DOI: 10.2478/frp-2018-0037
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Grudzień / December 2018, Vol. 79 (4): 365–375

re View ar ticle

e-ISSN 2082-8926

Current possibilities of mechanized logging in mountain areas

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Abstract. Modern technologies allow wood harvest in almost all terrains, including hard-to-reach mountain areas. Each of the technical measures used, however, has limitations due to its construction and the nature of the work. The present study discusses issues related to the selection of machinery and technology as well as planning work in mountainous terrain, taking into account factors such as accessibility of the stand and terrain properties (slope, ground bearing capacity). Adaptive changes of forest machinery for work in mountain stands are also presented. This article furthermore discusses possibilities of applying machinery and technologies already used in other countries to harvest wood in mountainous forests in Poland.

Keywords: Wood harvesting, steep terrain, mountain conditions, harvester, forwarder

1. Introduction

Price and others (2011) state that mountain forests cover 9 million km^2, which is 23% of the area of forests growing on Earth. They also point out that forests in Europe occupy 41% of mountain areas, more than half of the Alps, Balkans and Pyrenees. The need to log these areas has resulted in the successful use of harvesters there (Sauter et al. 1998; Heinimann 1999; Moskalik, Stampfer 2003; Probst 2005; Spinelli et al. 2013; Visser, Stampfer 2015), and the wood logged there is skidded by using various technical means, mainly cable yarder and forwarders.

Poland does not abound in significantly differentiated types of mountain forests. Lack of information about stand areas in terms of the slope of the terrain does not facilitate choosing the technology that can be used. With some approximation, the share of upland habitats – 5.9% and mountainous ones – 8.2% of the total forest area in Poland, available on the Data Bank on Forests portal may be used.

Over the last 25 years, the number of specialized machines for harvesting timber, especially harvesters and forwarders, has been systematically growing in Poland (Kusiak 2008; Żabierek, Wojtkowiak 2013; Mederski et al. 2016). Most of these machines work in the lowlands, but increasingly more often, they are used in areas with a varied topography.

2. Specifics of logging in mountain condition

A number of problems are encountered by machines working in mountain areas that do not occur in lowlands, such as:

- increased need for power relating to moving on slopes,
- problems with stability during work and transit,
- large diversity of substrate – from rocky to considerably thick soils, which collect moisture during spring thaws or intense rainfall,
- the large volume of trees obtained during harvesting, often greater than in lowland areas,
- weather conditions influencing the planning and course of logging in mountain areas to a much greater extent than is the case in the lowlands, for example, melting snow, heavy rainfall, which practically stops the work due to the very high risk of erosion.

In the following chapters of this paper, the authors present the technical and technological solutions for the use of machinery to harvest wood in the mountain forests of many countries, focusing mainly on the selection of machinery and technology, planning the work and the adaptive changes made to the machines themselves. Learning about the experiences of using these machines in other countries is worthwhile in terms of the potential of transferring the applied solutions to Poland.

r eceived: 24.06.2018 r., reviewed: 17.10.2018 r., accepted: 4.11.2018 r.

3. Choice of machines and technologies

When choosing the right technology and planning the work of logging in mountain areas, both the limitations due to the construction of the technical equipment, as well as the terrain and the type of ground (Fig. 1, 2) should be taken into account. The type of technology used depends on: the degree of slope, local traditions and the availability of technical equipment.

The NEWFOR[1] project (www.newfor.net) distinguishes seven technologies used in alpine conditions – from the simplest 'chain saw + horse/skidder' to the most advanced 'harvester + forwarder and chain saw + helicopter'. The level of mechanization of the technology used depends on many factors. In addition to the previously mentioned restrictions, the economic aspect should also be taken into account, visible even in the Italian regions of Veneto and Lombardy (data from 2008–2010). The vast majority of logging companies are very small businesses – almost 70% of registered companies in the Veneto region are single-person companies. In turn, about 40% of the companies in Lombardy are very poorly mechanized, having only a small tractor for hauling and transporting timber. 49% of the companies have logging tractors, tracked harvesters (on an excavator undercarriage) and cable yarders, 11% also have forwarders. Austria and Bavaria are found at the other extreme in terms of the level of mechanization of wood harvesting in mountain areas. In Austria, the share of harvesters and processors is definitely increasing, and cable systems (winches and cable cranes) are used for skidding, with a gradual increase in the share of forwarding. In Bavaria, where over 30% of wood harvesting occurred in the Alpine region in 2013, the share of tractors and skidders dropped to 35%, while the share of forwarders remained at 15%. Much depends, therefore, on the wealth of the local community.

