Developing new-generation machinery for vegetation management on protected wetlands in Poland

A.P. Dubowski, K. Zembrowski, A. Rakowicz, T. Pawlowski, S. Weymann and L. Wojnilowicz

PIMR-Industrial Institute of Agricultural Engineering, Poznan, Poland

SUMMARY

Many protected wetlands and (especially) fen peatlands in Poland require vegetation management to restore and maintain them as breeding areas for endangered bird species. The current practice of harvesting, baling and transporting grasses, reeds and other vegetation using tracked snow groomers and wheeled farm tractors can conflict with the nature conservation goals for these sites through disturbance of the ground surface and accidents leading to spillage of oil. To address these problems, the Industrial Institute of Agricultural Engineering (PIMR) is developing new-generation agricultural machinery that will also be applicable in formal paludiculture. This article describes an innovative method for towing large bales of harvested biomass across wetlands that minimises ground pressure using any vehicle, and the development of amphibian tracked (ATV) and hovercraft vehicles for biomass harvesting operations in wetlands.

KEY WORDS: ATV; biodegradable oil; biomass bales train; hovercraft; ratrak; snow groomer; tractor

INTRODUCTION

The total area of wetlands in Poland's National Parks (NPs), Landscape Parks and Natura 2000 areas is approximately 120,000 ha. Nature conservation objectives for these protected areas often require the removal of vegetation such as grass, reeds, bushes and small trees to combat unwanted succession and restore the breeding areas of endangered bird species (e.g. Tanneberger & Wichtmann 2011, Kotowski *et al*. 2013). This usually involves the harvesting, baling and transport of biomass by farmers or contractors using wheeled agricultural tractors or second-hand tracked snow grooming machines, which are known as ratraks in Poland (Figure 1A). Such vehicles are suitable when the ground is frozen and/or snow-covered in winter, but their use for summer harvesting (in August and September) can be antagonistic to nature conservation objectives. Some of the problems are listed below.

- The wheels and tracks of currently available machinery devastate the vegetation and shear the peat surface, especially when turning (Figure 1B). The traditional snow groomer turns by directing power to one track while the other is dragged along, and this is particularly damaging to both the vegetation and the ground surface. Similar damage (Figure 1C) occurs when snow groomers and/or wheeled tractors are used to transport biomass bales, usually one at a time, across swampy terrain or wet (fen) peatland (Dubowski *et al*. 2012e,h).
- Snow groomers and tractors can drive on peaty terrain, harvest biomass and transport it out of the wetland. However, when the ground is covered by more than a few centimetres of water, they can easily sink and suffer substantial damage if disabled by a wheel or track becoming trapped in a hidden ditch or hollow.
- Because a snow groomer is designed primarily for winter use, there is a high risk of its engine overheating in summer that is routinely reduced by opening (Figure 1A) or removing the engine cover. However, this increases the risk that biomass dust created during mowing will come into direct contact with the oil-covered hot engine and ignite. The resulting fire may completely destroy the engine.
- Another risk is the spillage of oil from broken hydraulic hoses.
- The machinery is usually lubricated with mineral oil, which causes serious pollution when spilled as a result of accidents or breakdowns.

To overcome these problems, we are currently developing new vehicles and techniques for agricultural operations in wetlands that are likely also to be suitable for applications in paludiculture. In this article we outline the various innovative ideas, models and prototypes generated so far, and summarise the results of testing. Finally, we consider how the risk of soil and water pollution associated with the use of agricultural machinery in wetlands arises, and how it might be alleviated.

A. Snow groomer with an open engine cover. The build-up of biomass dust on oily surfaces makes this a potential fire hazard.

B. Ground damage caused by the snow groomer on wet fen peatland.

C. Ground damage caused by the use of a wheeled tractor for transporting biomass bales (one by one) across wet (fen) peatland. Adapted from Dubowsky *et al*. (2012e).

