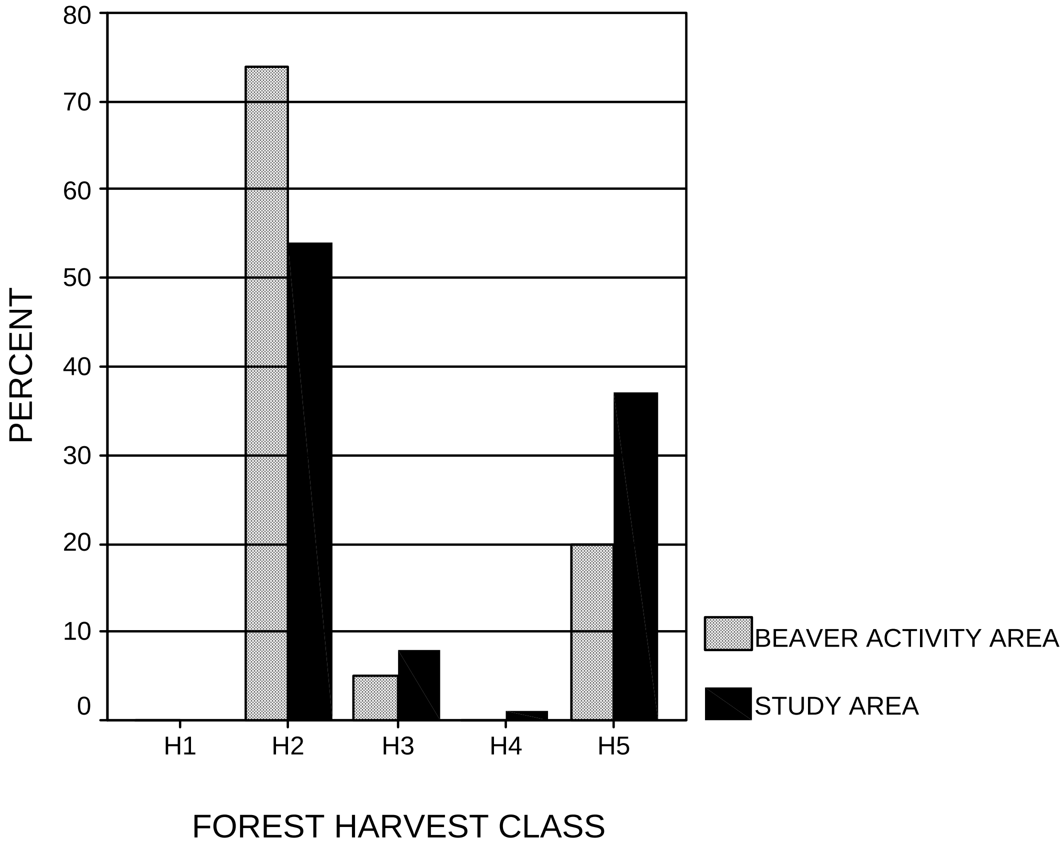
45
40
35
30
25
20
15
10
5
0
PERCENT
LP
S8
S11
S14
S17
S20
FOREST SITE QUALITY CLASS
BEAVER ACTIVITY AREA
STUDY AREA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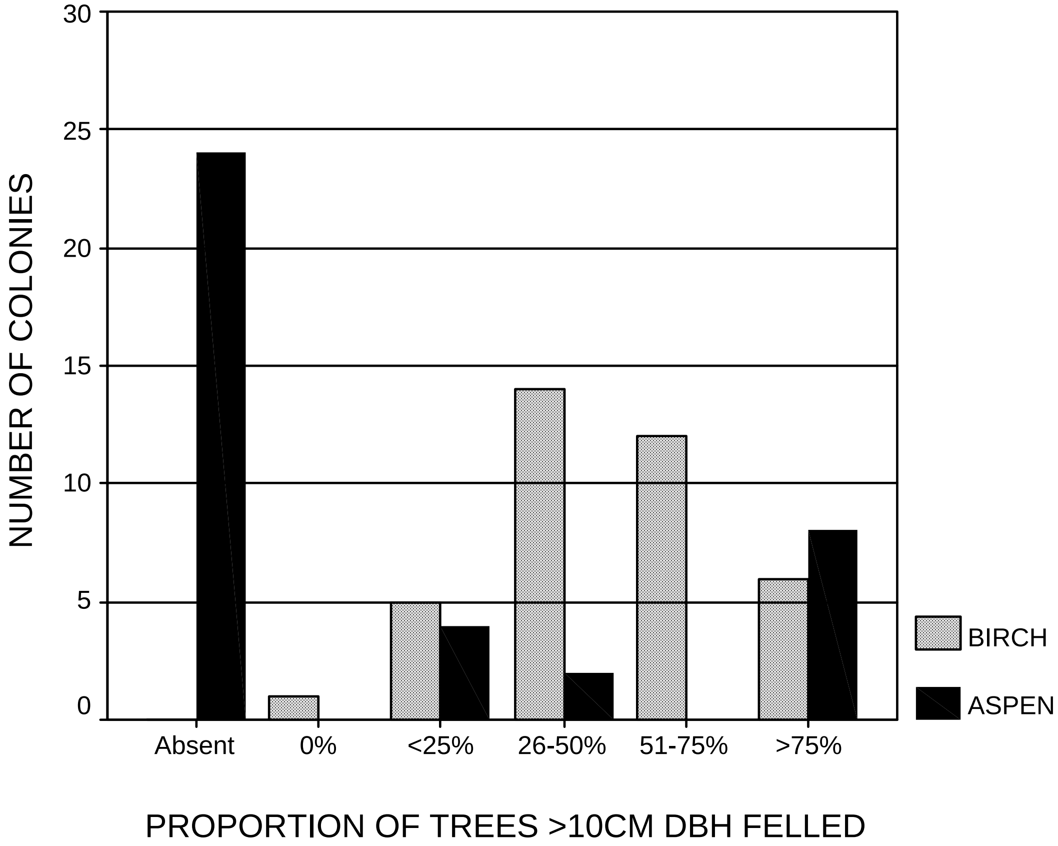
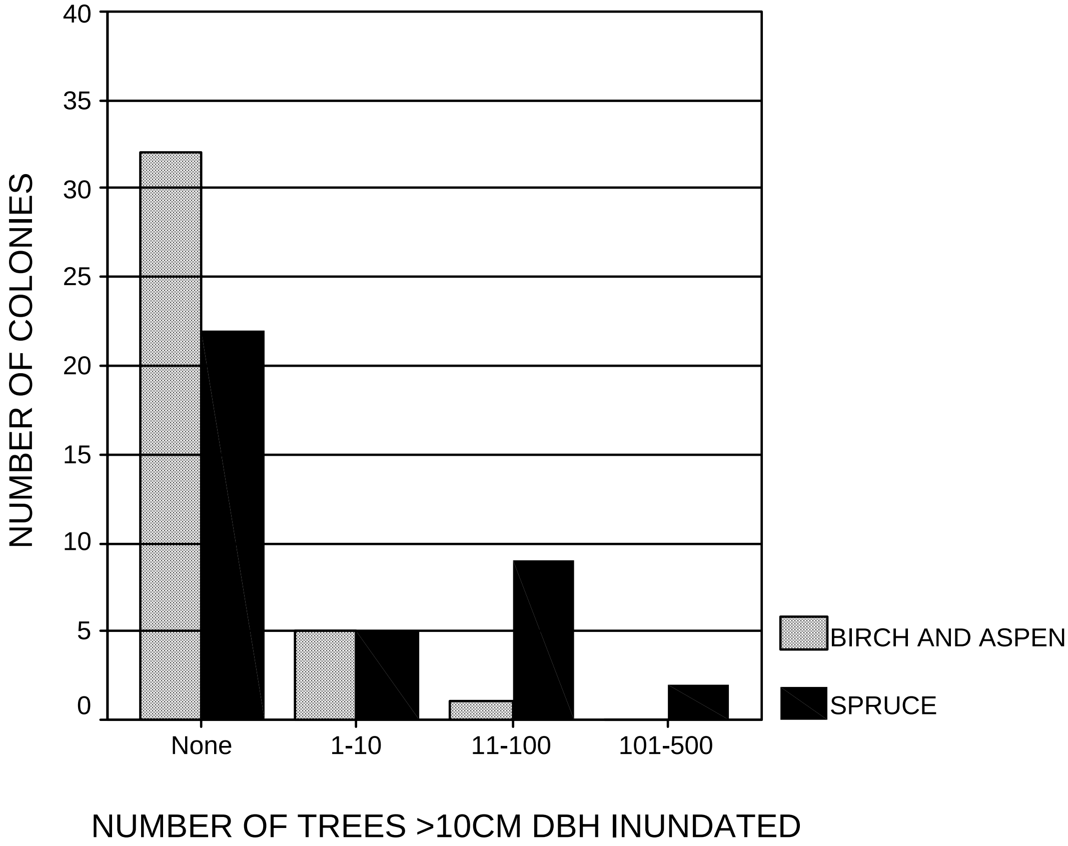
70
60
50
40
30
20
10
0
PERCENT
H1
H2
H3
H4
H5
FOREST HARVEST CLASS
BEAVER ACTIVITY AREA
STUDY AREA



NUMBER OF COLONIES
30
25
20
15
10
5
0
Absent
0%
<25%
26-50%
51-75%
>75%
BIRCH
ASPEN
PROPORTION OF TREES >10CM DBH FELLED


40
35
30
25
20
15
10
5
0
NUMBER OF COLONIES
None
1-10
11-100
101-500
BIRCH AND ASPEN
SPRUCE
NUMBER OF TREES >10CM DBH INUNDATED