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Analysis of work economics of mowing boats in standing waters

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The mowing of underwater plants is a water supporting measure and a part of mechanical landscape management. Standing waters are mowed and weeded mainly for reasons of recreational use, nature conservation, fishing and the preservation of navigability. Highly specialized machines are used for this task. The use of the mowed underwater plants is becoming increasingly important. Only a small amount of data is available for estimating work process costs. This work provides benchmarks for working times, traveling speeds and area performance for various mowing processes.

Keywords
Mowing boat, amphibious vehicle, water management, working time

Water management is a part of the landscape maintenance and water maintenance, respectively. It is regulated by the German Wasserhaushaltsgesetz (WHG 2009). The owner is obliged to maintenance with regard, among other things, to water drainage, shore maintenance, preservation of navigability and preservation and promotion of ecological functionality. Therefore a wide range of interests of utilisation can be derived, for example flood protection and nature conservation, shipping, leisure and tourism, energy industry and fisheries. Surveys among federal and state authorities, municipalities, water associations and contractors show the following reasons for mowing and weeding of standing waters (Röhl 2017):

- Swimming and bathing use - Private and public operators of swimming pools preserve water quality and reduce the risk of swimming accidents by keeping the swimming pool free of plants.
- Shipping – Many waters are used for yachting as well as for professional shipping. Particularly in harbours or in the confluence area of streams and rivers, increased water plant growth can occur. There is a demand for free water zones, so that the ship's screws cannot be disabled by underwater plants.
- Leisure and commercial fishing - demand of cultivated waters with low water crops.
- Nature conservation - Restraint of non-endemic species.

The mowing material is currently mainly composted. Within the scope of the AquaMak project of the Helmholtz Center for Environmental Research (UFZ), the German Biomass Research Center (DBFZ) and the Nürtingen-Geislingen University (HfWU) a utilization as a substrate for biogas plants is investigated (Stinner et al. 2017).

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Mowing boats have been further developed by specialized manufacturers and new concepts were presented in recent years. Bayer (2016) gives an overview of current mowing boats. These machines are often operated by companies specialized in water maintenance (Wannags 2012, Zimmerling 2014). Moeller and Zehnsdorf (2017) describe the mowing of underwater plants from the perspective of a practitioner.

There are only a few data on mowing boats for water management (Ackermann et al. 2006). Recent developments in mowing boats have not yet been considered. Therefore, the primary objective was to determine the working time of mowing procedures in standing water divided into individual time categories for regular operations under normal conditions. Furthermore, additional characteristic values should be determined such as typical driving speeds and fuel consumption. These values are intended to be used to carry out model calculations or to estimate concrete new missions. The results are based on investigations by Bayer (2016).

Observation procedure

The missions were accompanied by an observer. The travel distances and driving speeds of the machines were recorded with a GPS receiver. In order to assign the application time to the various time categories in seconds, a water-tight miniature video camera was mounted on the machine and directed to the working tool. In addition, the mission was filmed from the shore with a video camera. All devices were synchronized to the GPS time. The devices used are shown in Table 1. The machine operators were interviewed with regards to operation of the machines, maintenance and fuel consumption. The harvesting quantities were determined by measuring the loading capacity of truck loading platforms, containers and trailers, and their degree of filling.

Table 1: Devices for observing

Device	Manufacturer and type	Acquired data
GPS-receiver	Canmore GT730 GPS-Logger Garmin Oregon 450 (as back-up)	Datenformat .gpx Erfassungsfrequenz 1 Hz
Video camera	Panasonic HCV777	Datenformat .MTS (Advanced Video Codec High Definition, ACVHD-Format)
Miniature camera	GoPro Hero 3+	Datenformat .mp4

Each application was then analysed in accordance with the time categories of the KTBL (Winkler 2014, KTBL 2016). For this purpose, the video recordings of the miniature camera were used with priority and were completely sighted. The time sections were entered manually into a preconfigured Excel spreadsheet. The GPS data were available as a gpx file and were imported into this Excel file. By means of an automated adjustment with each time segment, the corresponding driving speeds were extracted from the GPS data. For situations where the images of the miniature camera were not significant enough, the data from the video camera was used with which the mission had been filmed from the shore.