Figure 1. Problems associated with the use of currently available machinery on protected peatlands.

THE BIOMASS BALES TRAIN

This is a new method for moving biomass bales out of wetlands, which was introduced at the International Conference of Agricultural Engineering (AgEng 2012) in Spain (Dubowski *et al*. 2010b, 2011e, 2012e,g). The bales are connected together so that they can be rolled over the ground as a 'biomass bales train' (Figure 2A). In this way, a wheeled or tracked tractor can tow three, six, and possibly up to ten bales at one time (Dubowski *et al*. 2012c,d). The large contact area of a biomass bale with the ground during rolling means that the maximum ground pressure is significantly lower than that of the wheels or tracks of a tractor carrying one biomass bale, or a wheeled trailer loaded with (usually) 4–10 bales. Textile covers may optionally be placed on the bales to protect them from damage during rolling (Figure 2B) (Dubowski *et al*. 2012e,g).

To form a biomass bales train, the bales are linked with special lightweight adaptors (steel frame 25 kg, axle unit 7 kg). The axle of the adaptor can be drilled into the body of the biomass bale and its frame unfolded and clamped onto the axle (Figure 2C) or previous bale by one person without any technical problems, although the procedure is safer and much faster with two operators. This will seldom be an issue in practice, as work in wetlands should routinely be carried out by two-person teams (tractor driver and assistant) for safety reasons.

At a test site between Byszewice Village and the Notec River, measurements of the ground resistance to penetration (around 0.7 MPa) showed practically no impact of the bales train on the peatland surface (Figure 2A). The force on the tractor's coupling hitch that was required for rolling was 2–3 kN, and a four-bale train could move at up to 9 km h^{-1} (Dubowski *et al*. 2012g). When the ground to be crossed was very uneven or covered by woody brash, bales with textile covers suffered less damage than bales with only their net wrappings for protection (Figure 2D).

The next test of the biomass bales train principle will employ a new version of the adaptor and a Kubota M9960 tractor fitted with Soucy Track modules (Soucy Track 2012) (Figure 2E).

AMPHIBIAN TRACKED VEHICLES

The use of amphibian tracked vehicles (ATVs) on wetlands is potentially advantageous not only because they can move easily across peaty or muddy terrain even when it is flooded and float when disabled, but also because they can work in lakes, ditches and streams. An ATV designed specifically for harvesting and transporting biomass in wetlands is currently under development (Zembrowski 2009b). The concept encompasses an amphibian tracked towing vehicle with permanently coupled trailer that is equipped with a small cabin, light track modules, a hitching system for cutting-shredding apparatus, a biomass conveyor system and an unloading system.

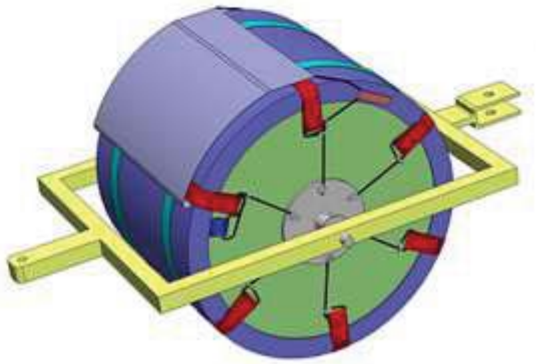
In developing the ATV, particular attention was paid to designing tracks that would inflict the least possible damage on the vegetation and ground surface. First, virtual and real models of a pre-prototype ATV were subjected to both simulation testing (Dubowski *et al*. 2012b,h) and a short period of field tests (Figure 3A). The results supported an iterative virtual design process leading to the prototype ATV tractor-trailer, which features modified rubber tracks and a new coupling device for the tool modules (Dubowski *et al*. 2011g). Instead of a single track along each side of the vehicle (Figure 3B), one of the virtual models (Figure 3C) has two-segment tracks. In this case, the smaller front tracks make for easer turning. The final version (Figure 3D) will have six track modules, all the same size (2.06m long and 0.95m wide), giving an estimated maximum ground pressure of 0.0057 MPa (Dubowski *et al*. 2013). Each track module will be powered independently by a hydraulic engine, and the track modules on the two sides of the vehicle will be capable of running at different speeds during turns, depending upon whether they are located on the inside or the outside of the turning radius. This feature aims to minimise the ground damage caused by turning the vehicle on peatlands and other wetlands.

