

Wave damping by flexible aquatic vegetation

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Abstract

Aquatic vegetation provides ecosystem services of great value. Its protection and restoration has become a major focus in coastal management. We seek to better understand the role of vegetation in protecting shorelines from wave energy. The motion of flexible vegetation blades can significantly reduce the drag force, which will in turn affect the wave decay. The wave decay can be characterized using an effective blade length, l_{eff} , which represents the length of a rigid blade that generates the same wave damping as a flexible blade with length l . Previous studies suggest that the effective blade length ratio $l_{eff}/l \sim (Ca)^{-1/4}$, in which Cauchy number Ca defines the ratio of hydrodynamic drag to blade stiffness and the normalized blade length L is the ratio of blade length to wave orbital excursion. This laboratory research extends the existing studies and the aim of finding the link between drag force on an individual blade and wave dissipation over a meadow. Flume experiments were conducted to measure the wave decay over an artificial meadow constructed from plastic blades and wooden dowels. Another set of experiments were conducted to measure the drag force on the individual blades. It's observed that the scaling law (force on individual blade) is able to predict the wave decay over the meadow. A correction factor was needed to account for the fact that the individual blades within the meadow shelter one another. As the stem density increases, the sheltering becomes more significant, resulting in a reduced rate of wave energy dissipation.



Wave Damping by Flexible Aquatic Vegetation

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INTRODUCTION

Aquatic vegetation provides a variety of ecosystem services, including the protection of shorelines from storms and erosion. Shoreline vegetation slows down wave motion and keeps sediments from being kicked up, such that the erosion due to wave impact can be reduced. However, the benefit of vegetation has not been incorporated into coastal management, because a universal physical model of wave damping over aquatic vegetation has not been developed.

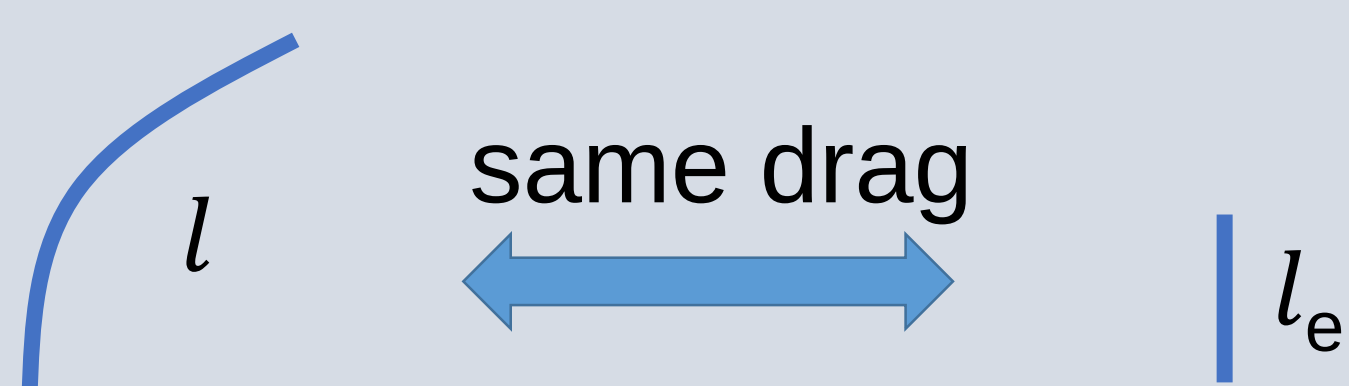
The project will develop such a model to characterize the wave energy dissipation based on the flexibility and geometry of the vegetation. Using the model, coastal engineers and scientists will be able to estimate how much the wave impact diminishes.



Figure 1. *Zostera marina* blades under current. Photo taken by Dr. Eduardo Infantes Oanes.

OBJECTIVES

The impact of reconfiguration of the blades is addressed through the effective blade length, l_e , which is the length of a rigid, vertical blade that generates the same drag as the flexible blade of length l .