Table 2 shows the time categories with a brief explanation. The main time is characterized by mowing and collecting. The average driving speed during the main time is also indicated. Traveling within the area to be mowed is also a part of reversing, for example travels to the unloading point on the shore. The travel speeds occurring in the time category ‘reversing’ are defined as positioning speed. Fuel can count to operating material. Thus, fueling operations would have to be part of the ‘supply’ category. On the other hand, refueling serves to maintain the functional capability of the engine and would then be a set-up time. Therefore, refueling is defined as a part of the set-up time. Travel time is the time needed to come to the place of work or to return to the point of departure. In the present investigations, no travel times occured because the boats had already been at the place of work. For the mowing boat with a mowing bucket and the mowing harvesting boat with loading platform, however, traveling speeds could be determined, which would typically occur during traveling between work and home locations.

Table 2: Time categories

Category [1)]	**Description** [1)]	**Corresponding event during mowing boat missions**
Main time	Scheduled activity directly serving the task	- Mowing and harvesting - Pushing and collecting in the waters
Reverse time	Turning the machine at the headland	- Change of travel direction at the end of a working track - Positioning of the vehicle at obstacles - Travels between the bunker unloading point and the last position of a working (mowing and harvesting) within the area to be mowed
Supply time	Filling the machine with operating material and unloading the container with the harvested material	- Time for unloading the collecting bucket or loading platform at the unloading point (boat does not move)
Down time	Interrupts by disturbances	- Break downs or blockages of tools and conveyor devices
Waiting time	Workflow-related interrupt, e. g. for partial work in a process chain	- Work-flow related communication between stakeholders - waiting for other process participants (here removal of driftwood)
Set-up time	Prepare machine for work and maintenance	- Re-filling fuel and oil - Attaching tools and putting them into operation
Travel time	Time needed to come to the place of work or to return to the point of departure	- No acquisition

1) Definition according to Winkler (2014).

Description of the waters and used mowing vehicles

The data were recorded under normal working conditions during regular operations. The mowing vehicles were used in various still waters at six sites (Table 3). Waters 1 and 5 were mown in order to avoid that ships’ screws could be disabled by underwater plants. The shoreline was stabilised with vertical walls. Piles demarcated the areas to be mown on the shores and lakeside. Within the mowing area there were no obstacles. The growth of the underwater plants to be removed was low in waters 1 with 16 m^3/ha compared to waters 5 with 63 m^3/ha.

Table 3: Description of the mowed waters

	Waters					
	1	2	3	4	5	6
	Area size					
	0,3 ha	0,6 ha	2,8 ha	0,2 ha	0,32 ha	1,0 ha
Reason of the measure	Keeping the fairway safe for ships	Swimming and bathing use	Swimming and bathing use	Avoidance of succession/ sedimentation	Keeping the fairway safe for ships	fishery
Obstacles	Side walls, piles	non	non	6 „islands“ Ø 3 m	Unilateral limitation by piles	non
Plant growth, app.	16 m³/ha	5 m³/ha	n. s.[1)]	75 m³/ha	63 m³/ha	n. s.[1)]

[1)] Quantity not determinable because it was not removed.

The waters 2 and 3 are open-air swimming pools and have been mown to reduce the risk of swimming accidents and offer the guests a good water quality. These areas were delimited only by the shore areas, but a sufficient clearance was maintained during turning. The plant growth in waters 2 was very loose with 5 m³ / ha. In waters 3, the mown underwater plants were deposited in the water at the open-sea boundary of the mowing area. They were drifted away from there by wind and water currents. Therefore, a quantitative determination of the plant growth was not possible. The growth was classified by the boat operator as very dense. Water 4 is located in a park. Here, the sedimentation and succession should be counteracted. Within the area to be mown are 6 circular obstacles with a diameter of 3 m. The plant growth was very dense with 75 m³/ha. Water 6 is used for fishing and should be preserved by mowing as such. In contrast to the other waters described here, mainly reeds and only a small proportion of underwater plants were mowed. The mown material was distributed on the landside of the embankment with an excavator. As a result, a quantity determination was not possible.