The total length of the ATV unit will be around 10 m. To move it from site to site, a new gooseneck trailer (gross vehicle weight 11 t) is being developed from a tested design (Dubowski 2008) and will be coupled with a new light research truck IVECO Daily D35 (Dubowski *et al*. 2012f, 2014; Zembrowski *et al*. 2014).

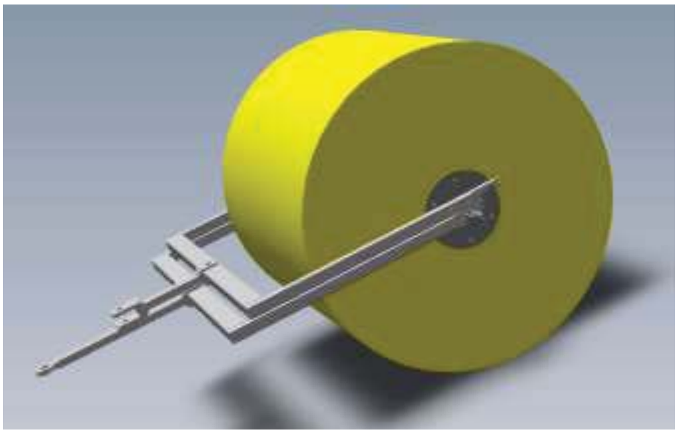
HOVERCRAFT

If hovercraft could be used for all of the necessary agricultural operations on protected wetlands (especially peatlands), there would be no possibility of surface rutting by wheels or tracks. Therefore, we have begun to explore the potential of hovercraft for removing grass, reeds, bushes and small trees, and for transporting harvested biomass (Zembrowski 2009a). As a result, several patents have been disclosed (Dubowski *et al*. 2010a, 2011a–d) for two

A. A ‘biomass bales train’ consisting of a farm tractor and three biomass bales (diameter 1.25m).



B. Virtual model of the textile cover mounted on a biomass bale.



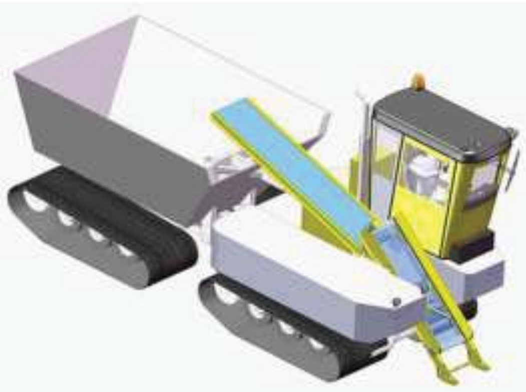
C. The folded frame of the adapter is laid on the axle after the axle has been drilled into the body of the biomass bale.

D. Textile cover on a 1.25 m diameter biomass bale after a 1.6 km rolling test on peatland (from Dubowski *et al*. 2012e). There was no damage to the textile cover.

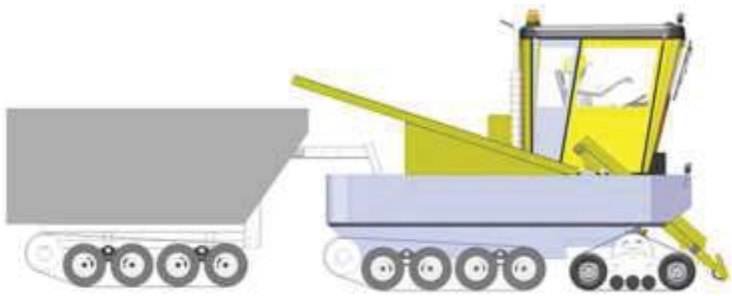
E. The Kubota M9960 tractor with Soucy Track Modules.