The selection of a logging system also depends to a large extent on the density of the existing road network (www.newfor.net). In the case of poor road quality, the second stage of logging − transporting the raw material to the nearest roadside landing accessible to transport vehicles − is significantly extended. Certain limitations relating to mechanized logging and its efficiency in mountain areas include the volume of the harvested trees (if it is too large, it can sometimes make it impossible to use a harvester) and silviculture requirements. Sometimes the factor limiting the mechanization of such work may also be the lack of qualified machine operators

[1]The project involved Alpine countries, among others: Austria (Montafon and Tyrol), France, Germany (Bavaria), Slovenia and Italy (the Veneto and Lombardy regions).

Enache et al. (2015) draw attention to the specific characteristics of mountain forests and the richness of their ecosystem services and functions. They note that the goal of traditional silviculture is sustainable timber production, whereas sustainable forest management is a concept that supports the multifunctional role of forests. In this case, the use of selective felling seems to be the right approach, but difficult to apply and debatable in terms of technical feasibility and economic efficienc . The selection of a harvesting system is hindered on the one hand by the growing interest in semi-natural silviculture and its adaptation to climate change, and on the other by the growing demand for good quality wood and wood for energy production.

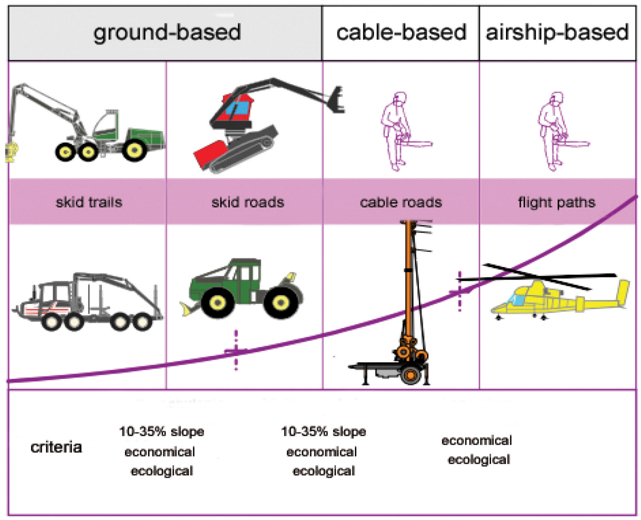

Figure 1. Different concepts of logging depending on the slope (Heinimann 1999)

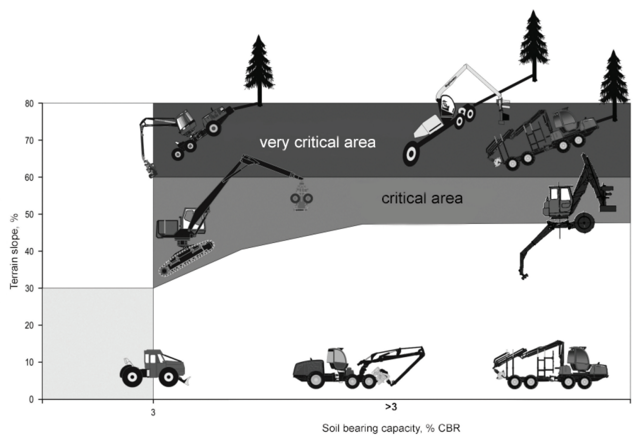

Figure 2. Safe scope of work of ground-based wood harvesting machines depending on the slope [%] and bearing capacity of the ground, measured by the California Bearing Ratio – CBR (Heinimann 1995 after Visser, Stampfer 2015)

A separate issue is the selection of harvesting technologies depending on the volume and species composition of tree stands. Laurow and Trześniowski (2000) emphasize that the harvesting process should be preceded by a thorough analysis of the impact of individual organizational, technical and technological solutions on the environment.

4. Planning the harvesting work

4.1. Choosing the right harvesting technology depending on accessibility to the stand and other selected parameters

In mountain areas, the most important factor affecting the selection of the right technology for harvesting timber is accessibility to the land (Heinimann 2000). The transport of wood is divided into two closely related stages, conducted in the stand and on transport roads. With greater frequency, special software is used to plan the work, providing support to the decision making process on building roads, determining the location of landing sites and deploying wood harvesting equipment – skidders, cable cranes (Heinimann 1998; Epstein et al. 2001; Grigolato et al. 2017). Such systems are developed based on the data from GIS databases and powered by them (Fig. 3).

