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# Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment

Ricardo Radulovich *, Schery Umanzor, Rubén Cabrera, Rebeca Mata

*Dep. of Agricultural Engineering, University of Costa Rica, San José, Costa Rica*

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ABSTRACT

As a response to growing land and freshwater shortages and climate change, the use of seaweeds as food, their cultivation at sea and its effect on biodiversity are being researched on both the Caribbean and Pacific coasts of Costa Rica. Native species, more plentiful on the Caribbean coast, were collected and pre-selected based on existing information and on criteria including ubiquity, abundance, growth and palatability. These species were then evaluated as food and subjected to floating long-line cultivation using vegetative propagules. After establishing postharvest procedures, use as food involved many preparations to be eaten fresh or after drying, including a dry-ground meal. Ten of these species, which had nutrient contents within expected values including 9.8% crude protein on a dry weight (dw) basis and high iron, were considered adequate as food, both directly and as part of recipes in quantities not exceeding 20% dw of a given dish. Higher concentrations either 'overwhelmed' traditional recipes or their taste was rejected by tested consumers. Near-coast cultivation was in general a simple matter, easily transferred to artisanal fishers. To a great extent due to herbivory and theft of ropes, yield (ranging from 51.7 to 153.2 t $ha^{-1}$ $yr^{-1}$ on a fresh weight basis) was quantified for only five species with a mean of 9.3 t $ha^{-1}$ $yr^{-1}$ dw, equivalent to 0.91 t $ha^{-1}$ $yr^{-1}$ of crude protein—very similar to yields of two grain crops per year. Species of *Codium*, *Gracilaria*, *Sargassum* and *Ulva* were considered adequate both for use as food and cultivation. Cultivated seaweed plots rapidly attracted biodiversity, including a significantly larger number of fish species and individuals than nearby control areas. Based on this we postulate the need to further explore a 'biodiversity enrichment' service from seaweed cultivation and any effect of this on fisheries enhancement. While noting areas in which further research and international collaboration are needed, it is concluded that tropical seaweeds, besides their many other uses, can at this stage substitute up to 15% of food on a dry weight basis, their cultivation is simple, and effects on biodiversity are a previously undocumented advantage. Given the lack of experience in most of the world excepting some Asian countries, the agriculture-like approach followed here may be of use to others in tropical developing countries who wish to explore seaweed cultivation at sea, for food and other products and for environmental/biodiversity services.



## 1. Introduction

Needed increases in world food production are hindered by growing land and water shortages and by climate change (Falkenmark et al., 2009; OECD/FAO, 2012; UNU, 2012); however, at sea space abounds and food production does not require any freshwater (Radulovich, 2011). The use of seaweeds (macroalgae)—the only existing choice for primary production at sea—for human food and other applications, has grown to ~21 million tonnes (Mt) on a fresh weight basis annually, of which ~20 Mt are cultivated at sea, the rest is from natural harvests (FAO, 2012, 2013). It is considered that 76% of world seaweed production and 88% of its value are for direct food consumption (Chopin, 2012). However, 99.8% of cultivated production happens in only nine countries, of which eight are Asian (four of them tropical: Indonesia, Philippines, Malaysia and Vietnam), and one African (Tanzania, particularly Zanzibar); the remaining 15 tropical countries with some cultivation reported produce a combined yearly total of only ~32,000 t (FAO, 2012).

Although tropical seaweeds have amply demonstrated 'cultivability' and productivity, and their nutritional adequacy and edibility as human food have also been shown, at least at the laboratory level (e.g., Black, 1952; Matanjun et al., 2009; McDermid and Stuercke, 2003; Reed, 1907; Robledo and Freile, 1997), most of the limited cultivation experience outside Asia is for hydrocolloid uses, as it is, e.g., for Zanzibar (Msuya, 2011). In all countries of tropical Latin America, the Caribbean and most of Africa seaweeds are essentially an ignored resource, and scant or no cultivation is reported for any purpose much less for food (FAO, 2012).

Given the overarching opportunity this may represent, it was considered convenient to evaluate seaweeds as a food source, including their cultivation and effects on biodiversity in Costa Rica, a country

* Corresponding author. Tel.: +506 8315 0613.
*E-mail address:* ricardo.radulovich@ucr.ac.cr (R. Radulovich).

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with coasts on both the Pacific ocean and the Caribbean sea and an abundance of native seaweed species (Fernández-García et al., 2011; Wehrtmann and Cortés, 2009). Since there is a generalized lack of proven methodology to follow, it was necessary to establish and implement an agriculture-like protocol to conduct this work, thus expanding aims into generating specific experience which can be of use in the context of coastal tropical developing countries seeking solutions at sea to their food-production limitations.

## 2. Materials and methods

Work was conducted in Costa Rica from early-2011 through mid-2013 in the near-shore waters of the Cahuita/Puerto Viejo region of the Caribbean coast and in the Gulf of Nicoya, Central Pacific and Cuajiniquil, North Pacific coast. Since it was considered essential to use only native species, at least at this early stage, the procedure followed consisted of prospecting for seaweed species, pre-selecting species, evaluating pre-selected species as food and for their cultivability, and final selection.

