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Observations on fish grazing of the cultured kelps *Undaria pinnatifida* and *Saccharina latissima* (Phaeophyceae, Laminariales) in Spanish Atlantic waters

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Abstract. Despite the great importance of grazing by herbivorous fishes in the marine environment, the knowledge of this phenomenon on seaweeds cultivation is very limited. Indeed, there is not available information on the effects of fish grazing in the farming of economically valuable kelps. During an investigation of the cultivation of commercial kelps *Undaria pinnatifida* and *Saccharina latissima* in North Western Atlantic coast of Spain (Galicia), it was found that grazing by fishes was sometimes responsible for removing of algal's material from culture ropes. Fish grazing were generally rare and with a minor influence, usually its adverse effects are limited to a small decrease in the yield in some culture ropes, however, in some cases, it can also involve the lost of virtually the entire crop of culture rope. Most of herbivore grazing was associated to sparid fishes such as bogue (*Boops boops*), and salema (*Sarpa salpa*). Preferably, herbivorous fishes consumed blade of both cultured kelps when they were still young fronds (juvenile stage of algae). Indeed, blade of adult fronds was clearly less affected, and in *S. latissima* adults there was even not observed any fish grazing effects. Herein, different biotic and abiotic factors are discussed as possible causes of the influence of fish grazing on cultured kelps.
Key Words: grazing, mariculture, kelp species, herbivorous fish.

Introduction. Marine macroalgae (i.e. seaweeds) constitute the main food items of marine herbivorous fishes in coastal ecosystems (Tolentino-Pablico et al 2008). Grazing by herbivorous fishes affects cover and biomass of algae; however, the importance of these macrograzers is variable according to habitat features (Taylor & Schiel 2010). Although herbivorous fishes have been mentioned as detrimental on yield to seaweeds mariculture, little information is available about their effects (Buschmann et al 2001; Ganesan et al 2006). Prior to this study, the damage of herbivorous fishes on kelp farming species had not been documented.

The kelps *Undaria pinnatifida* (Harvey) Suringar, 1873 (Laminariales: Alariaceae) and *Saccharina latissima* (Linnaeus) C. E. Lane, C. Mayes, Druehl et G. W. Saunders, 2006 (Laminariales: Laminariaceae) are large brown seaweeds. In fact, kelp forests have an important ecological function in the coastal zone, as they inhabit a high number and a specific composition of fauna (Steneck et al 2002). In addition, these two kelp species are economically valuable seaweeds due to their use as food for human consumption (Holdt & Kraan 2011). In recent years, many others applications have emerged and thus, they are considered as possible food for aquaculture of marine herbivorous (Chang et al 2005), and they potentially represent a significant source for production of fungible liquid transportation biofuels such as bioethanol (Kraan 2010).

During an investigation into the cultivation of commercial kelps *U. pinnatifida* and *S. latissima* in Atlantic coast of Spain, it was found that grazing by fishes was responsible for the removing of algal's material in some culture ropes (Peteiro et al 2006; Peteiro & Freire 2009, 2011, 2012). This paper is a brief summary of these observations, with the main aim of documenting the effects of fish grazing on both cultured kelps.

Material and Methods. Observational data from several cultivation trials carried out with *U. pinnatifida* and *S. latissima* between 2002 and 2004 on North Western Atlantic coast of Spain (Galicia) were used. Cultivation trials were conducted at Ría de Ares y Betanzos (A Coruña, Galicia), which is a semi-enclosed bay (Figure 1). Experimental culture site (43º22′N, 8º15′W) was located in the inside part of the bay in a coastal sheltered area specifically devoted to aquaculture.