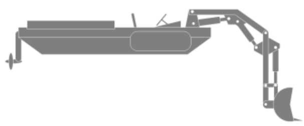
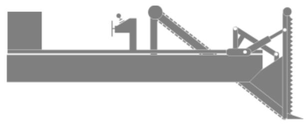
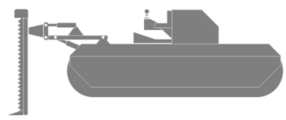
Three different types of mowing vehicles were used (Table 4). Type 1 was a flat-built, compact mowing boat with a 36 kW diesel engine and screw drive. The boat was equipped with a 3-way hydraulically adjustable and swivelling front boom, which can lower the working tool up to 3 m below the water surface. Various tools can be attached to this boom. For the missions in waters 1 and 3 a 2 m wide and in waters 2 a 3 m wide mowing bucket was mounted. The cutter bar was hydraulically driven.

Type 2 was a mowing and harvesting boat with a 51 kW diesel engine and screw drive. The boat is characterized by a horizontal 1.4 m wide cutter bar and two vertically 1.4 m high cutter bars at the right and left side. The mowing material reaches an inclined conveyor belt and is collected on a loading platform of approx. 7 m². The operator’s stand is arranged on the side of the loading platform so that the machine’s operator can also distribute the mowing material on the loading platform in addition to controlling the boat.

Boat types 1 and 2 must be launched into water with a crane. In water 1, the lifting of the boat could be documented, in the case of waters 5, the launching, because a longer mission period in this area came to an end or started, respectively. In all other observations the boats were already in the water due to longer missions. The crane times required are indicated in the evaluation, but not taken into account for set-up times, since the crane work did not take place in all operations.

The amphibious tool carrier was a floatable crawler (type 3). Thanks to the crawler tracks, it is possible to drive on land with low ground pressure. In the water the crawler tracks act as paddles, which serve for propulsion and control. Aluminium housings were used as floating elements. A variety of attachments can be mounted to a hydraulically actuated boom arm via a quick-change system. For the mowing examined here, a cutter bar with a working width of 2.2 m and a vertical cutter bar of 1.4 m centred over it were used. Subsequently, the mowing tool was replaced by a 3.5 m wide rake collecting the material, which had been cut and floated in the water, and pushing it to the shore. The vehicle could drive from the transport trailer and over an embankment into the waters.

Table 4: Investigated vehicles

Characteristic	**Type 1: Mowing boat with mowing and collecting basket**	**Type 2: Mowing and harvesting boat with loading platform**	**Type 3: Amphibious tool carrier**
Bauform	 Flat-built mowing boat, front and low-lying driver's seat (sitting), hydraulic, 3-way adjustable and swivelling front boom, cutter bar with collecting basket	 Flat-built mowing boat, side and central driver's console(standing), submersible longitudinal conveyor belt with U-shaped cutter bar, loading platform approx. 7 m²	 Floatable crawler, crawler tracks acting as paddles, central driver's seat (sitting), hydraulic front boom T-shaped cutter bar or reed rake
dimensions l x w x h	4.0 m x 1.80 m x 0.80 m	6 m x 2.30 m x 1.5 m	4.7 m x 2.1 m x 2.1 m
Working width	2.0 m / 3.0 m	1.4 m	2.2 m / 3.5 m
Cutting depth	3.0 m	1.4 m	1.4 m
Weight	2.0 t	2.1 t	1.4 t
Propulsion	Diesel engine	Diesel engine	Diesel engine
Power	36 kW / 49 PS	51 kW / 70 PS	33 kW / 45 PS
Used in waters	1, 2, 3	4, 5	6

Results

In Table 5 the results of the missions with the mowing boat with mowing basket (Type 1) are summarised. In waters 1 only short sections could be mown due to the dense growth until the collecting basket was filled. For this reason, the main time share is 38 % and the working speed is 0.9 km/h. Both, time share and speed are the lowest and the share of travels between the unloading point and the mowing point is highest in waters 1. The mown material from waters 1 was unloaded in a hopper hanging from a crane. Since this was only slightly wider than the collection basket, the boat had to be shunt to the hopper with the help of a second person with a boat hook.