- **Verify (modify) existing scaling laws for individual strap-like blades**
 $\frac{l_e}{l} \sim (Ca_w L)^{-1/4}$
- **Extend the scaling laws to predict wave damping**
- **Consider wave-current conditions and vegetation of more complex morphology**

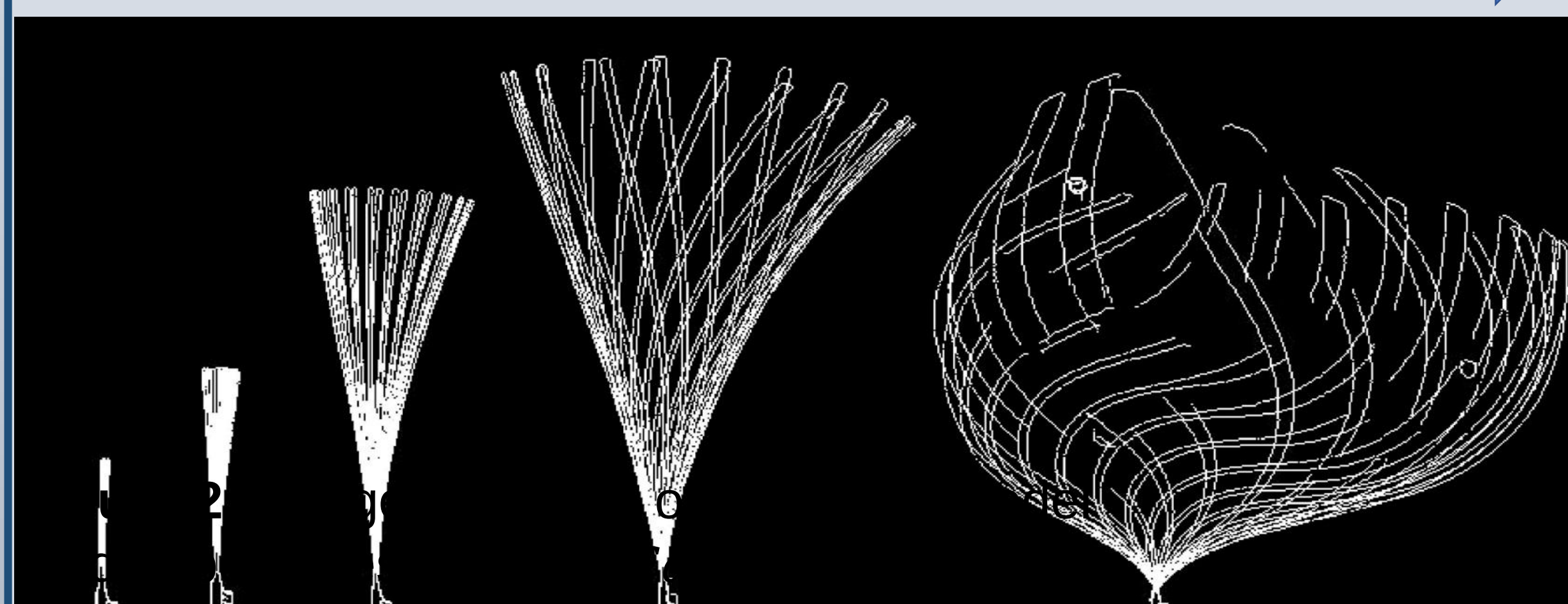
METHODS and MATERIALS

Two dimensionless parameters govern the blade motion in waves

$$Ca_w = \frac{\text{hydrodynamic drag}}{\text{blade stiffness}} = \frac{\rho b l^3 U_w^2}{EI}$$