Based on a numerical terrain model and road network as well as inventory data and boundary parameters for different logging systems, Poršinsky et al. (2008) developed a functional terrain classification for selecting harvesting technology. The model for selecting an environmentally protective harvesting system for the managed forests of northern Velebit (Croatia) takes into account three factors: slope, skidding distance and average diameter at breast height of the stand. On the basis of the developed model, the harvesting system was determined for each forest stand. The results show that DBH size limits the mechanized harvesting and delimbing of the wood. It turned out that fully mechanized harvesting systems could only be used on 7.27% of the studied area. In the analysed case, ground-based logging dominated.

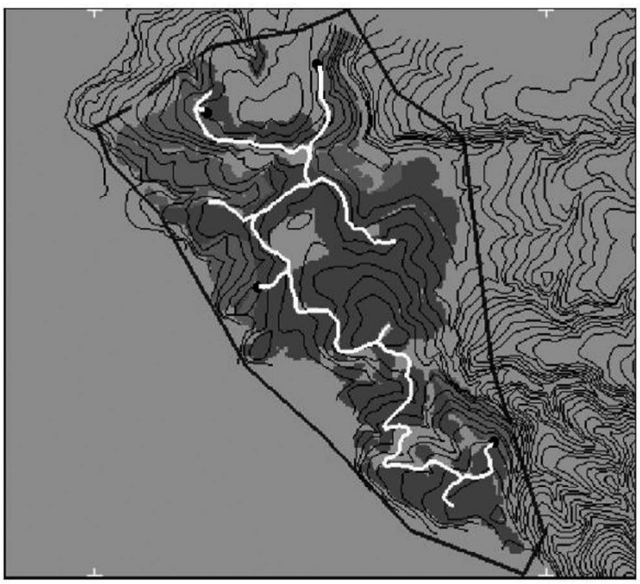

Figure 3. The effect of using the PLANEX system for planning harvesting tasks. Roads are marked in white, dark areas are tree stands for skiders and bright for cable cranes. (Epstein et al. 2001).

In turn, Kühmaier and Stampfer (2010) developed a decision-making support system in selecting wood harvesting technologies and correcting the road network. The system was used to select the best technologies for obtaining and estimating the environmentally protective, economic and social effects of their application, after correcting the road network. The model was implemented in a steep terrain in an area of 1100 ha of forests in the southern part of Lower Austria. The positive effect of using a cable-assisted forwarder on efficienc , CO_2 emissions and stands was noted. The authors found that the combination of increasing forest road density and deployment of cable-assisted forwarder technology led to tripling of productivity, an increase in the contribution margin from 40 to 56 EUR/m^3, as well as a reduction in stand damage rate by 53% and injury rate by 93% for the analysed forest company. No other option brought such high benefits. However, increasing the road network density may be difficult to implement, due to social pressure requiring the more selective type of logging forest stands and limited road infrastructure (Stampfer et al. 2006).

The density of the road network affects the possibilities of using skidding resources. Optimum network density is associated with the amount of wood to be obtained from one hectare, the cost of road construction and the size of a single load of harvested timber. Under the conditions in Austria, Ghaffariyan et al. (2007) determined the optimal road density at 19.9 m/ha, with the following assumptions: average forwarder load – 8.25 m^3, harvested volume – 100 m^3/ha and road construction cost – 20 EUR/m. Assuming that the machine will always skid a full load (17.5 m^3), the road density could be lower – 13.5 m/ha. The inclination of the slope on the study site surface was 11%.

With similar assumptions regarding harvesting and road construction costs, Ghaffariyan et al. (2010) determined the optimal distance between roads in the event of skidding using the Wanderfalke tower yarder with a cable length of about 500 m. The results obtained for one-way and two-way hauling are 261 and 374 m respectively. The authors noted that harvesting costs for one-way uphill hauling drop sharply when the distance between roads increases from 20 to 230 m; while in the range from 230 to 290 m, they decrease only by 0.16 EUR/m^3, which is an indication for those planning to modify a forest road network.

When planning logging work in mountain areas, the economic constraints of different technologies should be remembered. Heinimann (1998) modelled the costs of two logging systems – a skidder and using a cable yarder, depending on the slope of the terrain (30% and 60%) and road network density. With the parameters set by the author, among others, a main cable system length of 500 m, the model suggested choosing a cable crane when the hillside slope was more than 42%, and a skidder when the road network density was above 25 m/ha.

When planning harvesting work and related potential road investments, the protection of the following elements should be taken into account (Heinimann 2000):

- catchment area – road construction and applied logging technologies may pose, among others, the threat of erosion and landslides;
- habitat – harvesting and skidding timber directly affects the soil, causing erosion and compaction. The mechanical properties of the soil depend on its water content. Disruption of the soil structure can be prevented in three ways: avoid driving machines on the soil surface when the soil moisture is high, use low-pressure tires, and limit the number of machine trips along the logging routes;
- employee safety – forestry is a sector with high accident rates. Manual-machine technologies are particularly dangerous;
- natural resources – production processes involve the consumption of materials, energy and the release of waste into the environment. LCA[2] analyses are becoming signifi cantly more important in this case. The later works of Heiniman et al. (2012) and Klein et al. (2015) showed that LCA analyses are not widely used to assess forestry work, focusing more on the invested energy and bypassing the environmental burden.