In contrast, in the case of waters 2, the collecting basket could be unloaded on a bank meadow in less than half the time. However, a second person was required to load the plants by hand with a pitchfork on a trailer. The loose growth allowed longer mowing times at higher speeds.

In water 3, the mown material was not lifted out of the water but pushed with the collecting basket. Thus, despite dense growth, it was possible to drive with an average speed of 2.8 km/h over 200 m until the collecting basket was emptied at the sea side edge region during turning. Only one person was needed for the entire operation. The launching process into waters 1 lasted with a stationary port crane 14 min. In waters 2, the boat was immediately ready for use. In both cases, no further set-up times arose. In water 3, due to the comparatively large application area, the boat had to be refilled once from two 20 l jerry cans. After work the mowing bucket had to be cleaned. The fuel consumption was stated between 6 and 8 l/h for all applications with the mowing boat.

Table 5: Mission analysis of the mowing boat with mowing basket (type 1)

Characteristic	Unit	Waters 1	Waters 2	Waters 3
Description of the area to be mowed				
Area size	ha	0.3	0.6	2.8
Plant growth	m^3/ha	16	5	n. s.
Time shares and characteristic values				
Main time	%	38	69	74
Reverse time	%	40	21	14
Supply time	%	17	10	-
Waiting time	%	5	-	6
Set-up time	%	-	-	7
Average working speed	km/h	0.9	3.1	2.8
Average positioning speed	km/h	3.3	4.8	-
Average travel speed	km/h	-	-	6.5
Average time for unloading material	s	94	40	-
Time for handling the boat with the crane	min	14	-	-
Area performance (without set-up time)	ha/h	0.12	0.64	0.72
Number of workforces		2	2	1

The mowing and harvesting boat with loading platform (type 2) was observed at two different missions. The evaluation is summarized in Table 6. Waters 4 were covered very densely and obstacles had to be driven around. This allowed only a driving speed of 0.5 km/h during mowing. The course could be set in such a way that the positioning travels between the mowing and unloading locations could be kept shorter compared to waters 5.

The plant growth in waters 5 was significantly lower and the mowing area could be operated without hindrance. Thus, the mowing speed at 1.0 km/h was higher than in waters 4. However, the waters 5 were very extensive, and only a small part of it had to be mown. For this reason, the client instructed the operator of the mowing boat at the site. Therefore, the waiting period for work organization is relatively long. In addition, it was necessary to remove driftwood. Both resulted in a comparatively high time share for the waiting period of 18%. In addition, the driftwood led to a break-down of the conveyor belt and thus to down-times.

In both missions, the loading platform of the boat was cleared by a loading crane with a clamshell grab mounted on a truck standing on the shore. Due to the high volume of mown material in waters 4, the unloading operations took up 24 % of the total time. The unloading and the launching of the boat was 5 minutes faster than the lifting and loading of the mowing boat with the collecting basket (type 1), although in both cases the working conditions were very similar. The time difference can be explained by the different time required to secure or release the boat on the trailer. Set-up times occurred when working in waters 4 through cleaning work and by re-filling hydraulic oil. The fuel consumption for both missions was 3 l/h.