Figure 2. Illustrations of various features of the ‘biomass bales train’.

A. The pre-prototype version of the tracked amphibian tractor during field testing.



B. Virtual model of an amphibian tracked unit with long tracks, similar to those used on snow groomers.



C. Virtual model of an amphibian tracked unit with modified front tracks.

D. Virtual model of the final version of the ATV unit designed for cutting grass and reed.

Figure 3. Illustrations of different versions of the ATV unit.

new hovercraft vehicles, namely the “Agricultural Hovercraft Tools Carrier” (AHTC) (Figure 4A) and the “Agricultural Hovercraft Transportation Module” (AHTM) (Dubowski *et al*. 2011f,h).

The first prototypes

Virtual models of the hovercraft units and cutting/mowing tools were designed incorporating parts (Brielmaier, Conver) from JUKON, Poland (http://www.conver.pl/). The bodies and stainless steel frames of both vehicles were manufactured by Hovertech Poland (http://www.hovertech.com.pl/).

The AHTC has two 1,329 cm^3 VM 133MK aircraft engines, each capable of delivering up to 51 kW continuously (maximum power 63 kW) (Verner Motor 2014). One of these drives the main three-blade propeller (diameter 172 cm, with electrically adjustable blade pitch) and the second drives an air cushion pressure fan with nine fibreglass-reinforced polyamide blades (diameter 79 cm, again with adjustable blade pitch). There are several removable tool modules for mowing and cutting vegetation on wetlands, lakes and rivers, which may be mounted either on a special adaptor near the front or directly on the deck in the free space between the cabin and the engines. The AHTC may be optionally equipped with a lightweight (250 kg) crane. The Hiab 022 T crane (Cargotec 2013) has three hydraulic extensions and can easily lift 500 kg from a distance of 4.2 metres (Figure 5D). A circular saw module for cutting bushes and small trees can be mounted at the end of the loading arm. The crane can be operated only when the side covers of the air cushion chamber are open, so that the body of the AHTC is always resting firmly on the ground during procedures requiring use of the crane.

A specially designed loading ramp for the gooseneck trailer (Figure 4C) (Dubowski *et al*. 2012a) enables the AHTC to be transported between sites, and it has been tested briefly in the field (Figures 4B and 5). The results indicate that the design should be improved. The engine has two traditional carburettors but lacks an electronic control unit (ECU). On a few occasions, the lack of an ECU caused the propeller motor to seize when the propeller torque was being changed from forward to reverse position. Also, the breakdown of components interrupted the field tests several times. These issues led to a revision of the design, after which a new prototype was built (see below).

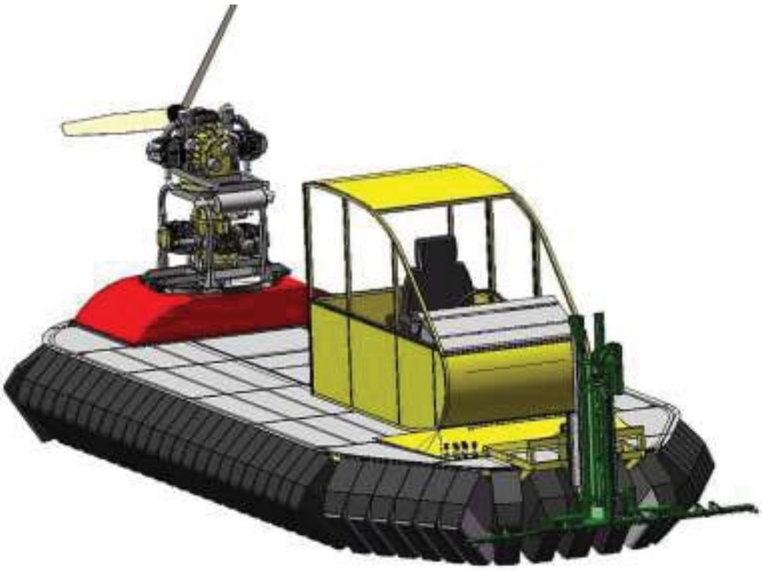
The body and steel frame of the AHTM are the same as in the AHTC, but there is only one engine which is used to drive the air cushion fan. The deck space thus freed is occupied by a light container for biomass collection. Mounted on the front of the AHTM body there is a towbar for coupling with the ball hitch of the AHTC and a swatch pick-up attachment with shredder.