The authors of this paper propose one more element, whose protection should be taken into account – the populations of the animals and plants living in a given area.

4.2. Availability of the technology

The extent of using the modern technologies of ground-based technical equipment (harvesters, skidders, forwarders) is still low in the mountain areas of some countries. Survey studies conducted in the Italian Alps of the Lombardy region showed that cable systems are most often used by logging companies (Mologni et al. 2016), and only three forwarders and one skidder were operating in the area included in the study. This is confirmed by the results of research conducted several years earlier (Spinelli et al. 2013). The most popular systems were sled yarders (almost 65% of all cable systems), used for skidding down a slope for a distance of 800–850 m. The share of mobile cable cranes with spars and cable systems with carriages with their own drive was 15%, while mobile cable carriages without a spar accounted for less than 5%.

According to the authors, an alternative to cable systems currently used in the Italian Alps could be ground-based machines belayed with synchronized winches that can work on hillsides with up to a 60% slope (Visser 2016). This would mean limiting the use of cable yarders to very steep slopes, although the size of the slope itself is not the absolute measure of using a given technology, but also its morphology and relief. Cable logging systems are, however, more expensive than ground-based systems (Ghaffariyan et al. 2007).

4.3. Slope and other properties of the terrain

Cable technologies dominate in logging timber in mountain areas, but the use of ground-based, wheeled or tracked machines is becoming more common (Visser, Stampfer, 2015). One of the factors limiting their use is the slope of the terrain. Initially (FAO/ECE/ILO 1971 cited in Visser, Stampfer 2015), practical limits were set for skidding logs downhill for wheeled skidders at 50%, and tracked skidders at 60%, depending on the terrain. Subsequent experiments have shown that due to the risk of soil erosion, however, these values should be limited to 30% and 40% respectively (Peters 1991 in Heinimann 1999; Visser, Stampfer 2015). Research conducted on 22 machines in New Zealand (18 machines), Austria (2 machines) and Norway (2 machines) showed that modern machines often exceed the limits adopted in New Zealand – by 17% (~38%) and 22% respectively (~50%) (Berkett, Visser 2012; Visser, Berkett 2015).

Sometimes manufacturers provide guidelines on the traction abilities of machines on their websites. According to Komatsu (after Visser, Stampfer 2015), machines secured with a winch can work on hillsides with a slope of up to 55%. Cavali and Amishev (2017), citing Cavali (2015), accept the following slope limits (Table 1).

In addition to the slope of an area, the bearing capacity of the ground (Heinimann 1999; Strandgard et al. 2014) and its local relief (ruggedness) – rifts, boulders and so on (Amishev et al. 2009; Cavali, Amishev 2017) – are also important elements affecting a machine's ability to work, as well as the presence of stumps (Visser, Berkett 2015).

In Heinimann's research (1999), three machines were considered in terms of the dependence between climbing ability and undercarriage properties: the IMPEX 'Bengal Tiger' tracked harvesting machine, the Timberjack 1270B wheeled harvesting machine (with 600/55–26.5 tires), and the FMG 1710 (with 800/40–26.5 tires) clambunk skidder.

[2]LCA is the Life Cycle Assessment.

Table 1. Slope limit [%] for different types of forest machines

Type of machine undercarrige	Harvesting	Skidding	Forwarding
		[%]	
Wheeled, equipped with chains and half-tracks	35–45	35–45	30–35
With trapezoidal caterpillars	50–70	-	-
Tracked	45–60	45–55	35–45
Wheeled-walking	60–80	-	-
Winch-assisted machine	75–85	75–85	75–85

The author notes that in most textbooks on forestry work, machine mobility limits are provided in relation to the maximum agreed slope gradient. The test results presented in Figure 4 show that slope gradient alone is not a sufficient criterion and that soil properties should also be taken into account, especially under low load bearing conditions.