$$L = \frac{\text{blade length}}{\text{wave excursion}} = \frac{2\pi l}{U_w T}$$

$Ca_w L$ increasing

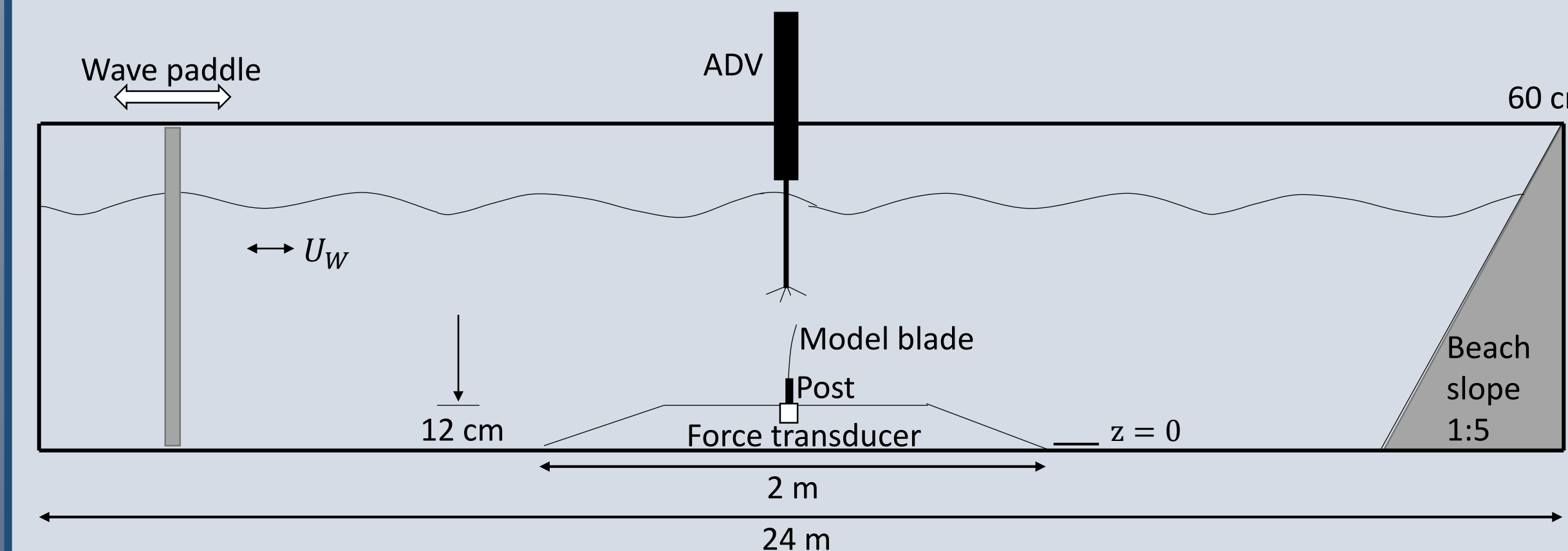


1. Materials and Wave Parameters

LDPE Blade
Wave period $T = 0.5 - 2s$
Wave amplitude $A = 0.5 - 5cm$
 $Ca_w = 0.2 \text{ to } 1 \times 10^4$
 $L = 0.5 \text{ to } 45$

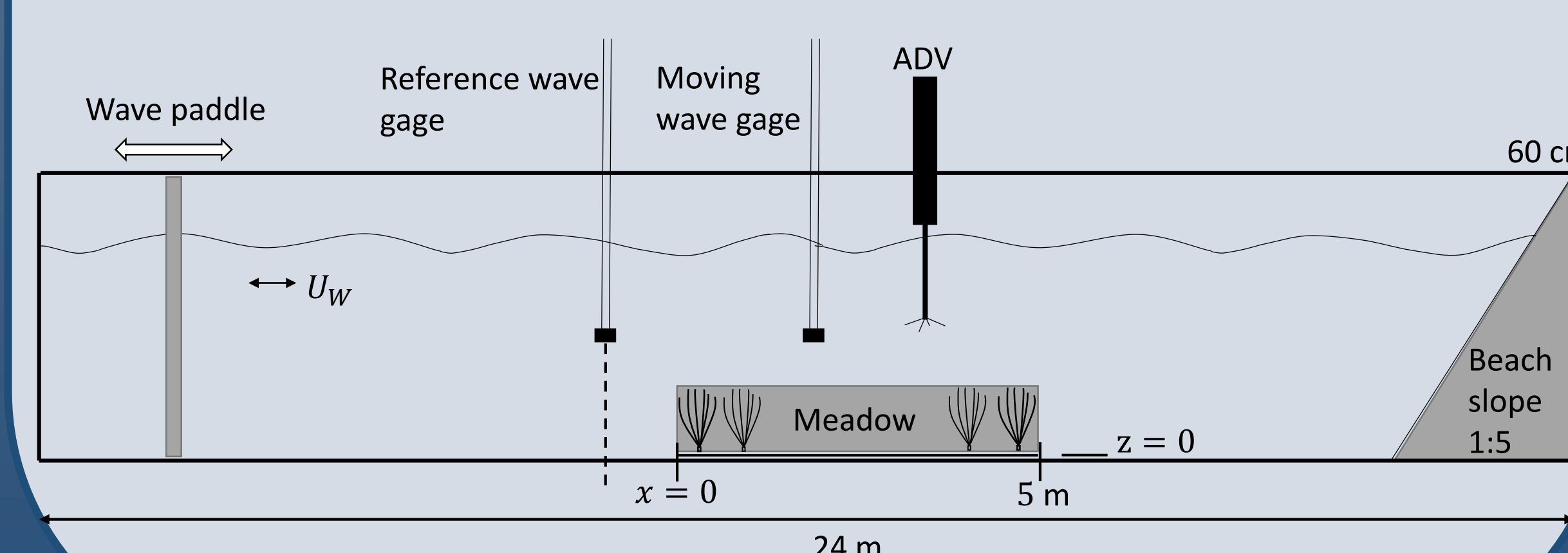
2. Experimental setup for drag force measurement