Field tests of the prototype AHTM showed that its biomass cargo volume (600 kg) is impractically small and it may be better to replace this module with a commercial self-propelled heavy cargo hoverbarge (Hovertrans Solutions 2013). This is a marine barge that floats even when it is not powered, but it is equipped with fans and skirts so that it can also perform as a hovercraft. The standard hoverbarge has total deck area of 24 × 7 m (168 m^2) and a cargo capacity of up to 50 t. Its modular construction means that it can be dismantled for shipping to remote locations then re-assembled for operation (Proefrock 2011). A similar hoverbarge with cargo capacity 10–20 t could easily collect biomass after mowing by an AHTC. Because hoverbarges are very stable, collecting biomass from the ground and transporting it to a temporary holding area outwith the wetland should not be problematic.

The second prototype

The new AHTC prototype has a single electronically controlled six-cylinder VM MOTORI diesel engine (type R 75OEU5, 4,455 cm^3, 105 kW) that powers all installed sub-assemblies. The new cabin has an ergonomic dashboard with a clear control panel and an LCD screen for monitoring the engine (Figure 6A), a comfortable pilot seat and a simple air conditioning system. The hydraulic oil tank is in the same location as in the previous design (Dubowski *et al*. 2011a) but its volume has been increased three times, up to 105 dcm^3, because a larger tank is necessary for proper working of the hydraulic system. Unfortunately, the second prototype is heavier than the first one, weighing approximately 500 kg. With fuel, other necessary fluids and a tool mounted on the hitch module, the total weight is around 2,100 kg.

Laboratory and yard testing of this prototype was carried out in January and February 2013. The air cushion pressure measured under the body was around 0.00235 MPa, which was double that for the first prototype (0.0012 MPa) but still only 39 % of the ground pressure exerted by the tracks of a snow groomer (0.006 MPa). When flying over a concrete surface, the propeller thrust was in the range 400–500 N (Figure 6B) and speeds of 4–13 km h^{-1} were attained (Figures 6C and 7). However, the air cushion height was only ~10 cm. Ground clearance is a very important part of the specification for flights over peatlands. A clearance of 10–20 cm may be sufficient for winter flights over snow-covered terrain. However, for efficient summer



A. Virtual model of the Agricultural Hovercraft Tools Carrier (AHTC) with a T-shape mower.

B. The tangible prototypes: the Agricultural Hovercraft Tools Carrier coupled to its Transportation Module.

C. The AHTC during unloading from a PIMR-N1 gooseneck trailer.

Figure 4. Illustrations of the agricultural hovercraft units (AHTC and AHTM).

A. Field test of the AHTC with a front mower.

B. Field test of the AHTC with a T-shape mower.

C. Field test of the AHTC with side-mounted mower.

D. The AHTC with equipment for removing bushes and small trees, during a yard test.

Figure 5. Testing of the first prototype of the Agricultural Hovercraft Tools Carrier (AHTC).

A. Dashboard of the second AHTC prototype.

B. The second AHTC prototype undergoing propeller thrust force tests during a flight over a concrete surface. A Kubota tractor is being used as an anchor point for the rope.