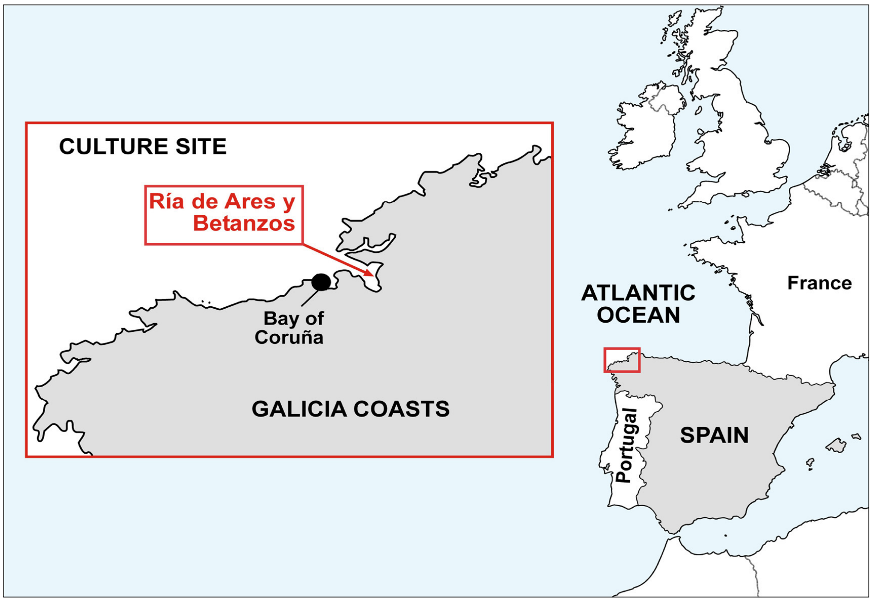

Figure 1. Location of the culture site in the Ría de Ares y Betanzos (A Coruña, Galicia) on the Atlantic coast of Spain.

In cultivation trials, strings with seedlings of *U. pinnatifida* and *S. latissima* were inserted on culture ropes, which were deployed in culture rafts (Figure 2). Seedlings (i.e. young plants) were produced using indoor production methods according to previous studies (Peteiro & Freire 2009, 2011). Culture ropes were transferred to the sea between October-December and they were harvested between April-May (for more details, see Peteiro et al 2006; Peteiro & Freire 2009, 2011, 2012).

Figure 2. View of a culture raft for cultivation of *U. pinnatifida* and *S. latissima* (Photo by Ó. Freire).

Results and Discussion. Observations allow us to state that fish grazers were sometimes responsible of the removing of algal's material during cultivation trials with *U. pinnatifida* and *S. latissima*. In general, damage by herbivorous fishes was not too much frequent on kelps' mariculture (Figures 3 and 4). The adverse effects are usually limited to a decrease in the yield of some culture ropes. Consequently, it is very difficult to make an estimation of lost biomass because of the small amount of grazing, its temporal variation and its variability within ropes; however, crops losing could be observed despite the fact that this lost was generally small or negligible. Nevertheless, it is necessary to signalise that fish grazing could also involve the lost of virtually the entire crop of culture ropes when extensive fish grazing affects to young kelps during the early months of culture. Although some studies have signalised the damage by fish's grazing on farming of red seaweeds as *Gracilaria* spp., *Kappaphycus* spp. and related species (Buschmann et al 2001; Ganesan et al 2006), effects on maricultured kelps had not been reported to date.

