Measuring standing crop on offshore seaweeds using drag forces

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Introduction

Globally, seaweed aquaculture is rapidly expanding, both in annual biomass production as in financial value [1]. Traditionally, most aquaculture takes place in Asia, but the interest in cultivating seaweeds in the North sea is increasing. The North sea is very dynamic during winter, the growing season of the main crop, *Sacharina latisima*, which can lead crop losses. Visiting offshore farms during the growing season is a costly enterprise, and therefore there is a demand for a system to remotely monitor offshore seaweed farms that should enable an enterprise to determine 1) if the farming system is still running and 2) the quality and quantity (i.e. standing crop) of the cultivated seaweed. In an earlier research several potential techniques to do so have been identified [2], and measuring drag forces exerted by the current is one of them. For measuring standing crop, drag forces have been explored in 2021 and 2022 for *Saccharina latissima*. According to the NorthSeaFarm foundation this seaweed species is presently the most suitable one for cultivation in the North Sea.

In fluid dynamics the drag force is determined by:

$$F_D = \frac{1}{2} \rho v^2 C_D A,$$

where F_D is the drag force (N), ρ is the density of the water (kg/m^3), v is speed of the line relative to the water (m/s), C_D is the drag coefficient -a dimension less number- and A is the cross sectional area (m^2). The drag coefficient C_D is a coefficient that depends on the Reynolds number of the fluid. This last number depends on the viscosity of the fluid which is dependent on the speed of the fluid.

During the growing season A will increase and C_D might change, as the shape of the crop changes. The hypothesis of this research is that it is possible to estimate the standing crop that is, the fresh weight, based on the drag force and the current speed.

Material and method

Cultivation lines were seeded with *S. latissima, a winter growing brown seaweed* by Stichting Zeeschelp and deployed at the Mattenhaven (Neeltje Jans) in December 2020 and October 2021, and dragforce measurements were performed the following year in March and June 2021 and May and June 2022, respectively.

A total of 4 lines with *S. Latissima* have been used; two in 2021 and two in 2022. Empty lines were used as a control. The Saccharina lines were located at the Mattenhaven at Neeltje Jans in the Eastern Schelde under supervision of Stichting Zeeschelp. The lines measured in 2021 were seeded in December 2020, while the lines measured in 2022 were seeded in October 2021. The seeding of the line was done by Stichting Zeeschelp. The lines measured in 2021 had a length of 21 meter. In 2022 line 1 was 34 meter and line 2 was 24 meter. In the growing system some weights were added to the line to make sure they stayed below the water level.

Figure 1: The skeleton used to drag the lines through the water(Photo by: Janne Kool 2021).

To measure the drag force a skeleton has been built between two rubber boats. On the skeleton two rods have been attached, with one side pointing about 1 meter below the water surface. On this end load shackles (SHK 12126-2 Strainstall) were attached, on which the lines were knotted. In Figure 1 a picture of the skeleton used during the measurements. The shackles measured and monitored the force twice per second. On the front of the skeleton a current meter was attached (LS1206B SMAAT TECHNIQUES SAS). The weights of the lines have been determined by lifting the line into a fish crate, waiting until no water did flow out of the crate anymore. As the lines did not fit in one piece in the crate the procedure took place in several parts of the line. To determine the weight of the lines a wet empty line was measured. Also the weights of the crates were determined. In the farming system the lines were made more heavy by adding weights about every 3 meters. These have been counted, and the weights have been subtracted. To simulate current, the lines were towed through the water at the Mattenhaven at different speeds; in 2021 0.3, 0.6 and 1.5 m/s were used, and in 2022 0.5, 1 and 1.5 m/s. Speeds of the boats were not constant so the speed was monitored using the current meter. For each speed – line – weight combination a series of five times of one minute measurement was performed. Both the speed and the drag-force have been averaged per minute.

In 2021 measurements have been carried out on the 31th of March and 4th of June. Unfortunately, the measurements on the 31th of March 2021 failed, as one of the load shackles did not seem to function. The weather conditions on both days were extremely quiet without any waves. In 2022 measurements have been carried out on the 5th of April and 2nd of May. On both days there was some western wind causing some wave action, but as the Mattenhaven is quite sheltered from western wind, this did not disturb the measurements. Unfortunately, the measurements on the 5th of April failed as the current meter did not function. The drag force formula suggests that a densely overgrown rope with short thalli would cause a smaller drag force than a sparingly overgown rope with large thalli, because in the first case the cross sectional area (A), would be smaller than in the second case. Therefore, the measurements on the 4th of June 2021 were a bit more expanded; after one series of measurements parts of the seaweeds were removed and the removed weights were measured. The removal of the seaweeds was done for the two lines in two different ways, 1) by sparcing the line by removing about 20% of the seaweeds and 2) by shortening the seaweed, that is, cutting away about 20% of the length of each of the seaweed blade. Measurements were done with 100%, 80%, 60% and 30% of the original seaweeds lengths. Both treatments may result in a different dragforce at the same current and weight, as the shape differs between the treatments.