$$\frac{l_e}{l} (rms) = \frac{\text{measured rms } F}{\text{expected rms } F \text{ for rigid blade} (= \int_0^l \frac{1}{2} \rho C_D b |u_w| u_w)}$$



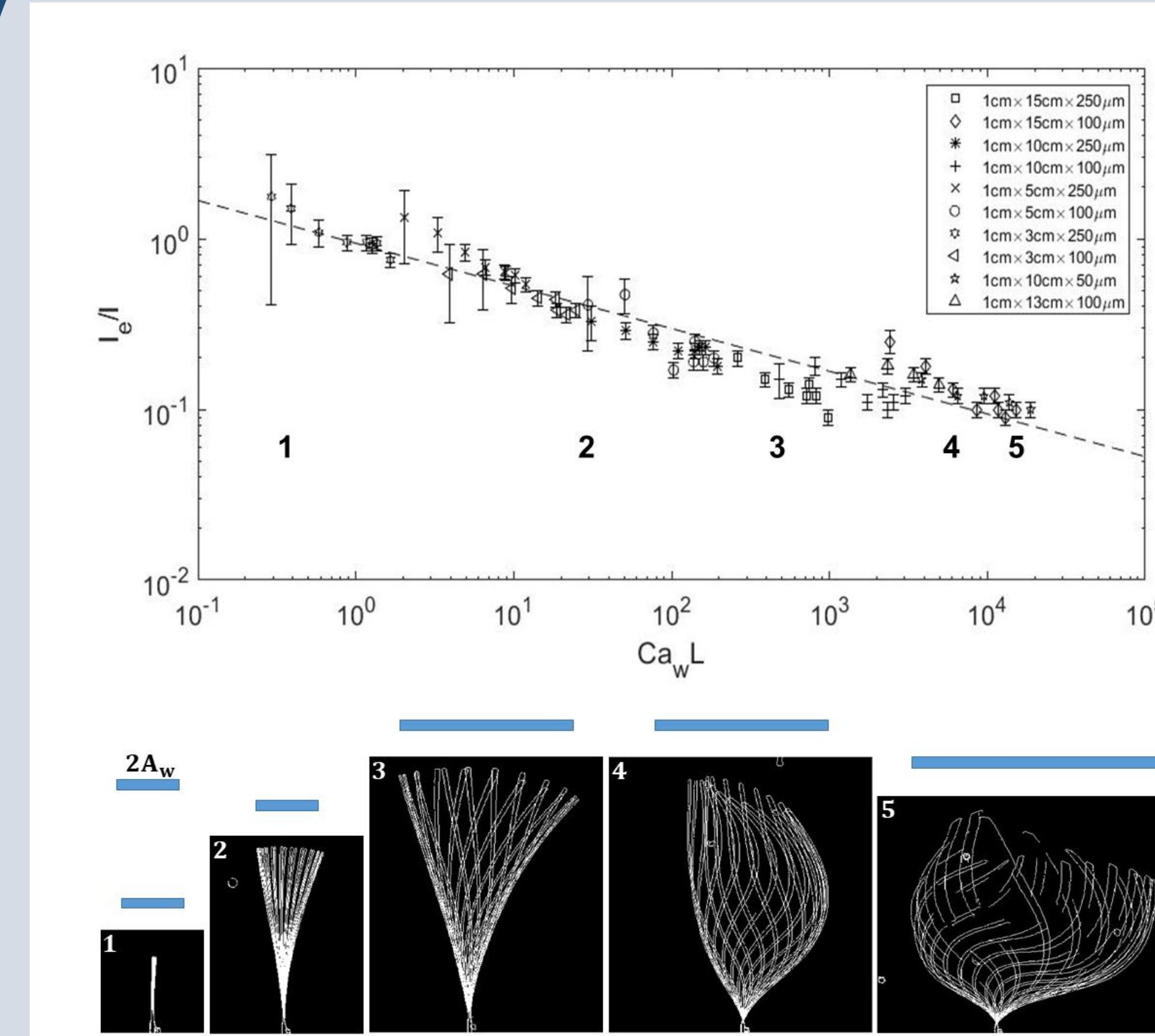
3. Experimental setup for wave damping measurement

