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Review

Wild and cultured edible tunicates: a review

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Abstract

Most tunicate species are not edible but some solitary stolidobranchs in the Styelidae and Pyuridae families are wild-harvested or cultured. The main species are *Halocynthia aurantium, H. roretzi, Microcosmus hartmeyeri, M. sabatieri, M. vulgaris, Polycarpa pomaria, Pyura chilensis, Styela clava,* and *S. plicata,* and they may be eaten raw, cooked, dried or pickled. Historically the Maoris ate *Pyura pachydermatina* in New Zealand. Aboriginal people ate *P. praeputialis* in Australia, and although it is now only used for fishing bait in that country, it is eaten in Chile where it has invaded Antofagasta Bay. There is a large market for cultured tunicates, especially among Asian populations. *Styela clava* and *S. plicata* have become extremely abundant in many countries as non-native introductions; they could easily be harvested and sold as seafood in these newly colonized regions, as could other common solitary stolidobranchs that have not previously been consumed. However, hurdles remain; diseases and overexploitation can significantly reduce cultured product and wild populations. Recently, the disease 'soft tunic syndrome' caused up to a 70% loss of *H. roretzi* crop in Korea, and harvesting wild *P. chilensis* reduced their numbers three fold in some parts of Chile. Most aquaculture operations are located in bays with urban runoff where pollutants including heavy metals and toxic substances could accumulate in tunicates. Natural disasters like tsunamis can also negatively impact aquaculture, as happened in Japan in 2011. Nevertheless, with proper culturing, monitoring, and preparation certain edible tunicate species that are currently an underutilized but highly nutritive food in many parts of the world could be easily cultivated, and the huge numbers of invaders could be harvested and marketed.

Key words: Aquaculture, ascidian, Styelidae, Pyuridae, *Halocynthia, Styela, Microcosmus*

Introduction

Tunicates (Ascidiacea) are primarily consumed in Asia, Chile and the Mediterranean, where product is sourced from both the wild and, in the case of the *Halocynthia* and *Styela* species in high demand, from cultured populations. All edible species are solitary stolidobranchs. The main species eaten are *Halocynthia aurantium* (Pallas, 1787), *H. roretzi* (von Drasche, 1884), *Microcosmus hartmeyeri* Oka, 1906, *M. sabatieri* Roule, 1885, *M. vulgaris* Heller, 1877, *Polycarpa pomaria* (Savigny, 1816), *Pyura chilensis* Molina, 1782, *Styela clava* Herdman, 1881, and *S. plicata* (Lesueur, 1823) (Table 1). Most of these species are sold fresh or dried in seafood markets (Figure 1). Processed *H. aurantium, H. roretzi, P. chilensis*, *S. clava* and *S. plicata* are important exports to Europe, N. America and elsewhere (Figure 2). Preparation techniques and recipes are available (Supplementary material Appendix 1).

Pyura chilensis is consumed under its local, common name of *piure* in Chile (Davis 1995) (Figure 3A), as is the recently introduced Australian *Pyura praeputialis* (Heller, 1878) (Castilla et al. 2014). It is also exported to numerous countries, including, as of 2007, Sweden (32.5% of exports) and Japan (24.2%) (Tapia Jopia and Baharona Toledo 2007) and is important enough to the

Table 1. Wild-harvested and cultured tunicates for human consumption

Wild-harvested species

Species	Common names	Where collected
Boltenia ovifera		Russia
Halocynthia aurantium	*bee-dahn-mung-geh* (Korea)	Korea, Russia
Microcosmus hartmeyeri Oka, 1906	*harutoboya* (Japan)	Japan
Microcosmus sabatieri Roule, 1885		Mediterranean
Microcosmus vulgaris Heller, 1877	sea violet	Mediterranean
Polycarpa pomaria (Savigny, 1816)		Mediterranean
Pyura chilensis Molina, 1782	piure	Chile
Pyura pachydermatina (Herdman, 1881)	sea tulip	New Zealand (historically)
Pyura praeputialis (Heller, 1878)	*cunjevoi*	Australia (historically), Chile
Pyura vittata (Stimpson, 1852)	*karasuboya* (Japan) *dohl-mung-geh* or *kkeun-mung-geh* (Korea)	Japan, Korea