Table 6: Mission analysis of the mowing harvesting boat (type 2)

Characteristic	Unit	Waters 4	Waters 5
Description of the operation area			
Area size	ha	0.2	0.32
Plant growth	m^3/ha	75	63
Time shares and characteristic values			
Main time	%	53	38
Reverse time	%	20	25
Supply time	%	24	16
Down time	%	-	2
Waiting time	%	-	19
Set-up time	%	3	-
Average working speed	km/h	0.5	0.8
Average positioning speed	km/h	0.7	1
Average travel speed	km/h	-	4.8
Average time for unloading material	s	416	384
Time for handling the boat with the crane	min		9
Area performance (without set-up time)	ha/h	0.06	0.10
Number of workforces		2	2

Waters 1 and 5 were comparable in terms of use and spatial situation. However, the plant growth in waters 5 was significantly higher. Waters 1 were mowed with the mowing boat with collecting basket and waters 5 with the mowing and harvesting boat with loading platform. Table 7 shows the results without taking into consideration the times for set-up, waiting and down-time. Despite the larger plant growth the mowing boat with loading area has a larger share of the main time. Due to the loading platform, the boat had to travel less to the unloading station and thus has less unproductive positioning and turning parts. The time shares for unloading are almost the same for both applications, despite the different harvesting quantities. This is due to the lower capacity and the time-consuming shunting to the hopper with the mowing boat with mowing basket.

Table 7: Comparison of waters 1 (mowing boat with collecting basket) and waters 5 (mowing and harvesting boat with loading platform)

		Waters 1	Waters 5
		Mowing boat type	
Characteristic	**Unit**	**Mowing boat with collecting basket (type 1)**	**Mowing and harvesting boat with loading platform (type 2)**
Description of the operation area			
Area size	ha	0.3	0.32
Plant growth	m³/ha	16	63
Time shares and characteristic values			
Main time	%	40	49
Reverse time	%	42	31
Supply time	%	18	20
Average working speed	km/h	0.9	0.8
Average positioning speed	km/h	3.3	1
Average time for unloading material	s	94	384
Area performance (without set-up time)	ha/h	0.12	0.10
Number of workforces		2	2

An amphibious tool carrier was used for mowing waters 6. Mowing and collecting were carried out in two separate operations (Table 8). Due to the advantageous shape of the waters with an approximately circular bank line and no obstacles, only 5 % of the total time was required for turning and positioning during mowing. The down-time was caused by a released shear bolt of the cutter bar suspension, which had to be put back into operation on land. The set-up time consisted of the time for unloading the machine from the trailer and the attachment of the cutter bar.

Table 8: Mission analysis of the amphibious tool carrier during mowing and collecting (type 3)

Characteristic	Unit	Waters 6	
		Mowing	Collecting
Description of the operation area			
Area size		1.0 ha	
Plant growth		n. s.	
Time shares and characteristic values			
Main time	%	77	83
Reverse time	%	5	3
Supply time		-	-
Down time	%	11	-
Waiting time	%	2	2
Set-up time	%	4	11
Average working speed	km/h	1.3	2.3
Average positioning speed	km/h	1.2	2.0
Average travel speed	km/h	3.9	3.9
Area performance (without set-up time)	ha/h	0.29	0.51
Number of workforces		1	2

1) On land.

For the second operation, the cutter bar was removed and the reed rake was attached. The loading of the amphibious tool carrier on the trailer was added to the set-up time. The mown material was collected by pushing it with the reed rake to the bank. The course was chosen in such a way that it was possible to begin and end with the collection in the immediate vicinity of the unloading point. As a result, the share of unproductive reversing and positioning travels was small. The mown material pushed to the bank was distributed with a mobile excavator on the landside of the embankment for rotting. For this, a second person was needed on the excavator during the collection process. In contrast to the cutter bar, the reed rake was in a lower water depth during operation. Thus, the operation speed during collection was faster than during mowing. The fuel consumption for mowing and collecting was 11 l/h on average.