5. Machine adaptations for work in mountain areas

5.1. Improving stability

Machines designed for working in mountainous conditions require modifications in two areas: to improve the stability of the machine while working on the slope and to improve its ergonomics. Issues relating to ergonomics were resolved in the United States in the 1980s. Tracked excavators were adapted for forestry work there, and instead of buckets, they are equipped with felling heads, processors, harvester heads or grippers. Some of these machines already had a levelled cabin and a crane. Such design solutions improve operational capabilities and are more efficient than machines without levelled cabins (Schiess et al. 1983 in Visser; Stampfer 2015; Stampfer 1999 in Amishev, Evanson 2010). A levelled cabin, and especially a levelled crane column, is also important due to the durability of the equipment's elements – when a crane column is tilted from the vertical, an additional torque is added to the construction/structure during rotation.

While the first solution for levelling cabins had a manual-mechanical control, the actions of an operator are now replaced by automatic mechanisms. The standard also includes levelled, swivel seats, full cabin glazing and cameras to improve visibility during work. The cabin follows (to a certain extent) the movements of the crane, reducing the exertion of neck muscles.

A much more difficult issue is to ensure the stability of the machine while working on a slope, that is, controlling the position of the centre of gravity. The levelling of the cabin and crane, used in forestry machines with a tracked undercarriage, also changes the position of the centre of gravity of the entire structure, improving its stability.

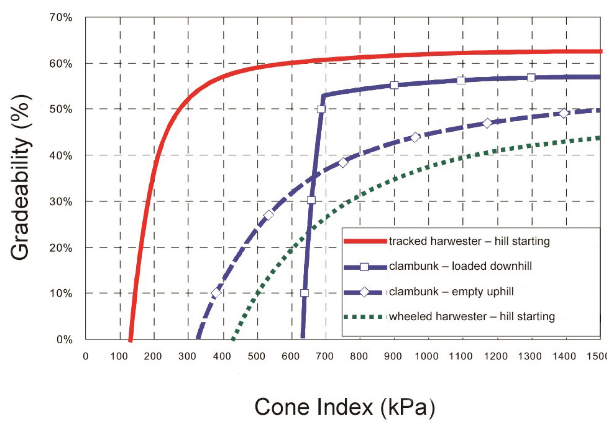

Figure 4. Slope climbing ability for tracked and wheeled machines depending on the ground properties determined using the Cone Index (Heinimann 1999)

In addition to levelled cabins, which only improve the operator's comfort, wheeled machines use other solutions to maintain stability. One of the most common is to increase the number of wheels to eight, group them in tandems (bogie axles) and equip them with half-tracks. The use of tandems makes it much easier to overcome small obstacles – stumps, hollows and so on, reducing the lateral tilting of the machine (harvester or forwarder). The tandems make the machine lean out half as much as it would with a single wheel.

Sometimes, additional hydraulic cylinders are used to lift the wheels in the front tandem. This temporarily transforms the eight-wheeled machine into a six-wheeled machine, but it makes it easier to overcome uneven terrain, such as ditches.

5.2. Changes to the undercarriage chassis

Depending on the solution used for the undercarriage construction, the possibilities of using a harvester in mountainous conditions are also different (Fig. 5). The use of more wheels and half-tracks significantly increases the scope of the use of these machines on slopes.

An example of a harvester with a specialized undercarriage is the Valmet 911 'Snake' (Moskalik, Stampfer 2003) – a tracked machine specially designed for harvesting wood in mountain stands. The modification of the standard Valmet 911 wheeled harvester consisted of replacing the wheels with four trapezoidal, independently moving 50 cm wide caterpillar tracks. Field studies conducted in Austria (Stampfer, Steinmüller 2001) showed that a machine constructed this way can more easily overcome various uneven terrain and work on hillside slopes of up to 70% than a standard two-track harvester (on an excavator undercarriage).

About 50% of harvesters in Austria (Pröll 2001 in www.newfor.net) are equipped with caterpillar tracks. Their use reduces the pressure of the machines on the ground and enables work on hillsides with a higher slope. This also applies to harvesters built on the basis of tracked excavators. It is important for the harvester to leave the branches and tops of trees on the logging road. They not only protect the soil – the depth of soil deformation decreased from 14 cm to 10 cm – but the material crushed by the machines more easily mineralizes (Duszyński, Walczyk 2009).

An interesting solution improving the stability of wheeled harvesters during work is a machine constructed by the Ponsse company – the Scorpion King harvester. Unlike other wheeled harvesters, it has a three-piece articulated frame, with a cab and a crane mounted in the middle part. This allows the centre of gravity to be lowered, as well as the cabin and crane to be levelled during work. This is controlled by an extensive sensor system. Sensors located between the cab and the crane monitor the rotation direction of the crane, while the sensor located in the lower part of the crane controls its position. The stabilization system is also active while driving, providing the operator with comfortable conditions while the machine is moving.