Cultured species (all are also wild-collected)

Species	Common names	Where cultured
Halocynthia aurantium (Pallas, 1787)	sea peach, ice floe tunicate, *akaboya* (Japan)	Japan
Halocynthia roretzi (von Drasche, 1884)	sea pineapple, *mung-geh* or *kkoht-mung-geh* (Korea), *hoya* or *maboya* (Japan)	Japan, Korea
Styela clava Herdman, 1881	*mee-duh-duck* (Korea)	Korea
Styela plicata (Lesueur, 1823)	*o-mahn-doong-yee or o-mahn-dee* (Korea)	Korea

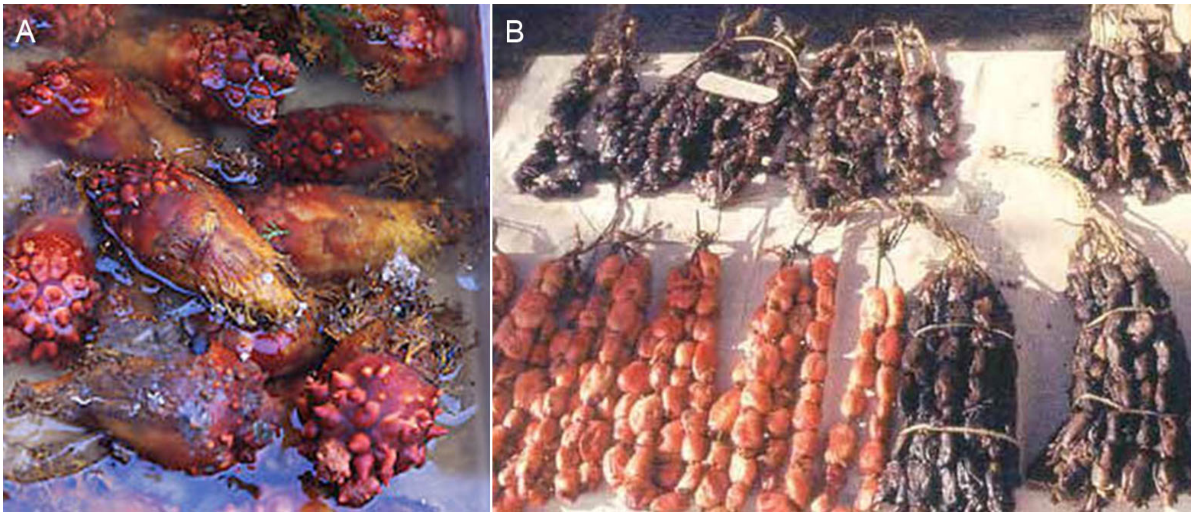

Figure 1. Edible tunicates for sale.
A) *Halocynthia roretzi* at the Tsukiji fish market in Tokyo. http://www.johnharveyphoto.com/Japan2/Tokyo%20Fish%20Market
B) *Pyura chilensis* dried bodies removed from tunic, at a market in Chile. Photo D. Schories.

economy that it was celebrated on a special postage stamp (Figure 3B). *Halocynthia aurantium*, the "sea peach" or "ice floe tunicate" (*akaboya* in Japan) is farmed in northern Japan (Meenakshi 2009; Tamilselvi et al. 2010) and also harvested wild in northern Russia, in the Provideniya region (I. Zagrebin, pers. comm.) (Figure 3C, D). *Halocynthia roretzi*, the "sea pineapple", is an important farmed species in Korea (Kim et al. 2014) (Figure 4A) and Japan (Tokioka 1953; Hirose et al. 2014) (known as *mung-geh* or *kkot-mung-geh* in Korea; *hoya* or *maboya* in Japan). *Styela clava* is considered a delicacy in southern Korea and has additionally acquired the cultural distinction of an aphrodisiac (Karney and Rhee 2009). It is known as *mee-duh-duck*; *mee* is an old Korean

Figure 2. Processed tunicates for local consumption and export. Photos G. Lambert.
A) Dried *Halocynthia aurantium* for sale in Sapporo, Japan.
B) Canned *Pyura chilensis* from Chile. C) Imported frozen Korean *Halocynthia roretzi* at a Korean market in Seattle, WA.
D) Frozen *Styela plicata* from Korea sold in the U.S.