During the analysis, a linear regression model has been created for each measurement series to relate the speed with the drag forces, using sklearn in python. These linear regressions have a slope. In a tidal movement system it is possible to measure these slopes by measuring the change in drag force during one tidal cycle. A linear regression model has been created relating the slope of these previous mentioned regression models with the kilograms of seaweeds per meter line.

Results

The drag force of the empty line did never exceeds the force corresponding to 1 kg. The line which was measured on the 4th of June 2021, which was obtained by sparcing so only 30% of the original weight was left. Corresponds to 0.3 kg/m, there was no clear increase in force when the current increased. The data of those two lines and the linear regression is plotted in Figure 2. The data and the linear regression lines for which there was a clear increase in force when the current increased are plotted in Figure 3.

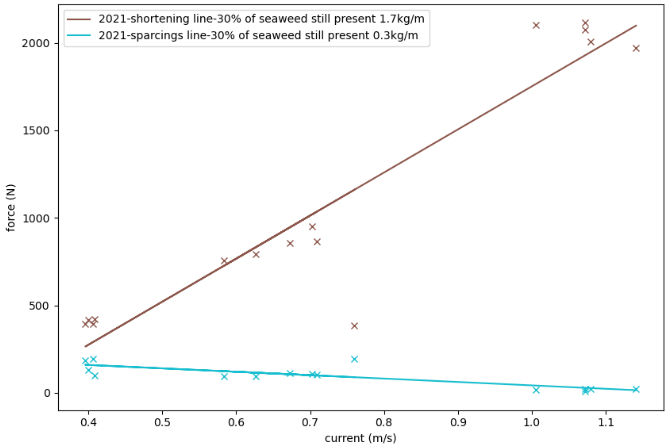

Figure 2: The measurements and the linear regression for the lines measured on the 4th of June 2021 with only 30% of the crop left. The weights and method of decreasing the crops are in the legend.

For the other measurements also regressions have been made to find a relation between the current and the drag force. The results are in figure 3.

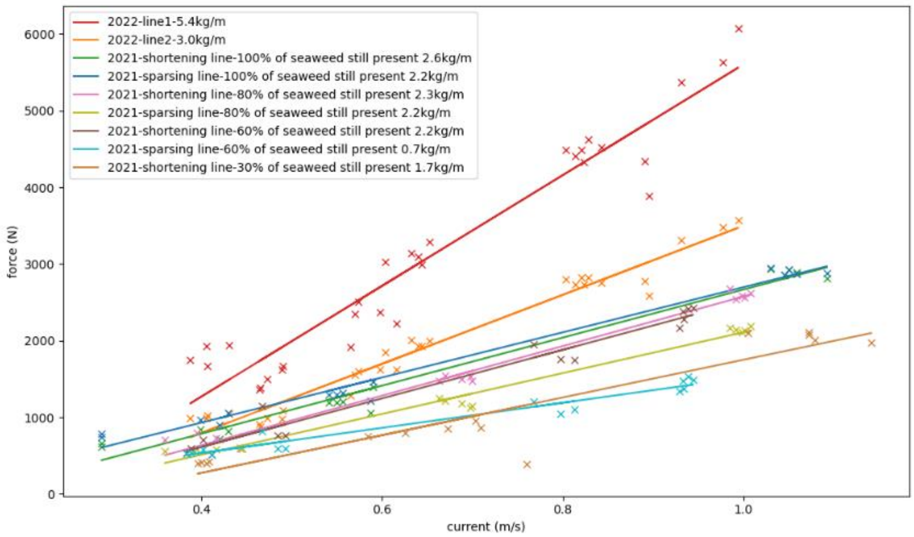

Figure 3: The linear measurements and linear regressions of all measurements for which the force increased with the current. The weights per meter are in the legend.

The plots in figure 3 suggest that the slope of the regression in larger when the density of seaweeds increases. Therefore, the slopes of the regressions in figure 3 have been plotted against the weight per kg. Also trough these points a linear regression has been performed. The results are in Figure 4.