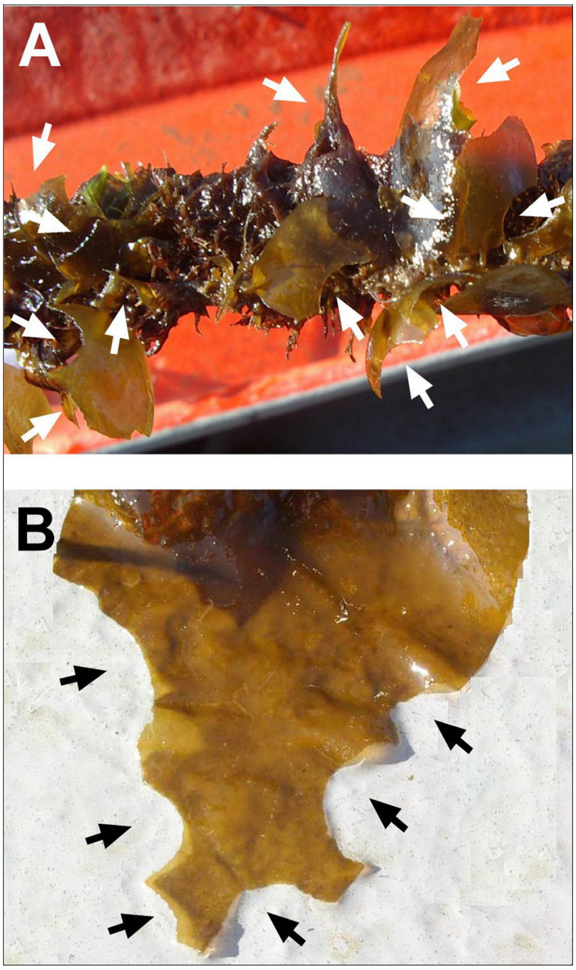

Figure 3. Herbivorous fishes grazing effects on juvenile cultured kelps. (**A**) Culture rope with juveniles affected by fish grazing (indicated by arrows); (**B**) Detail of fish bites (arrows) on a juvenile blade (fronds smaller than 5 cm long) (Photos by Ó. Freire).

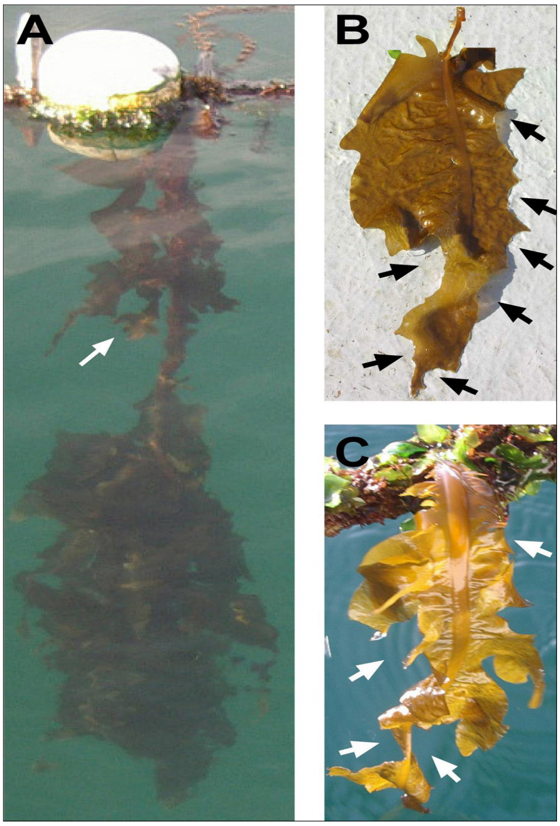

Figure 4. Effects of herbivorous fishes grazing on adult fronds of cultured *Undaria pinnatifida* (**A**) Appearance of culture rope with adult fronds of *U. pinnatifida* affected by fish grazing (arrow), it cause a decrease in yield; (**B**) Juvenile-adult of *U. pinnatifida* (frond about 15 cm long) affected by fish grazing, fish bites are observed on blade (arrows); (**C**) Adult of *U. pinnatifida* (frond about 1 m long) affected by fish grazing, fishes bites are observed on blade (arrows) (Photos by Ó. Freire).

Grazing caused by herbivorous fish was mainly due to representative marine species of Sparidae family such as salema (*Sarpa salpa* (Linnaeus, 1758)) and bogue (*Boops boops* (Linnaeus, 1758)). Their feeding habits are somewhat ambiguous, but in general, *S. salpa* adults are almost exclusively herbivorous, although the juveniles are mostly carnivorous, while *B. boops* are generally omnivorous (Bauchot & Hureau 1986; Froese &

Pauly 2012). They have been reported as common herbivorous fishes on macroalgae and seagrass in coastal waters both in Northeastern Atlantic as in Mediterranean (Bauchot & Hureau 1986; Havelange et al 1997; Ruitton et al 2006; Froese & Pauly 2012).