$$\frac{a_w(x)}{a_{w0}} = \frac{1}{1 + K_D a_{w0} x} \quad \text{Use wave gages to measure wave amplitude } a_w(x)$$



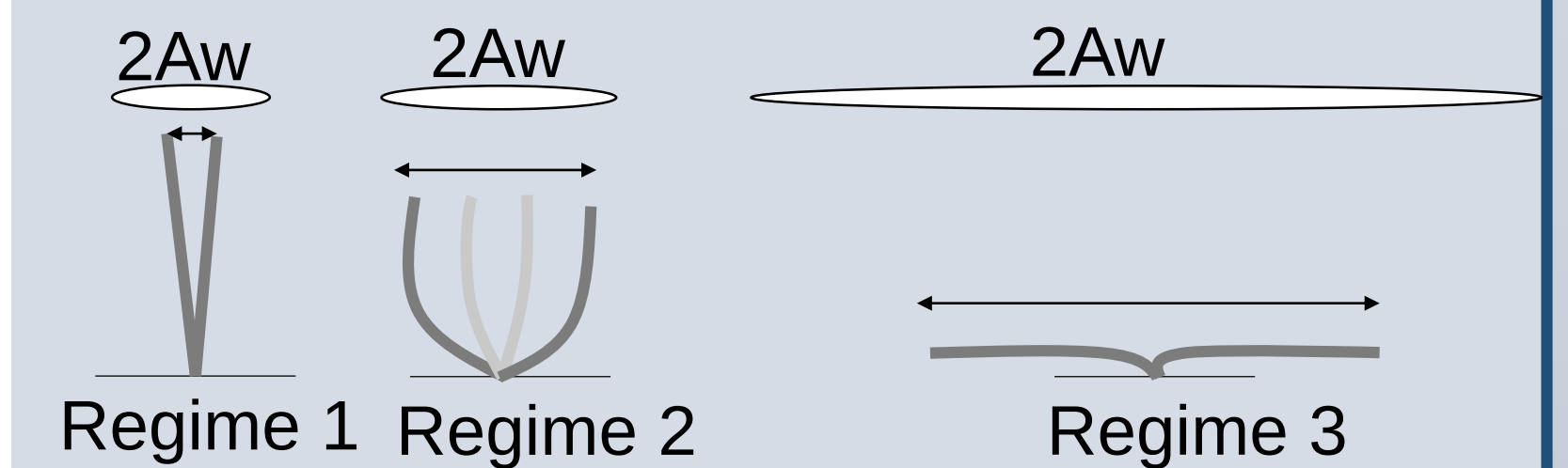
RESULTS and DISCUSSION

1. Drag force on individual blades



- **Verify (modify) existing scaling laws for individual strap-like blades**

$$\frac{l_e}{l} = 0.94 (Ca_w L)^{-0.25}$$



There are three regimes of the wave-vegetation interaction.

