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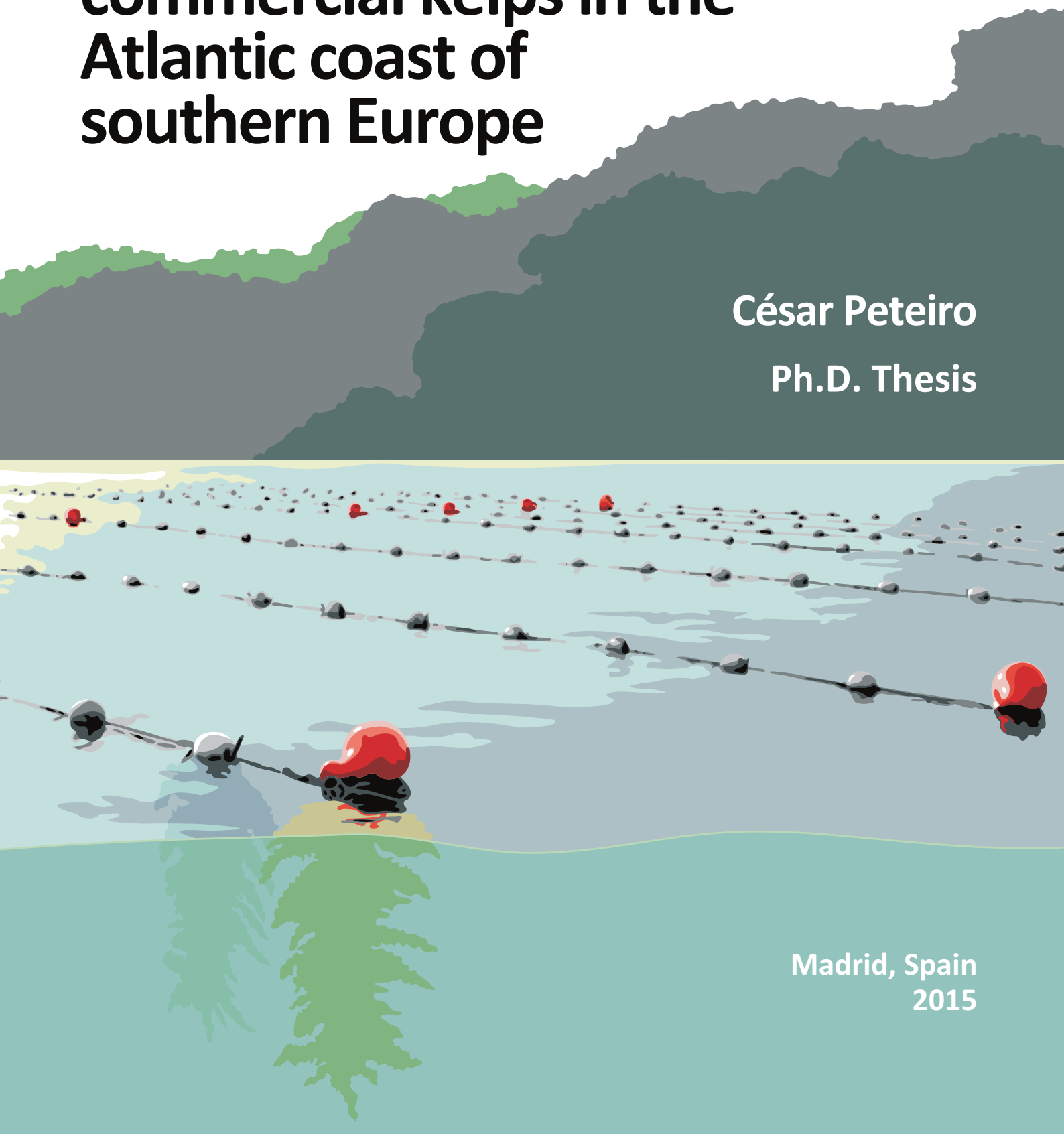
Open-sea cultivation of commercial kelps in the Atlantic coast of southern Europe



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Ph.D. Thesis

Madrid, Spain
2015

Universidad
Rey Juan Carlos

Escuela Superior de Ciencias Experimentales y Tecnología
Departamento de Biología, Geología, Física y Química Inorgánica
Área de Biodiversidad y Conservación

Open-sea cultivation of commercial kelps in the Atlantic coast of southern Europe

A dissertation submitted by

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to the

Universidad Rey Juan Carlos (URJC)

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy (Ph.D.)

in

Madrid, 2015

Supervised by

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SUMMARY

Kelps are one of the most economically and ecologically important groups of seaweeds in the world. They are used mainly as human food and as an alginate source for a wide range of industries; however, they also have many other applications. In addition, these large algae play important roles as ecosystem engineers and/or foundation species (kelp forest), providing habitat, protection, and food for numerous organisms in coastal ecosystems. Most kelps are confined to northern temperate regions with relatively cold water, usually below 20°C. The southern distribution limit of almost all European species is along the Atlantic coast of the Iberian Peninsula.