Conclusions

During the observation, the mobile front boom of the mowing boat with mowing basket (type 1) has proved to be advantageous for fast emptying of the material. No additional machine is required for unloading. One workforce is sufficient. If the mown material is to be collected at the bank for removal, the hopper must have a sufficiently large opening cross-section in order to keep the shunting times low. In the case of large areas with a lot of plant growth to be removed, the low loading capacity of the collecting basket demands frequent travels to the unloading point. The mowing and harvesting boat with conveyor belt and loading platform (type 2) is better suited for these work conditions. There are fewer travels to the unloading point due to the higher loading capacity. The mown material can be loaded from the boat onto the truck with a truck mounted loading crane. However, a corresponding transport vehicle and a further workforce are to be provided for this method. On the boat, two workers are needed in the case of large plant growth.

The advantages of the amphibious tool carrier (type 3) lie in the simple insertion into the waters without further aids. The prerequisite is only a traversable bank slope. The tool carrier provides an excellent overview on the working tool. During the observed mission the waters were mowed and cleared in two steps. Although the tool carrier could have been equipped with a mowing collector basket for a one-stage operation, the size of the water would have resulted in high unproductive time shares for travels to the only possible unloading point. In a two-stage process, the mowing and gathering was carried out very effectively, which was demonstrated by very high main time shares. The tool carrier is also particularly suitable for jobs where it is often necessary to switch between land and water. Examples of this are rainwater retention basins, smaller standing waters close to one another, which are approached subsequently. This type of vehicle has limited manoeuvrability in wind and current.

The results of the missions represent individual values and cannot be easily generalized. As a rule, the work conditions in landscape management are very different. The analysis of a larger number of missions would be desirable but is hardly possible due to the enormous time demand and the limited possibilities of automated data collection. Through a detailed analysis of the missions, however, characteristic values such as travel speeds during working and turning or positioning, unloading times and set-up times could be determined. With these, model calculations can be carried out to estimate the total times for other water sizes and forms as well as plant growth stages. The results of these model calculations serve as a guide for the planning of new missions.

References

Ackermann, I.; Baals, C.; Hundsdorfer, H.; Kraut, D.; Rothenburger, W.; Sauer, N. (2006): Landschaftspflege 2005. Darmstadt, 5. überarbeitete Auflage

Bayer, H. (2016): Arbeitseinsatz von aquatischen Mähfahrzeugen in der Landschaftspflege im Zusammenhang naturschutzfachlicher Zielkonflikte. Bachelor-Thesis Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen

KTBL (2016): Betriebsplanung Landwirtschaft 2016/17. Darmstadt, 25. Auflage

Moeller, L.; Zehnsdorf, A. (2017): Wasserpflanzenmahd aus der Sicht des Praktikers. Tagung AquaMak – Aquatische Makrophyten – Ökologisch und ökonomisch optimierte Nutzung, Helmholtz-Zentrum für Umweltforschung, Leipzig, 30.-31.03.2017

Röhl, M. (2017): Biomassepotenziale submerser Makrophyten in Deutschland - Synergien und naturschutzfachliche Zielkonflikte einer möglichen Nutzung. Tagung AquaMak – Aquatische Makrophyten – Ökologisch und ökonomisch optimierte Nutzung, Helmholtz-Zentrum für Umweltforschung, Leipzig, 30.–31.03.2017

Stinner, W.; Moeller, L.; Wedwitschka, H.; Roth, S.; Brummer, V.; Röhl, M.; Herbes, C.; Zehnsdorf, A. (2017): Wasserpflanzen als Substrat für Biogasanlagen - praxisgerechte Silierung und Vergärung. Tagung AquaMak – Aquatische Makrophyten – Ökologisch und ökonomisch optimierte Nutzung, Helmholtz-Zentrum für Umweltforschung, Leipzig, 30.–31.03.2017

Wannags, S. (2012): Mit Mähboot und Amphibienfahrzeug. Flächenmanager 2(1), S. 48-49

WHG (2009): Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz – WHG) vom 31.07.2009

Winkler, B.; Frisch, J. (2014): Weiterentwicklung der Zeitgliederung für landwirtschaftliche Arbeiten. Bornimer Agrartechnische Berichte 83, S. 14–21

Zimmerling, D. (2014): Mähen und reinigen am und im Wasser. Flächenmanager 4(2), S. 60–63

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