Wheeled-walking harvesters are another design innovation, constructed on the basis of excavators designed to work in very difficult terrain. An example of such solutions are the machines proposed by Menzi Muck AG and Kaiser (Kaiser S3 Spyder), which are technically very similar. Each of the four wheels is independently suspended on outriggers additionally equipped with various spurs, so that each of these machines maintains high stability while working in difficult terrain. Instead of a harvester head, the crane can be mounted with timber handling grippers. In difficult conditions, these machines often have to support the stabilizers that carry their entire load (Amishev, Evanson 2011), which is why their weight is not large, reaching a maximum of 12–13 tonnes. They have high swing torque and a large lifting capacity. In this respect, they have operating parameters similar to a 20-tonne tracked excavator. Some of these machines are also equipped with a winch.

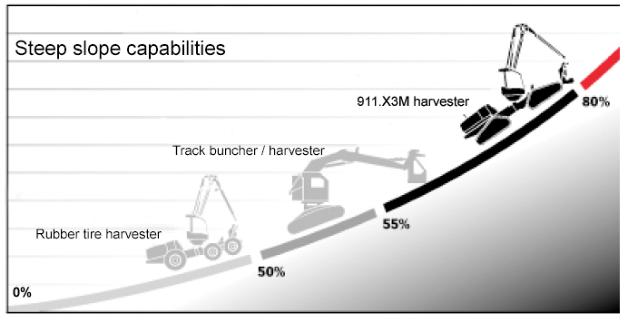

Figure 5. Different types of harvester undercarrige and their capabilities to work on steep slopes (Jaffe, O'Brien 2009 after Ghaffariyan et al. 2012)

Due to their specific characteristics (mainly low mass), wheeled-walking machines have cranes with a reach of about 8 m, which is small in comparison to other harvesters. As a result, they have to move more often (Amishev, Evanson 2011).

A study of the walking Kaiser 2 harvester conducted in Slovakia (Slugeň, Jankovský 2012) showed that in terms of the impact of logging on the forest environment, 6.19% of the remaining trees were damaged in a mixed stand (spruce, fir and beech) located on a slope with an inclination of 70%. According to the authors, this is acceptable compared to the results of other studies. Most soil damage in the form of ruts up to 15 cm deep was recorded under the supports. However, the authors did not evaluate this negatively, because these deformations were not continuous and would not result in soil erosion during heavy rainfall. Low soil compaction was also noted in the ruts.

Another interesting solution of a harvester developed exclusively for work in mountains is a proposal from the Konrad company, the Highlander harvester. The elements characterizing this machine is a telescopic frame and steering wheels. Konrad proposes not only a harvester, but basically a complete system that allows logging by the assortment method of both wood and whole logs, with the simultaneous skidding of the obtained raw material using a remote controlled trolley for short or whole timber removal. The harvester itself can also work in a harvester-clambunk version, after mounting bunk grapple on the frame (Kormanek, Kępa 2016).

5.3. Winch-assisted machines

As Visser (2013) notes, the beginnings of securing machines working on slopes using cables occurred in the army, which tested them in the 1950s. In European forestry, this solution emerged in the 1990s (Sebulke 2011), when a number of companies began offering integrated winches (built-in) with machines or mounted on machines. Initially, they were used on forwarders, later also on harvesters.

In order for a machine to be able to move uphill, the traction force T should be greater than the force Wg pulling the machine (Fig. 6). If the value of Wg for a given hillside slope remains essentially unchanged, then the pull force value depends on the parameters of the ground. For example, for a moist, soft substrate, it is 0.4, and for a dry and stable substrate – 1. The coefficient of traction depends on the type of machine, because tracks have a greater coefficient of traction than wheels. Rainfall can significantly reduce the value of this coefficient. Figure 7 shows how these parameters affect machine operation capabilities. In the case of a soft, moist substrate (CoT = 0.4), the analysed machine can run alone on a slope with an incline of up to 20%. However, if the coefficien has the maximum value (CoT = 1), then the maximum slope value increases to around 45%.

The use of a winch supporting the machine's movement allows it to improve traction conditions and to work on hillsides with a steeper slope and the same substrate. In the case analysed by Visser (2013), an 'investment' of approximately 100 kN allows the hillside's slope to increase (e.g., for CoT = 0.4) from 20 to 40% (Fig. 7). Shear force is also signifi cantly reduced. The winch can be mounted on the machine or on external mobile equipment.