C. The second prototype AHTC during a yard test. The mast is a mounting for HD cameras.

Figure 6. Illustrations of the second prototype AHTC.

Figure 7. The second prototype AHTC with mower. The mower has been fitted (temporarily) with a wheel to increase driveability during flights over the training area.

working in wetlands it should be at least 20–30 cm, and possibly up to 60–70 cm, to enable smooth movement across the often hummocky terrain at the required slow operational speeds of 4–6 km h^{-1}. To increase ground clearance, the rotational speed of the air-cushion fan and the thrust force of the propeller should be higher than can be achieved with this prototype. Therefore, the next step in development will be to increase the engine power.

THE RISK OF OIL POLLUTION

Just one cubic centimetre (i.e. one-thousandth of a litre) of mineral oil spilled in a wetland can contaminate five litres of water. The replacement of adapted snow groomers with new technology should help to reduce the number of accidents and breakdowns resulting in spillages. However, the deployment of any machinery lubricated with mineral oil in nature conservation areas will always involve some risk of pollution. A similar problem arising from the use of hand chainsaws in forestry operations in Poland, which formerly released 3–5 million litres of mineral oil *per annum* into the environment, has been addressed by making the use of biodegradable oil in place of mineral oil lubricants obligatory. Nonetheless, from our fact-finding visits to nature conservation areas (Biebrza NP, Warta River Mouth NP, Wolin NP, plus a few of the Natura 2000 areas near Poznan), it appears that biodegradable oil is generally not being used in either hydraulics or engines and is unlikely to gain popularity for lubrication of snow groomers and other machinery working in protected areas without additional regulation and/or other (e.g. price) incentives.

CONCLUSIONS

The most developed of our new techniques for working in wetlands and peatlands is the biomass bales train. Rolling the bales across peaty ground is faster and much less damaging to vegetation and habitats than lifting and transporting them on snow groomers, tractors, trailers or even specialised transport vehicles. Also, rolling is possible at any time of year, and it can be carried out by a single operator (although working in pairs is recommended for other reasons). In addition to reducing the cost of transporting harvested biomass, this technique could be instrumental in removing the problem of biomass bales that have been left lying on some wetlands for years, and in avoiding its recurrence in the future.

We have made substantial progress with the development of ATVs, which already show great promise for improving environmental protection in National Parks and Natura 2000 areas by reducing the negative impacts of vehicle tracks.

Hovercraft will potentially impact on wetland and peatland surfaces even less than ATVs because they can fly over both land and open water in summer, and even more effectively over snow and lakes covered by thin ice in winter. Thus, hovercraft technology could provide a complementary method for biomass harvesting and transport in wetland and peatland areas where access and safe operation by other vehicles such as snow groomers, tracked trailers and even ATVs is not possible. However, the hovercraft technology requires further research, development and field testing.

Before these new technologies for harvesting and transporting wetland biomass can be fully implemented also in formal paludiculture, it will be necessary not only to successfully complete the technical development phases, but also to address environmental safety and economic aspects; for example, to estimate the bio-economic value that can be attached to the sustainable development of mires and peatlands. For this, international research co-operation and additional types of field testing will be required.

Finally, urgent attention must now be given to the matter of oil pollution originating from agricultural machinery. Although national (forestry) legislation requiring machinery operators to use biodegradable oils is now in place in Poland, enforcement is often weak. To minimise oil pollution risks for wetlands and peatlands, we consider that it should be made mandatory for all agricultural vehicles, machines and tools not only to use biodegradable oils but also to undergo annual technical/mechanical inspections to ensure that they are adequately maintained.

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Author for correspondence:
Dr. Adam P. Dubowski, Power and Dynamics of Agricultural Machines Research Group, PIMR-Industrial Institute of Agricultural Engineering, Starolecka 31, 60-963 Poznan, Poland.
Tel.:+48 61 8712 230; Mobile: +48 601 453602; E-mail: dubowski@pimr.poznan.pl or ad@pimr.eu