### *2.1. Prospecting and pre-selection*

Prospecting for seaweed species by scouting different areas on or near the sites throughout the year required seeking, collecting and identifying specimens of different species. Species were pre-selected according to cultivation and nutritional properties as described in the literature, as available, and their characteristics like ubiquity, abundance, vigorous growth and perceived advantages of using them—something that included observing preference of herbivores and eating the raw seaweed *in situ*.

Noting that for some species final taxonomic classification is in progress, after pre-selection seaweed species were subjected interactively to both a variety of postharvest treatments and uses as food, and to cultivation.

### *2.2. Uses as food*

For pre-selected seaweeds harvested either from the wild and/or cultivated, postharvest treatment consisted of thorough washing with freshwater, cleaning away debris, small fauna and epiphytes, while removing unwanted parts like holdfasts and damaged tissue. After that excess surface water was removed by agitation. Those to be consumed raw were used or bagged and refrigerated. Others were oven-dried at 60 C for 24 h, time that proved sufficient for constant dry weight (which was established for 23 species at a mean of 9.7% [$\pm$1.6%] of dry weight over fresh weight). After drying and allowing to cool down to room temperature, seaweeds were packed in polyethylene bags which were sealed after expelling excess air by hand, and stored in the shade at room temperature.

A variety of cooking methods and recipes were tried following in every case standard culinary practice and using regular house kitchens, appliances and tools in order to simulate real-life applications. While the detailed description of this is beyond the scope of this paper, and is presented elsewhere (Radulovich et al., 2013), the major types of food preparations used seaweeds:

a) Fresh (raw): as part of salads; blended with fruit and vegetable juices; whole or chopped to be cooked into a variety of specific food preparations (dishes) like rice and/or beans, similar to spinach and as a beverage; baked to crispy; and, fried in a variety of manners including a recipe similar to green beans covered with egg batter;
b) Rehydrated after drying: whole or chopped into a variety of dishes like rice and/or beans; and,
c) Dried, ground to different levels of coarseness: as partial substitute of wheat and maize flour in the preparation of a variety of recipes like cookies, fried chips, grissinis and spaghettis; as a meal or a powder to be sprinkled liberally on or into different recipes, including fruit juices and scrambled eggs; and, encapsulated to be consumed as a dietary complement.

Food preparations were first preliminarily evaluated by panels composed of project personnel considering appearance, taste/palatability, color, smell, consistency, after-eating effects, ease of use for cooking and perceived departure from typical/traditional control recipes that did not include seaweeds. After preliminary evaluation, selected recipes and modes of use were further evaluated with groups of people through 25 informal food tasting panels. Panels were composed of from 5 to 43 participants, mostly urban dwellers though some were conducted with only coastal rural inhabitants. The main acceptability criteria considered were quantities consumed, including repeating, as well as comments on appearance, flavor, odor, texture and others as expressed by participants during and after tasting. This food preparation and testing process was iterated seeking improvements, including trying recipes with different species or with combinations of species. A third step consisted of evaluating postharvest treatment and packaged storage, both dry and refrigerated-raw.

Eight of the seaweed species selected due to advantages in both use as food and cultivation were subjected to bromatological analyses to determine content of fat, crude protein, total dietary fiber and iron on a dry-weight basis. All analyses were conducted in certified laboratories of the University of Costa Rica following quantitative Association of Official Analytical Chemists (AOAC) methods. Results are presented aggregated because these are exploratory determinations for only one harvest time, and due to the fact that in some cases the final taxonomic classification of some of the species is lacking.

### *2.3. Cultivation*

Pre-selected seaweed species were subjected to floating long-line cultivation in waters 1.5 to ca. 10 m deep. Sites used were chosen through a combination of accessibility and local conditions, avoiding the rougher waters yet attempting to represent prevailing conditions for a potential future expansion. Long lines were spaced 1 m apart and, depending on the species, vegetative propagules of 4 to 30 g each were tied to ropes (4 mm thick) spaced on average 0.3 m between them. Plots were placed in different locations ranging from rocky/coralline and seaweed prairie flats to barren sandy bottoms on the Caribbean and above muddy flats on the Gulf of Nicoya and rocky sandy bottoms in Cuajiniquil. Plot size varied from a few lines occupying ca. 50 $m^2$ to the largest occupying 1200 $m^2$ (20 m wide $\times$ 60 m long) off the Puerto Vargas beach at the Caribbean site. Sand-filled burlap sacks were used as anchors and reused plastic bottles and jugs as floats.

Main cultivation parameters evaluated were growth and survival rates, as well as other characteristics such as fouling, epiphytism, sediment accumulation, herbivory and relations of the cultivated plots with their surroundings, including biodiversity and responses to currents and waves. Yield data were obtained from weekly to monthly rates. Data presented on a per hectare and yearly basis were extrapolated from at least three monthly fresh weight measurements of 5 to 10 m of line per sample. Some of this cultivation work was conducted with local fishers.

### *2.4. Biodiversity considerations*

Biological diversity, defined as the number of species and of individuals present at a site, was evaluated through time for some of the Caribbean cultivation plots as compared to surrounding areas, identifying and counting selected groups of species and approximating their numbers for time intervals ranging from a few to up to 12 weeks.

Biodiversity data presented here are mainly for the larger plot at the Puerto Vargas beach, Caribbean site, which is in a protected area with no fishing allowed and exhibits very low native biodiversity having a sandy