**Lagascalia 19(1-2): 485-490 (1997)**

# LENGTH/DIAMETER ALLOMETRIC VARIATION OF THE STIPE FOR THREE LAMINARIA SPECIES

ISABEL PÉREZ-RUZAFA, JOSÉ LUIS IZQUIERDO & TOMÁS GALLARDO

**Abstract**

This paper reports the allometric variation between the stipe length and the stipe diameter for three species of the kelp *Laminaria, L. ochroleuca, L. digitata* and *L. hyperborea*. The allometry of stipe length with respect to the stipe diameter, provides a quantitative means to compare the morphologic adaptation of the stipe to the environment. The regression curve slope characterizes the relation between stipe length and stipe diameter that influence the mechanical stability of the stipes, and therefore their flexibility. Traditionally, one of the field characters used to identify *L. digitata* has been its stipe flexibility. It bends during the low tide while *L. ochroleuca* and *L. hyperborea* stipes usually stand up. Scaling exponents show a positive allometry ($\alpha > 1$) for the three species. Slope values greater than one indicate that taller stipes are proportionately thinner than their shorter counterparts. Slope values in *L. hyperborea* and *L. ochroleuca* are greater than in *L. digitata*, indicating that stipes taller are proportionately thinner in *L. hyperborea* and *L. ochroleuca* than in *L. digitata*. Scaling exponents suggest that shape stipe and habitat are related, especially with the hidrodynamic conditions.

## Introduction

In the morphometric study of mature specimens from three *Laminaria* species, *L. ochroleuca, L. digitata* and *L. hyperborea* (IZQUIERDO & al., 1995), two different geometries of the stipe were observed: cylindrical in *L. digitata* and conical in *L. ochroleuca* and *L. hyperborea*.

From these results we pose the following questions: 1, if this geometry would be keeped as a specific character independent of the specimens size; 2, if this stipe shape would be related to their environment adaptation, and 3, if this would explain the bending of *L. digitata* when is out of the water during the low tide, against the more standing stipes of *L. ochroleuca*.

The allometry of the stipe length with respect to the stipe diameter and of the basal stipe diameter with respect to the central stipe diameter, provide a quantitative means to compare the morphologic adaptation of the stipe to the environment. The relation between stipe length and stipe diameter characterized by its regression curve slope influence the mechanical stability of the stipes. Moreover, the relation between the basal stipe diameter and the central stipe diameter shows the maintenance of geometrical shape with size increase and consequently the mechanical resistence of the stipes. In the French Britain coast, where this three species live together, there is an altitudinal zonation. *L. digitata* grows in a higher position than *L. ochroleuca* and *L. hyperborea* which grow in the lower one.

Traditionally, one of the field characters used to identify *L. digitata* has been its stipe flexibility. It bends during the low tide while *L. ochroleuca* and *L. hyperborea* stipes stand up. We think this stipe bending may be due to a buckling event, i.e. it exceed the critical height in which a structure bends by its own weight.

## Material and methods

In this works, 242 specimens of the *Laminaria* were studied: 107 of *L. ochroleuca,* 90 of *L. hyperborea,* both collected on the atlantic coasts of Spain and, 45 of *L. digitata* from Helgoland (Germany). Measurements were taken for stipe height, basal stipe diameter and central stipe diameter for each specimen.

To evaluate the variations of these three characters related to the size increase of the specimens, the allometric relation of the stipe height with the basal and central stipe diameter and of the basal stipe diameter with the central stipe diameter was calculated. The allometric function is defined by the formula:

$$\lg y = \beta + \alpha \lg x$$

where $\alpha$ is the allometric scaling exponent (regression curve slope) and $\beta$ is the allometric scaling coefficient (regression curve intercept with the ordinate axis).

According NIKLAS & BUCHMAN (1994) Greenhill's formula was used to predict critical buckling height:

$$H_{crit} = C\,(E/\rho)^{1/3}\,D^{2/3},$$

where $H_{crit}$ is the critical buckling length, $\rho$ is the bulk density of the material, C is a constant value (C= 0.792 because it was assumed that the force inducing elastic buckling was distributed over the full extent of each vertical stipe), and E is the Young's modulus or the stiffness of the material and is also constant. For the three *Laminaria* species we have considered $E = 10^7$ Pa (according to DENNY, 1988). Finally, it was assumed that density is the same for the three species ($\rho = 1.1$ gr/cm$^3$).

Statystical analyses were perfomed with Statgraphics v.5.0.