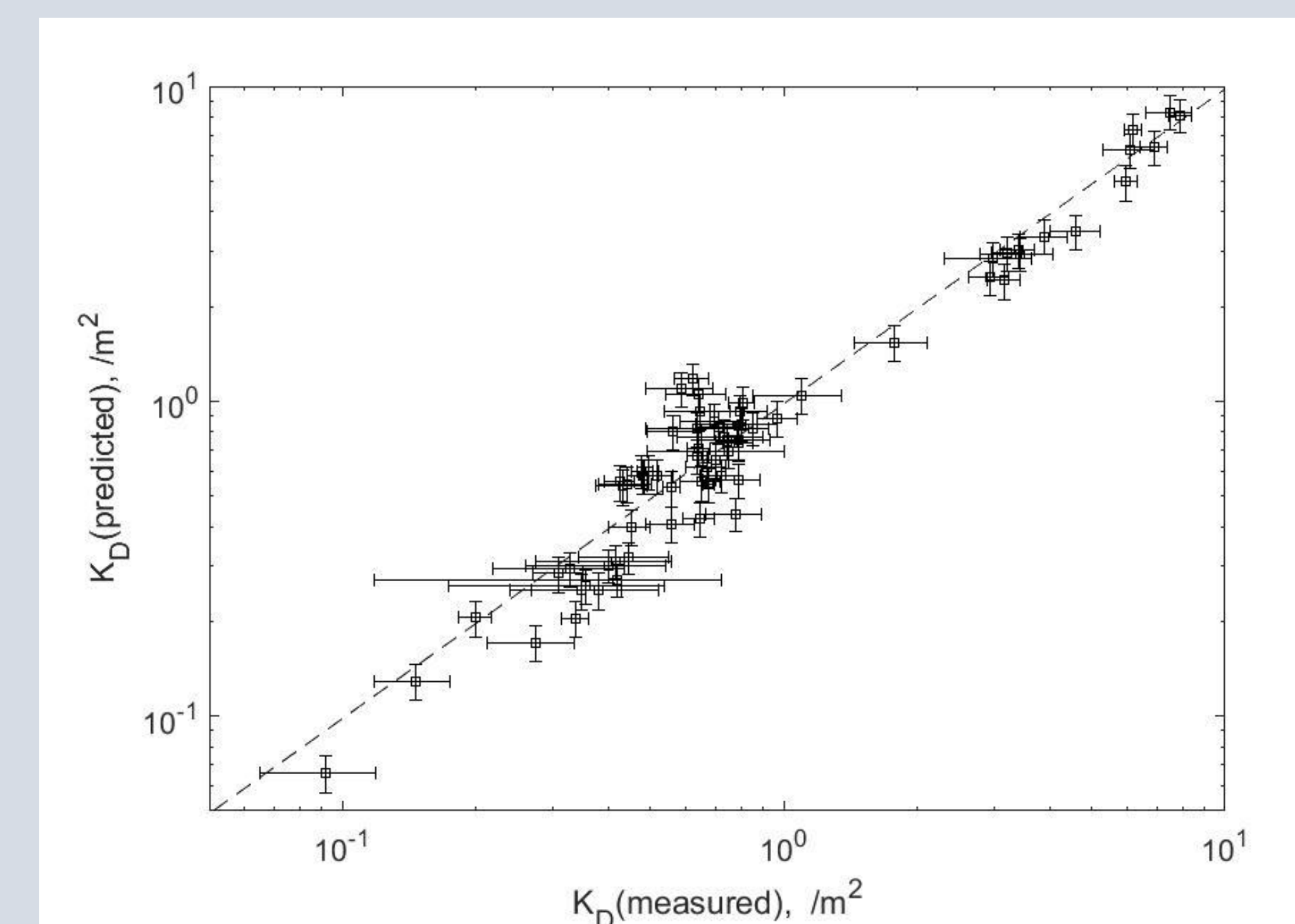
Regime 1: Stiff blade, $Ca_w < 1$, $\frac{l_e}{l} \approx 1$

Regime 2: Short waves, flexible blade, $Ca_w > 1, L \sim 1$

Regime 3: Long waves, flexible blade, $Ca_w > 1, L < 1$ (not included in experiments)

2. Extend the scaling laws to predict wave decay coefficient, K_D

$$\text{Predict } K_D \text{ using } l_e: K_D = \frac{2}{9\pi} C_D a_w k \left(\frac{9 \sinh(k l_e) + \sinh(3 k l_e)}{\sinh kh (\sinh(2kh) + 2kh)} \right)$$



Linear-fit of $K_D(\text{predicted})$ versus $K_D(\text{measured})$ yields

$$K_D(\text{predicted}) = 0.83 \pm 0.04 K_D(\text{measured}) \text{ with a correlation coefficient of } r^2 = 0.97$$

Overall, the predicted K_D has good agreement with the measurement (error < 20%).

3. Other findings

- Wave-induced current makes blades in meadow more pronated than blades in isolate; however, it does not play an important role in wave damping.
- Wave damping is similar for regular and random shoot arrangement in meadow.

4. Future work

Extend the proposed model to combined wave-current conditions and to vegetation of more complex morphology.