Sparid fishes appear to prey on kelp farms primarily in autumn and early winter, when the effects of grazing were most obvious and important. This is consistent with studies which point out that feeding activity of *B. boops* and *S. salpa* increases in autumn during pre- and post-spawning periods (spring and summer) (Ruitton et al 2006). According to Tolentino-Pablico et al (2008), small algae such as *Ulva* and *Dictyota* are highly preferred as food by sparid herbivorous such as *S. salpa*. Duffy & Hay (1994) found that some fishes preferentially fed on red and green seaweeds. The consumption of large brown seaweeds (e.g. *Sargassum* and *Cystoseira*) by herbivorous fishes has also been reported (Tolentino-Pablico et al 2008; Verges et al 2009; Vanderklift et al 2009). However, to date, no case of fish grazing on *U. pinnatifida* and *S. latissima* kelps has been described under natural or cultivated conditions.

Fish grazing seems to affects only to kelps blades, where herbivorous fishes appear to take small bites of blades during consumption (arrows in Figures 3 and 4). Furthermore, it was observed that sparid grazers ingested, preferably, blades of *U. pinnatifida* and *S. latissima* when they were still young, i.e. juvenile stage of algae (Figures 3 and 5). Adult fronds of *U. pinnatifida* were clearly less affected by herbivorous fishes, and in the case of *S. latissima,* they were even not observed effects of grazing on the adult fronds (Figures 4 and 5). Similarly, other studies have described that some herbivorous fishes fed mainly on juvenile fronds of algae (Barry & Ehret 1993; Taylor & Schiel 2010).