## Results and discusion

1, The allometry of *Laminaria* stipes height with respect to basal stipe diameter and stipe height with respect to central stipe diameter reported here, have a scaling exponent significantly greater than one ($\alpha > 1$, positive allometry), for the three species (Table 1). Scaling exponent values of one indicate that the stipe presents a proporcionate growth, with respect to the stipe height/stipe diameter ratio. Scaling exponents significantly less than one indicate that taller specimens have disproportionately thicker stipes than the shorter ones as in typical dicot tree species ($\alpha = 0.5$, NIKLAS & al., 1994). Slope values greater than one ($\alpha > 1$), indicate that taller stipes are disproportionately thinner than their shorter counterparts, as in the stipes of *Laminaria* spp. ($\alpha = 1.6$ y $\alpha = 1.9$, Table 1).

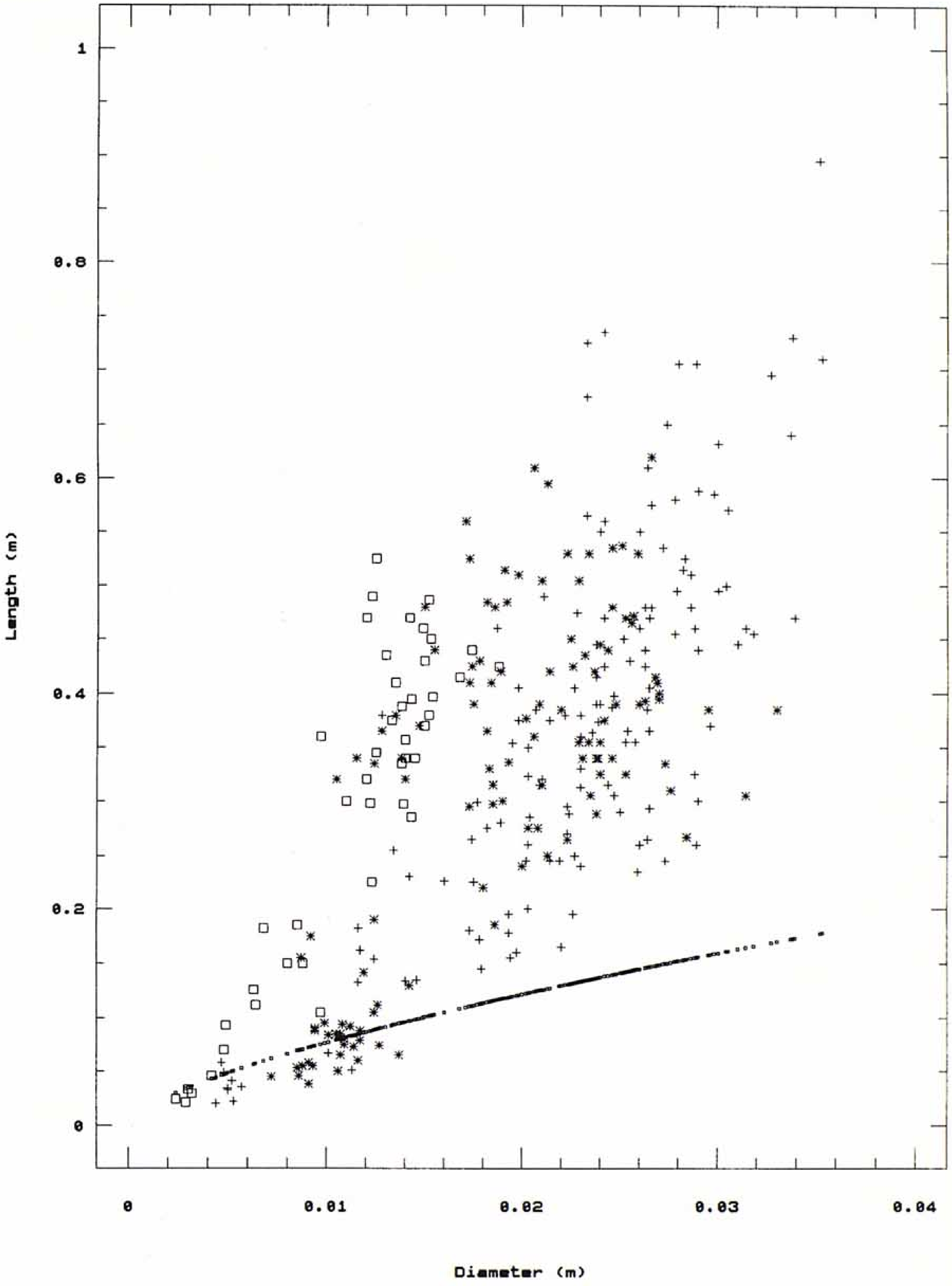


Figure 1. Stipe height plotted against basal stipe diameter (m) for *L. digitata* (□), *L. hyperborea* (*), *L. ochroleuca* (+) and for the critical buckling height (■).