Commercial kelp species in eastern Asia were traditionally collected from wild stocks, although this practice has been replaced to a great extent by kelp mariculture, which now supplies more than 80% of global production. In contrast, kelps in Europe are still wild harvested for industrial purposes. However, natural resources are limited, and populations from the Atlantic coasts of the Iberian Peninsula have declined in recent years due to climate change. The development of kelp mariculture in European countries may lead to increased production for commercial uses and, in turn, protect the kelp forest from overharvesting. The introduced kelp *Undaria pinnatifida* (wakame) and the native kelp *Saccharina latissima* (sugar kombu) are economically valuable seaweeds that have been harvested for human consumption in northern Spain. Mariculture of these edible seaweeds has generated great interest as an emerging Spanish industry due to their high demand and economic value.

This doctoral thesis provides baseline information required for cultivation of kelp species on a commercial basis along the Atlantic coast of southern Europe. More specifically, it contributes to development and implementation of methodologies suitable for mariculture of *U. pinnatifida* and *S. latissima* along the Spanish Atlantic coast. The manuscript's contents describe commercial-scale cultivation trials of *U. pinnatifida* in Galicia and *S. latissima* in Galicia and Cantabria, mainly focusing on the yield and quality of cultured sporophytes. The natural life cycle consists of the microscopic gametophyte stage and the macroscopic sporophyte stage, and kelp cultivation consists of two phases related to this life cycle. In this study, a laboratory phase provided environmental conditions necessary for the artificial production of young sporophytes from gametophytes. Young sporophytes were produced at the Spanish Institute of Oceanography (IEO) in Santander, and a subsequent farming phase involved cultivation of these sporophytes in the sea until they reached a suitable size for commercial harvesting.

The main results in this thesis contribute significantly to the knowledge necessary to develop commercial-scale cultivation of kelp species in this area. The thesis, which consists of a collection of six chapters (published articles) and a general discussion, focuses on the following main topics: **(1)** the effects of hydrodynamic conditions on kelp culture grounds in coastal bays (rías) in order to identify optimal locations for cultivation of *U. pinnatifida* and *S. latissima* [Chapters I and III, Discussion]; **(2)** the suitability of different floating rafts equipped with culture systems built using horizontal rope (long-line) or hanging rope (garland and vertical types) in sheltered and more exposed environments [Chapters I, II, III, IV, V, and VI, Discussion]; **(3)** identification of the suitable time frame (planting and harvesting period) for the mariculture of both kelp species along the Atlantic coast of southern Europe (northern Spain), and its relationship with environmental factors (seawater temperature, dissolved inorganic nitrogen, underwater irradiance, and daylength) [Chapters II, III, and IV, Discussion]; and **(4)** different methods of open-sea cultivation tested with *S. latissima*, based on practices traditionally employed for the Asian *Saccharina japonica* (two year cultivation, forced cultivation, cultivation by transplanting) [Chapters III, IV, V, and VI, Discussion]. Finally, **(5)** this thesis also discusses the development of mariculture of the introduced kelp, *U. pinnatifida,* in relation to the native kelp, *S. latissima,* from an economic standpoint (e.g., yield values and range of high value-added applications) and from an environmental point of view, taking into account the risks and/or benefits associated with cultivation of those species [Discussion].

This research revealed that mariculture of the kelps *U. pinnatifida* and *S. latissima* along the Atlantic coast of southern Europe is technically and biologically viable, as indicated by the high yields obtained. However, it is highly recommended that the native *S. latissima* be cultivated in northern Spain, as it is the most economically and environmentally advantageous species due to its high biomass yield of about 16 kg fresh weight per linear meter of rope (equivalent to more than 40 tons fresh weight per hectare of a farm). This yield can be used in many value-added applications and services, such as human food, animal feed, fertilizers, and feedstock for bioethanol production. It also is an ideal candidate for use in integrated multitrophic aquaculture.

Kelps are economically important edible seaweeds with many potential applications. As the supply from wild harvest cannot meet increasing current and future uses, methods to successfully cultivate kelp species are needed. This doctoral thesis provides baseline information required for cultivation of kelp species on a commercial basis along the Atlantic coast of southern Europe. More specifically, it contributes to development and implementation of methodologies suitable for mariculture of the kelps *Undaria pinnatifida* and *Saccharina latissima* along the Spanish Atlantic coast.