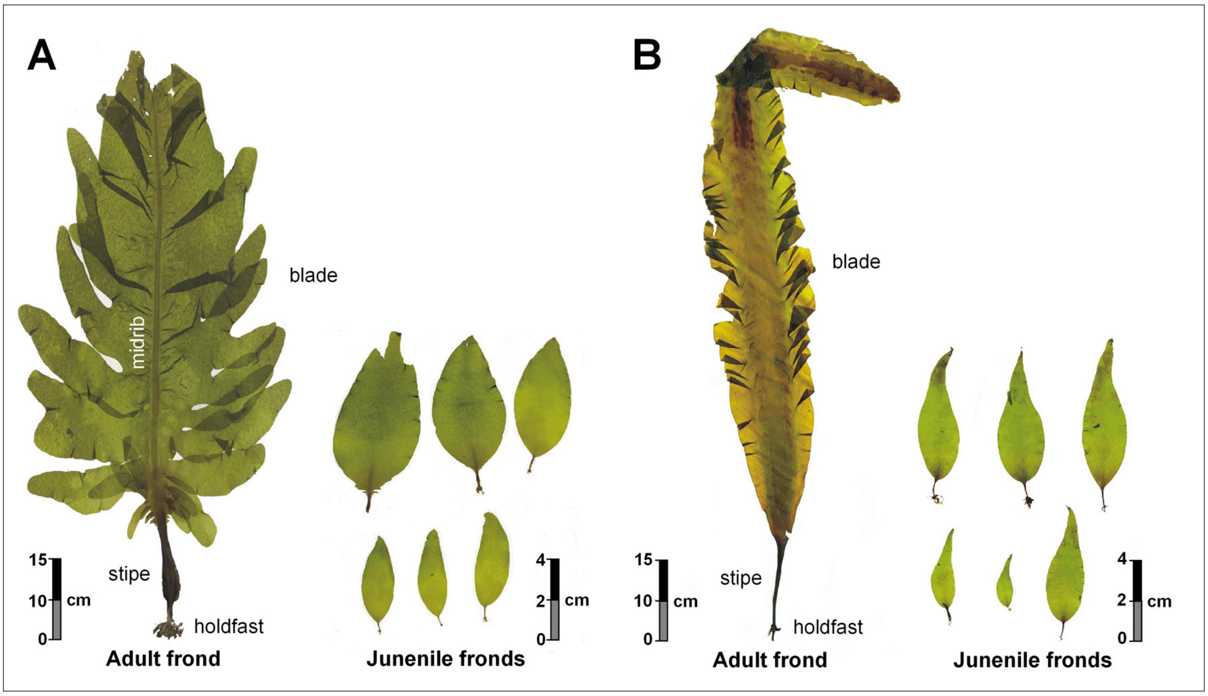

Figure 5. Frond morphology of: **(A)** adult and juvenile fronds of *U. pinnatifida* and (**B**) adult and juvenile fronds of *S. latissima* (Herbarium specimens scanned by C. Peteiro & F. J. Dosil).

Two main hypotheses explain the susceptibility of seaweeds to grazing by herbivorous fishes: (a) grazing has been mainly related to algal morphology (Hay 1984, 1997; Lewis 1985); (b) grazing depends on algae's chemical defenses against herbivorous (Paul et al 1990; Duffy & Paul 1992; Cronin et al 1997). Generally, the soft seaweeds (e.g. filamentous) are preferred by herbivorous fishes over hard seaweeds (e.g. calcareous) (Horn et al 1982; Ojeda & Muñoz 1999). Indeed, the seaweeds most often consumed are soft or fleshy fronds such as the algae *Ceramium*, *Polysiphonia*, *Ulva* and *Cladophora* (Tolentino-Pablico et al 2008). Adult fronds of both kelps species markedly differ from juvenile fronds in their morphological traits. Hence, the adult of *U. pinnatifida* has a thinner blade (soft) compared with adult of *S. latissima* (leathery) and, in contrast, the juvenile of both kelp species are thin and soft. Accordingly, the different fish grazing observed in the adults of both cultured kelps probably depend on structural toughness of blades. This postulate is similar to that observed with other marine herbivorous, in which the preference for seaweed foods appears to depend on the toughness of seaweed frond (Wakefield & Murray 1998; Steinberg 1985; Van Alstyne et al 1999a). On the other hand, defensive metabolites (phlorotannins or polyphenolic compounds) towards of herbivores have been found to occur in different concentrations in juveniles and adults of some brown seaweeds, including kelps species (Denton et al 1990; Van Alstyne et al 2001). Hence, after studies with several kelp species, it was corroborate that concentrations of phlorotannins were similar in both stages of algae or significantly lower in adults than juveniles (Van Alstyne et al 2001). However, the observations consistence within the analyzed kelps suggests that these metabolites do not affect the preferences of fishes herbivorous for juvenile fronds, and neither could explain the lack of fish grazing on adult fronds of *S. latissima* (Van Alstyne et al 1999b; Van Alstyne et al 2001). Nevertheless, these observations need further verifications, since the defensive metabolites against herbivores of both, juvenile and adult fronds, of *U. pinnatifida* and *S. latissima* have not been studied so far. Thus, overall, food preferences of fish grazers for juvenile fronds of both kelp species, as well as none consumption of *S. latissima* adults, are likely to be determined mainly by some of their morphological traits (toughness).