| | N | $r^2$ | β±SE | α±SE |
|---|---|---|---|---|
| Laminaria | | | | |
| H *vs.* basal D | 242 | 0.65 | 2.58±0.04 | 1.28±0.06 |
| H *vs.* mean D | 242 | 0.73 | 2.83±0.03 | 1.65±0.06 |
| L. digitata | | | | |
| H *vs.* basal D | 45 | 0.92 | 3.10±0.03 | 1.59±0.07 |
| H *vs.* mean D | 45 | 0.91 | 3.17±0.03 | 1.64±0.07 |
| Basal D *vs.* mean D | 45 | 0.94 | 0.04±0.01 | 1.00±0.03 |
| L. hyperborea | | | | |
| H *vs.* basal D | 90 | 0.71 | 2.24±0.07 | 2.01±0.13 |
| H *vs.* mean D | 90 | 0.77 | 2.85±0.04 | 2.42±0.14 |
| Basal D *vs.* mean D | 90 | 0.86 | 0.30±0.01 | 1.07±0.04 |
| L. ochroleuca | | | | |
| H *vs.* basal D | 107 | 0.83 | 2.28±0.05 | 1.43±0.06 |
| H *vs.* mean D | 107 | 0.87 | 2.50±0.03 | 1.87±0.07 |
| Basal D *vs.* mean D | 107 | 0.93 | 0.18±0.01 | 1.20±0.08 |

Table 1. Summary statistics of multiplicative regression analysis for stipes lenght (H, in m) against basal and central diameter (Dbasal, Dcentral, in m) and basal diameter against central diameter for N number of specimens *Laminaria*. Regression curves have the functional form $\log H = \beta + \alpha \log D$.

Higher slope values in *L. hyperborea* and *L. ochroleuca* than in *L. digitata,* indicate that taller stipes are proportionately thinner in *L. hyperborea* and *L. ochroleuca* than in *L. digitata*. Paradoxically, *L. digitata* stipe diameter grows proportionally more than the other two species, but these show the larger diameter values (Fig. 1).

The allometry of the basal stipe diameter with respect to the central stipe diameter have a scaling exponent significantly equal to one for both *L. digitata* and *L. hyperborea* ($\alpha$= 1.00, $\alpha$= 1.07, respectively, Table 1). This isometry represents the maintenance of the geometrical shape with size increase and, therefore, cylindrical shaped *L. digitata* and conical shape *L. hyperborea* not depend of the size. Scaling exponent of *L. ochroleuca* is greater than one ($\alpha$= 1.2, Table 1), thus, greater specimens are disproportionate with respect to the basal stipe diameter/central stipe diameter ratio and therefore, conical shape increase with size.

2, For the three species ($\alpha$>1 stipes height with respect to basal diameter) stipe adaptation to the environment present the general strategy as *Nereocystis leutkeana* (DENNY, 1988): They are large and extensible and not strong. We can found two different strategies based on the relation between morphology and the stipe hydrodynamism resistence. First, following the aforementioned results *L. digitata* keeps a cylindrical stipe during all its development. This geometric figure presents stronger resistence to a force application if material, diameter and height are the same. Thus, the stipe biomase cost is optimized with the acquisition of the most efficient geometric structure, and therefore it can present a smaller diameter. On the other hand, *L. ochroleuca* and *L. hyperborea* present a conical stipe and balance the lower resistance of this geometrical structure with a larger basal diameter.

3, Stipe height and basal stipe diameter data-points for the three species and for the critical buckling height are co-plotted in Figure 1. All the data-points corresponding to stipes longer than 5 cm exceed the curve for $H_{crit}$. Therefore, stipes of the three *Laminaria* species will present buckling events. However, at the same stipe length (e.g. near to 20 cm) *L. digitata* exceeds the critical buckling height much more than *L. ochroleuca* and *L. hyperborea*. In consequence, we think that the *L. digitata* bending stipes against the more standing stipes of *L. ochroleuca* during the low tide can be explained by a buckling event.

**References**

DENNY, M. W. (1988). *Biology and the Mechanics of the Wave-Swept Environment*. Princeton University Press.

IZQUIERDO, J. L., I. PÉREZ-RUZAFA & T. GALLARDO (1995). Estudio biométrico de la morfología del género *Laminaria* sección Digitatae (Phaeophyta) de las costas europeas. *Resum. XI Simp. Nac. Bot. Cript.*: 27-28.

NIKLAS, K. J. & S. L. BUCHMAN (1994). The allometry of Saguaro height. *American J. Bot.* **81(9)**: 1161-1168.

**Address of the authors:**

Drs. I. Pérez-Ruzafa, J. L. Izquierdo & T. Gallardo, Departamento de Biología Vegetal I, Facultad de Biología, Universidad Complutense, 28040 Madrid, Spain.