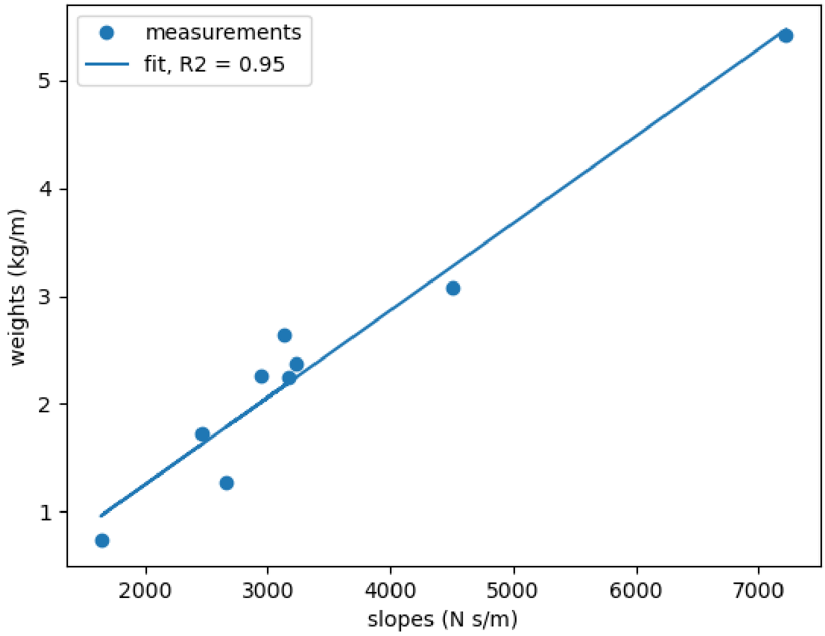

Figure 4: The weights of seaweed per meter plotted against the slopes of the regressions presented in figure 3.

Conclusions

The total amount of measurements is not sufficient enough, therefore strong conclusions can't be made. However, there is evidence for the following:

1. There is a correlation between the slope of the increase in drag force with increasing current and the fresh weight of the crop per meter, with lines varying between 20 and 34 meter in length, given that the fresh weight of crop per meter is at least 1.7 kg/m. When the fresh weight is too low, the slope is not informative.
2. To estimate the weight directly from the current and the force can be done only when the current is high enough (>0.8 m/s), and, again, the amount of crop is at least 1.7 kg/m. Small differences in weight however will not be detectable that way.

Discussion

In a tidal systems the currents exerted on the line will oscillate. In the North sea at Buitenbanken West the current speed can be oscillating between 0.1m/s and 0.8 m/s, but this doesn't happen every tidal movement (https://waterinfo.rws.nl/#!/kaart/stroming/ visited 3-8-2022) depending on the moon. However, it is feasible to detect and compute the slope, when forces and currents are measured over a range. Therefore, the slope results have serious potential.

With larger weights it might not be necessary to compute the slope. The slopes of the regressions increase with the increase of seaweeds and hence it might be possible to determine the weight per meter with only measuring at one time point the force and the current, provided that also the current is large enough.

The shape of the thalli could be dependent on the growth location, for instance due to different currents or light intensity. The constant C_D depends on this shape and this might hamper the practical applicability of this method. However, the sparcing and shortening experiment done in this research suggest that this is not the case.

That the empty line did not exceed a force corresponding to one kilogram load is in hindside not surprising given the formula for drag force. The cross sectional area A of an empty line is close to zero, and hence the drag force is low, independent of the length of the line. This is also why it is reasonable to look at the kilogram/meter as wight measure. The length of the line is not explicitly expressed in the formula for drag force, although it probably has an influence on C_D.

The relationship between fresh weight and drag force when the line is drifting freely was researched. To come to equipment that can give an indication of the total amount of seaweed on a farm the forces are highly dependent on the farm design, and should be gauged for each design. Also, when the lines are not kept well under the surface, waves might also have an influence on the measurements.

In [3] [4] experiments were done to determine the influence of the current on the drag coefficient on one species of seaweed, finding that for *Sargassum horneri* the coefficient C_D decreases with the increase of current, suggesting evolutional adaptation of the weeds to strong currents. The increase in force found in their work is proportional to $v^{3/2}$ instead of v^2, which would be expected from the drag force formula.

The weigths added to the lines for keeping the line below the water surface in the growing system were small compact pieces of concrete. As they did not contribute to the A in the drag force formula, we do not expect that this influenced the measurements.

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