In temperate seas, herbivorous fishes are considered to have minor influence on algae benthic communities (Hay & Steinberg 1992). However, there are remarkable examples in which herbivorous fish can also have a considerable impact on macroalgae, even though herbivorous fish diversity may be low (Andrew & Jones 1990; Sala & Boudouresque 1997; Taylor & Schiel 2010). Sparid fishes as *S. salpa* and *B. boops* form large schools in shallow waters of the Atlantic coast (Bauchot & Hureau 1986; Froese & Pauly 2012) and hence, farm's kelps represents an easily available food resource for these fishes. Although, these large schools are potentially capable of consuming large quantities of seaweeds, fish's grazing has been reported of minor influence on mariculture of both kelp species. This could be explained by the high biomass of seaweeds available in North Western Atlantic coast of Spain (Galicia) (Cremades et al 2004), then, the abundance of macroalgal resource could prevent the effects of fish grazing on kelps' farming. Some studies have shown that the preferences of fish grazers for seaweeds were related to the temporal and special variation in food availability (Horn et al 1986; Andrew & Jones 1990). However, other factors may be also considered as other possible reasons for this low grazing on these cultivation trials. For example, wave exposure and algal canopy cover has been recently related with feeding activity of herbivorous fishes in temperate waters of Australia (Vanderklift et al 2009; Taylor & Schiel 2010).

Measures suggested to control herbivorous fishes in seaweeds mariculture are based on simple protective methods such as the use of nets (Lipkin 1985). However, this control effort is translated to increased production costs due to the maintenance practices required. An alternative way of reducing the potential herbivore damage is the culture of seaweeds with less susceptibility to fish grazing. For example, as adults of *S. latissima* were not affected by fish grazing, we suggest that this stage could be cultivated in coastal areas where herbivorous fish rate is high. In this respect, we recently tested its successful cultivation by transplantation of adult fronds (about 50 cm long) from indoor culture, to outdoor farming of *S. latissima* in northern Atlantic coast of Spain (unpublished data). Other approaches to reduce the damage by herbivorous fishes might also include the identification of areas for seaweed mariculture subjected to lesser fish herbivore activity. These control measures are of interest for further investigation about its use controlling grazing by fishes.

Conclusions. Grazing by herbivorous fishes of the cultured seaweeds *U. pinnatifida* and *S. latissima* were generally rare and with a minor influence, usually its adverse effects are limited to a small decrease in the yield in some culture ropes. Table 1 shows the most significant observations of fish grazing and their interpretation.

Table 1
Summary of the most significant observations and their interpretation on fish grazing of the cultured kelps *U. pinnatifida* and *S. latissima*

Observations	*Interpretation*
Cultured kelps were sometimes consumed by sparid fishes such as *S. salpa* and *B. boops*	Seaweeds constitute the food items of these marine herbivores fishes, which are common in coastal waters of the Northeastern Atlantic
Herbivorous fishes appear to consume, primarily in autumn and early winter, on cultured kelps	Feeding activity of some sparid fishes increases in autumn during pre- and post-spawning period
Fish grazing differs between stage of algae (juvenile versus adults), showing preferences for juvenile fronds. Unlike adults of *U. pinnatifida*, fish grazing do not affect to the adults of *S. latissima*	Food preferences of fish grazers are likely to be determined mainly by the morphological traits (toughness)
Herbivores fishes usually have minor influence on kelp farming	Lower effects of fish grazing on cultured kelps would be attributed to high food availability in the culture site. Other influence variables could be degree of wave exposure and cover of fronds on culture ropes.

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References

Andrew N. L., Jones G. P., 1990 Patch formation by herbivorous fish in a temperate Australian kelp forest. Oecologia 85:57–68.

Barry J. P., Ehret M. J., 1993 Diet, food preference, and algal availability for fishes and crabs on intertidal reef communities in southern California. Environmental Biology of Fishes 37:75–95.

Bauchot M. L., Hureau J. C., 1986 Sparidae. In: Fishes of the north-eastern Atlantic and the Mediterranean. Whitehead P. J. P., Bauchot M. L., Hureau J. C., Nielsen J., Tortonese E. (eds). UNESCO, Paris, France, pp. 883–907.

Buschmann A. H., Correa J. A., Westermeier R., Hernandez-Gonzalez M. D., Norambuena R., 2001 Red algal farming in Chile: a review. Aquaculture 194:203–220.