The winch on a machine (Sebulke 2011; Visser, Stampfer 2013) can be built into the construction (most often under the crane in the case of forwarders) or mounted on its exterior to the machine frame (front or rear), which allows the winch to be disassembled when not needed. However, this always involves a significant increase in the weight of the machine, sometimes by nearly two tonnes, and an increase in power demand. Some modifications of the machine itself are also required, relating to the control system and the guiding of the cable, so that it does not break or pull on the ground. There are different approaches to anchoring a winch cable; in Europe, it can be attached to a growing tree, while in the southern hemisphere it can be attached to a trunk, a stake or a parked machine (bulldozer, excavator).

In the case of an external winch, it can be mounted on an self-propelled carrier or a tracked excavator, and sometimes even a tower yarder, usually used for skidding.

For safety, some systems use double drum winches, and the machine is then better protected. Cable tension should also be controlled. The forestry operations' safety rules developed in New Zealand (MBIE 2012) recommend that the cable tension should not exceed 33% of the breaking force. Visser (2016) stated that the biggest jumps in cable tension occur when the machine is moving, not when cutting or laying the raw material. The research of Holzleitner et al. (2018) provide slightly different conclusions, based on an analysis of the work of two machines supported by cables:

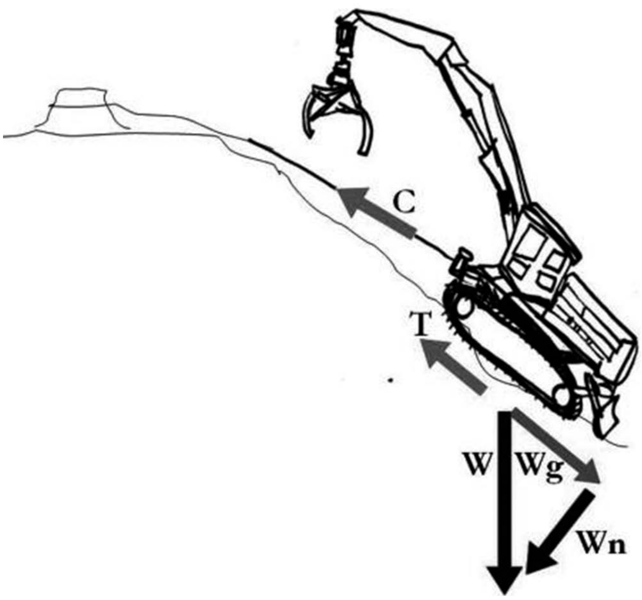

Figure 6. Schematic distribution of forces acting on the machine working on the slope, assisted with a rope: Wg – component of the gravity force W, drawing the machine downhill; T – pull force; C – tension of the winch rope (Visser 2013)

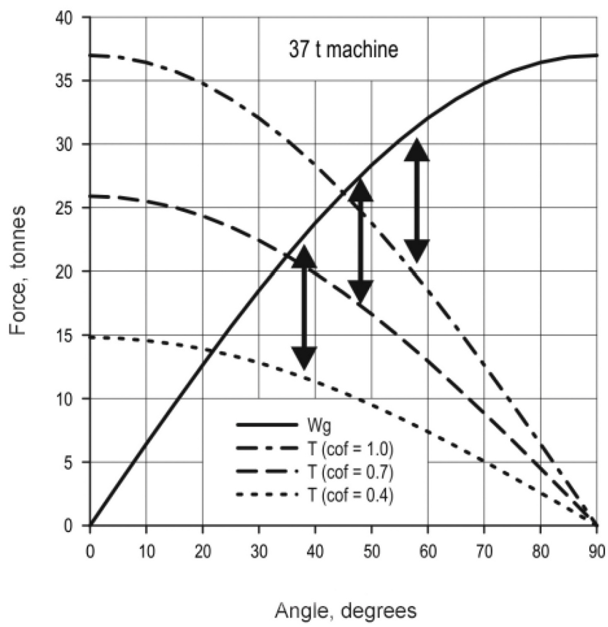

Figure 7. Influence of different coefficients of traction (CoT) and slope on tractive force (T) and rope tension (Wg) for a machine weighing 37 tons (Visser 2013)

a John Deere 1170E harvester and a John Deere 1110E forwarder. The greatest tension on the line in the case of the harvester occurred during tree felling and delimbing. In the case of the forwarder, the highest line tension was observed during breaks of less than 15 min. and driving during loading. However, the maximum cable tension did not exceed 50% of the breaking force value in either case.

The advantages of using cable support are quite significant, as above all, it guarantees safety (Cavalli, Amishev 2017). Supporting the machine with a cable improves the operator's comfort and creates a safe working environment, reducing the stress associated with working on a steep slope. These authors also point out that the use of cable support can improve the financial stability of the company and its competitiveness, among others by:

- improving the quality of the obtained raw material, reducing soil damage and so on,
- increasing the attractiveness of the work (improving the comfort and safety of the work), which can be an incentive for potential employees, as well as a factor in their decision to stay with the company,
- versatility – the technology can be used in various equipment configurations, allowing one to work in different conditions without the need to look for qualified employees to operate cable carriages,
- facilitating regeneration work due to a cleaner work area (less scrap and logging residues).