word for sea, *duh-duck* (*Codonopsis* sp.) is a Korean root vegetable with a similar shape. *Styela plicata* is consumed fresh in both Korea (Kim and Moon 1998) and the Mediterranean (Meenakshi 2009) and exported frozen (Figure 2D). *Microcosmus hartmeyeri* (*harutoboya* in Japan) is eaten in Japan (Meenakshi 2009; Tamilselvi et al. 2010). *M. sabatieri* and *M. vulgaris*, endemic to and commercially exploited in the Mediterranean, are consumed in France, Italy and Greece (Voultsiadou et al. 2007; Tamilselvi et al. 2010; Meenakshi et al. 2012). *M. sulcatus* (not a valid name though still commonly used; has been synonymized under *M. vulgaris*) and *Polycarpa pomaria* are consumed in the Mediterranean area (Meenakshi 2009). Historically, the Maoris in New Zealand consumed *Pyura pachydermatina* (Herdman, 1881) and the Australian *P. praeputialis* (long referred to as *P. stolonifera* (Heller, 1878) and still commonly misidentified as that S. African species (Monteiro et al. 2002)) used to be a food source by aboriginal people living around Botany Bay, Australia. Currently, other than an occasional use of *P. praeputialis* in alcoholic beverages in New Zealand (P. Cahill, pers. comm.), *P. pachydermatina* and *P. praeputialis* are now used mainly for fishing bait in New Zealand and Australia, respectively (Davis 1995; Monteiro et al. 2002; Voultsiadou et al. 2007; Meenakshi 2009; Tamilselvi et al. 2010).

Nutrients in tunicates

Tunicates overall have a high nutritional value (Lee et al. 1995; Odate and Pawlik 2007; Meenakshi 2009; Ananthan et al. 2012; Choi et al. 2014; Roje-Busatto and Ujevic 2014). A number of large solitary ascidians have been analyzed for their nutritive value, showing that they are potentially healthy seafood high in protein and low in calories (Lee et al. 1995; Choi et al. 2006; Meenakshi 2009; Tamilselvi et al. 2010; Kang et al. 2011; Ananthan et al. 2012). *Halocynthia roretzi* contains a number of vitamins (E, B12, and C in particular), minerals (sodium, potassium, calcium, magnesium, phosphorus, iron, zinc, copper), and amino acids (folic acid, fatty acid, pantothenic acid, cholesterol) (2005; Standard Tables of Food Composition in Japan, Fifth Revised and Enlarged Edition; K. Ryo, pers. comm.). *Halocynthia aurantium*, cultured in northern Japan, is sold fresh in markets (Supplementary material Figure S1), freeze-dried (Figure 2A), and made into food supplement tablets (Inanami et al. 2001). In Korea, dried *H. roretzi*

Figure 3. Harvesting edible tunicates.
A: A dense clump of harvested *Pyura chilensis*, with the bodies removed from the tunic.
http://jo-jo.ru/pictures/55362-pyura-chilensis-zhivoy-kamen-s-morskogo-dna.html
B: *Pyura chilensis* celebrated on a postage stamp.
http://images.marinespecies.org/resized/46759_pyura-chilensis.jpg
C, D: Russians harvesting *Halocynthia aurantium* through the ice in the Provideniya region. Photos I. Zagrebin.

have been analyzed for their antioxidant properties (Jo et al. 2010; Kwon et al. 2011) and are sold as health supplements with a price of $270 US for a box of 60 60-gram packets (http://m.herbseoul.com; accessed 6 December 2015). Meenakshi (2009) reported the levels of carbohydrate, protein and lipid in a number of colonial and solitary species, declaring them all potential food sources, though there is no information available that humans consume any colonials. Of the solitaries analyzed by Meenakshi (2009), several *Styela* and *Microcosmus* species had the highest protein values.