Chang Y. Q., Lawrence J. M., Cao X. B., Lawrence A. L., 2005 Food consumption, absorption, assimilation and growth of the sea urchin *Strongylocentrotus intermedius* fed a prepared feed and the alga *Laminaria japonica*. Journal of the World Aquaculture Society 36:68–75.

Cremades J., Bárbara I., Veiga A. J., 2004 Intertidal vegetation and its commercial potential on the shores of Galicia (NW Iberian Peninsula). Thalassas 20:69–80.

Cronin G., Paul V. J., Hay M. E., Fenical W., 1997 Are tropical herbivores more resistant than temperate herbivores to seaweed chemical defenses? Diterpenoid metabolites from *Dictyota acutiloba* as feeding deterrents for tropical versus temperate fishes and urchins. Journal of Chemical Ecology 23:289–302.

Denton A., Chapman A. R. O., Markham J., 1990 Size-specific concentrations of phlorotannins (anti-herbivore compounds) in three species of *Fucus*. Marine Ecology Progress Series 65:103–104.

Duffy J. E., Paul V. J., 1992 Prey nutritional quality and the effectiveness of chemical defenses against tropical reef fishes. Oecologia 90:333–339.

Duffy J. E., Hay M. E., 1994 Herbivore resistance to seaweed chemical defense: the roles of mobility and predation risk. Ecology 75:1304–1319.

Froese R., Pauly D. (eds), 2012 FishBase. World wide web electronic publication http://www.fishbase.org. Cited March 2012.

Ganesan M., Thiruppathi S., Sahu N., Rengarajan N., Veeragurunathan V., Jha B., 2006 In situ observations on preferential grazing of seaweeds by some herbivores. Current Science 91:1256–1260.

Havelange S., Lepoint G., Dauby P., Bouquegneau J. M., 1997 Feeding of the sparid fish *Sarpa salpa* in a seagrass ecosystem: Diet and carbon flux. Pubblicazioni della Stazione Zoologica di Napoli I: Marine Ecology 18:289–297.

Hay M. E., 1984 Predictable spatial escapes from herbivory: how do these affect the evolution of herbivore resistance in tropical marine communities? Oecologia 64:396–407.

Hay M. E., 1997 The ecology and evolution of seaweed-herbivore interactions on coral reefs. Coral Reefs 16:S67–S76.

Hay M. E., Steinberg P. D., 1992 The chemical ecology of plant-herbivore interactions in marine versus terrestrial communities. In: Herbivores: their interaction with secondary metabolites, evolutionary and ecological processes. Rosenthal J., Berenbaum M. (eds). Academic Press, San Diego, pp. 371–413.

Holdt S. L., Kraan S., 2011 Bioactive compounds in seaweed: functional food applications and legislation. Journal of Applied Phycology 23:543–597.

Horn M. H., Murray S. N., Edwards T. W., 1982 Dietary selectivity in the field and food preferences in the laboratory for two herbivorous fishes (*Cebidichthys violaceus* and *Xiphister mucosus*) from a temperate intertidal zone. Marine Biology 67:237–246.

Horn M. H., Neighbors M. A., Murray S. N., 1986 Herbivore responses to a seasonally fluctuating food supply: Growth potential of two temperate intertidal fishes based on the protein and energy assimilated from their macroalgal diets. Journal of Experimental Marine Biology and Ecology 103:217–234.

Kraan S., 2010 Mass-cultivation of carbohydrate rich macroalgae, a possible solution for sustainable biofuel production. Mitigation and Adaptation Strategies for Global Change. doi: 10.1007/s11027–11010–19275–11025.

Lewis S. M., 1985 Herbivory on coral reefs: algal susceptibility to herbivorous fishes. Oecologia 65:370–375.

Lipkin Y., 1985 Outdoor cultivation of sea vegetables. Plant and Soil 89:159–183.