Logging with the use of a chain saw is considered one of the heaviest of physical work (Nowacka, Moskalik 2013; Nowacka, Moskalik 2014). It is becoming increasingly difficult to find suitably qualified employees, especially for the demanding work in mountain areas, hence the need to introduce mechanical solutions (Berry 2016).

6. Summary and conclusions

Modern technologies allow wood to be obtained in almost all types of terrain, including hard-to-reach mountain areas. However, not all of the technical equipment used for this purpose is available in Poland. The number of harvesters and forwarders is systematically increasing, but adapted machines (equipped with synchronized winches), or those designed for work on hillsides with high slopes are still missing. In addition, there are practically no (apart from single instances) cable carriages that would enable logging on very steep, difficult to reach slopes. Logging in Poland is mainly done by private companies, so purchasing such specialized technical equipment can be too expensive and a risky investment for them.

Mountain habitats occupy 8.2% of the forest area in Poland. Their small share may be a reason for the low interest in the broadly understood mechanization of logging work in stands growing in these habitats. Presently, traditional technologies are mainly used there, consisting of cutting trees with a chain saw and hauling delimbed stems with an agricultural tractor or skidder, with the production of assortments on small, often temporary, landing areas along transport roads. However, multi-function machines – harvesters and forwarders – are being used with greater frequency.

The possibilities of using multifunctional machines in mountain areas are associated not only with the slope of the terrain, but also with many other factors, including: ruggedness of the terrain, availability of transport routes, type of substrate and season (mainly associated with soil moisture and related load bearing capacity) and the availability of technical equipment.

Therefore, Forest Districts must accurately inventory tree stands to determine the possibility of deploying available harvesting technologies. The examples presented in this paper show that the tools exist to conduct such an inventory and perform the needed analyses.

While the use of a chain saw to log trees (and possibly to prepare assortments) and the cable crane for skidding have a fairly wide range of applications – from wood cutting to pruning or thinning – the use of harvesters for logging timber in stands with deciduous species becomes problematic, especially in older age class stands. As Mederski et al. (2016) indicate, mountain areas characterized by a high proportion of deciduous species are not 'attractive' for harvesters. The attempts made in our country to use them for harvesting mainly deciduous species (Mederski 2013; Bembenek et al. 2015; Karaszewski et al. 2016) confirm this thesis. Deciduous trees growing in our climate zone often produce thick boughs, which are quite problematic when they are delimbed by harvester heads. This affects not only the quality of the delimbing process itself, but also the accuracy of the length of the assortments made and insufficient use of the timber for the assortments. For example, delimbing the Polish ecotype of the birch may be less effective compared to the Scandinavian ecotype (Mederski 2013; Glöde 1999 in Mederski et al. 2016). Therefore, mountain habitats with a large proportion of deciduous species should be excluded mechanized logging.

The opinion expressed by Mederski et al. (2016) that harvester heads will soon be developed to solve these problems is difficult to accept. Modern harvester heads use solid steel knives for delimbing. The delimbed tree is pulled through the head by means of feed rollers. As the thickness of the branches to be cut increases, so does the force required to cut them. Delimbing very thick branches often results in serious damage to the wood, even in the case of conifers. The feed rollers mill the surface of the wood being processed. The occurrence of large curves and thick branches makes it difficult to delimb a stem/trunk to the end of the log, and hence, the 'shift' of the valuable part of the timber to medium-sized wood, and sometimes even to fuel wood.

Another limitation is the size of the harvested trees. It was noted that some of the spruce trees to be harvested had diameters that were too large to be cut by a thinning-felling harvester. A similar observation was noted during the implementation of the NEWFOR project discussed earlier. Mountain stands require large felling harvesters equipped with appropriate harvesting heads. The use of forwarders is basically limited only by terrain conditions, mainly slope and substrate properties.

Mountain stands in Poland in many cases are undergoing conversion, which also results in technical and technological problems. The protection of regenerated sites requires a combination of different harvesting technologies, and in many of them, the use of manual-machine (chain saw) and machine (harvester) technologies.

Conflict of inte est

The authors declare no potential conflicts of interest

Acknowledgments and source of funding

The project 'Possibilities of using multifunctional machines for logging in the mountain areas of Poland' was financed from the research fund of the Forest Research Institute. Project no.: 26 04 02.

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Translated by: Barbara Przybylska