Ojeda F. P., Muñoz A. A., 1999 Feeding selectivity of the herbivorous fish *Scartichthys viridis*: effects on macroalgal community structure in a temperate rocky intertidal coastal zone. Marine Ecology Progress Series 184:219–229.

Paul V. J., Nelson S. G., Sanger H. R., 1990 Feeding preferences of adult and juvenile rabbitfish *Siganus argenteus* in relation to chemical defenses of tropical seaweeds. Marine Ecology Progress Series 60:23–34.

Peteiro C., Freire Ó., 2009 Effect of outplanting time on the commercial cultivation of the kelp *Laminaria saccharina* at the southern limit in the Atlantic Coast (N.W. Spain). Chinese Journal of Oceanology and Limnology 27:54–60.

Peteiro C., Freire Ó., 2011 Effect of water motion on the cultivation of the commercial seaweed *Undaria pinnatifida* in a coastal bay of Galicia, Northwest Spain. Aquaculture 314:269–276.

Peteiro C., Freire Ó., 2012 Outplanting time and methodologies related to mariculture of the edible kelp *Undaria pinnatifida* in the Atlantic coast of Spain. Journal of Applied Phycology. doi: 10.1007/s10811–10012–19788–10812.

Peteiro C., Salinas J. M., Freire Ó., Fuertes C., 2006 Cultivation of the autoctonous seaweed *Laminaria saccharina* off the galician coast (NW Spain): production and features of the sporophytes for an annual and biennial harvest. Thalassas 22:45–52.

Ruitton S., Verlaque M., Aubin G., Boudouresque C. F., 2006 Grazing on *Caulerpa racemosa* var. *cylindracea* (Caulerpales, Chlorophyta) in the Mediterranean Sea by herbivorous fishes and sea urchins. Vie et Milieu 56:33–41.

Sala E., Boudouresque C. F., 1997 The role of fishes in the organization of a Mediterranean sublittoral community. 1. Algal communities. Journal of Experimental Marine Biology and Ecology 212:25–44.

Steinberg P. D., 1985 Feeding preferences of *Tegula funebralis* and chemical defenses of marine brown algae. Ecological Monographs 55:333–349.

Steneck R. S., Graham M. H., Bourque B. J., Corbett D., Erlandson J. M., Estes J. A., Tegner M. J., 2002 Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation 29:436–459.

Taylor D. I., Schiel D. R., 2010 Algal populations controlled by fish herbivory across a wave exposure gradient on southern temperate shores. Ecology 91:201–211.

Tolentino-Pablico G., Bailly N., Froese R., Elloran C., 2008 Seaweeds preferred by herbivorous fishes. Journal of Applied Phycology 20:933–938.

Van Alstyne K. L., Ehlig J. M., Whitman S. L., 1999a Feeding preferences for juvenile and adult algae depend on algal stage and herbivore species. Marine Ecology Progress Series 180:179–185.

Van Alstyne K. L., McCarthy J. J., Hustead C. L., Duggins D. O., 1999b Geographic variation in polyphenolic levels of Northeastern Pacific kelps and rockweeds. Marine Biology 133:371–379.

Van Alstyne K. L., Whitman S. L., Ehlig J. M., 2001 Differences in herbivore preferences, phlorotannin production, and nutritional quality between juvenile and adult tissues from marine brown algae. Marine Biology 139:201–210.

Vanderklift M. A., Lavery P. S., Waddington K. I., 2009 Intensity of herbivory on kelp by fish and sea urchins differs between inshore and offshore reefs. Marine Ecology Progress Series 376:203–211.

Verges A., Alcoverro T., Ballesteros E., 2009 Role of fish herbivory in structuring the vertical distribution of canopy algae *Cystoseira* spp. in the Mediterranean Sea. Marine Ecology Progress Series 375:1–11.

Wakefield R. L., Murray S. N., 1998 Factors influencing food choice by the seaweed-eating marine snail *Norrisia norrisi* (Trochidae). Marine Biology 130:631–642.

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