Possible toxicity of edible tunicates

Ascidians sequester a variety of chemical defenses to help protect them from predation. These include secondary metabolites and inorganic acids, but may also include heavy metals, including manganese, magnesium, iron, molybdenum, niobium, tantalum, chromium, titanium, and vanadium (Stoeker 1978, 1980; Odate and Pawlik 2007). Levels of vanadium and other heavy metals are usually highest in the blood, with elevated concentrations also in the body tissues (Azumi et al. 2007a). Tunicates in the family Ascidiidae have the highest vanadium levels but are never eaten; edible species are all stolidobranchs, which have very low levels (Roman et al. 1988). The exceptional water filtration capacity of adult tunicates (Petersen and Riisgård 1992; Kim and Moon 1998; Draughon et al. 2010) can sometimes result in the accumulation of pollutants and toxic microorganisms or their byproducts to levels that may be toxic to the tunicate itself or make their tissues toxic to predators, including man (Sekiguchi et al. 2001; Lafferty et al. 2005; Lopez-Rivera et al. 2009; Echevarria et al. 2012; Rosa et al. 2013; Roje-Busatto and Ujevic 2014). Maintaining the tunicates in clean water after collection for 24–48 hours often greatly diminishes the concentration of ingested microorganisms. The Commission of the European Communities (Official Journal of the European Communities 2002) set regulations for the maximum levels of marine biotoxins for tunicates intended for immediate human consumption or for further processing before consumption, but many ascidians are collected in the wild by individuals and thus not tested before being eaten. Additionally, cultured tunicates are sometimes grown in bays with coastal pollution and should be periodically tested to insure food safety.

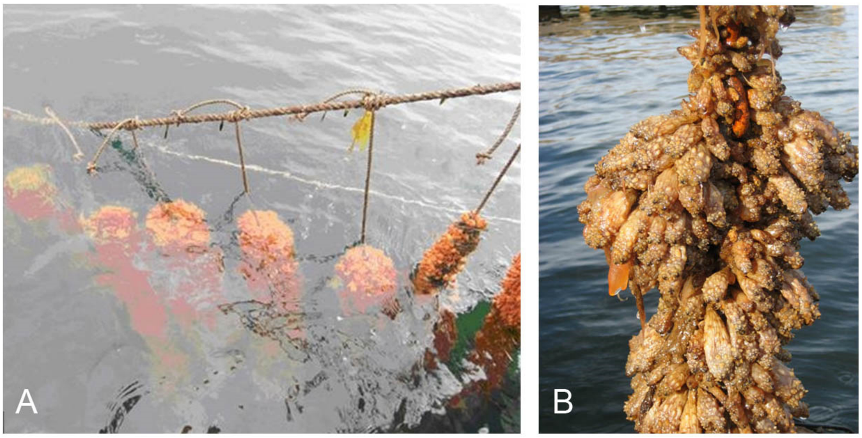

Figure 4. A) *Halocynthia roretzi* in cultivation in Korea. http://www.lib.noaa.gov/retiredsites/korea/main_species/sea_squirt.htm B) Non-native *Styela clava* on a rope, Prince Edward Island; photo G. Lambert.

Overexploitation of wild populations

Over harvesting of wild populations of popular edible tunicates has led to reduced numbers and significant ecosystem impacts. In several locations in the Aegean Sea, intense commercial exploitation of *Microcosmus sabatieri* reduced numbers to levels that could have cascading effects on the population and on the associated marine community ecosystem (Voultsiadou et al. 2007; Antoniadou and Vafidis 2008). In Chile, *Pyura chilensis* is harvested for seafood (Figure 3A), but the dramatic overcollection of adults (Davis 1995; Haye and Muñoz-Herrera 2013) has negatively impacted reproduction. Recruits are adult conspecific, resulting in adults clumping together. This makes them more easily harvested and leaves fewer reproducing adults to replenish the population, so harvested areas recover slowly. In 1994, *P. chilensis* populations were reduced up to 3 orders of magnitude in harvested rocky intertidal areas compared to a reserve where no harvesting was permitted (Davis 1995).

Aquaculture of tunicates

To meet product demand, *Styela* and *Halocynthia* species are farmed in Korea and Japan. The first farmed production of tunicates (*H. roretzi*) began in Korea in 1982 (Anonymous 2015). In 1991, a total of 16,966 tons of tunicates were harvested from culture (6,994 tons of *H. roretzi* and 9,972 tons of *S. clava*) in Korea (Kim 1991). Initially Korea exported *H. roretzi* to Japan. Japan subsequently began farming *H. roretzi* and began exporting *H. roretzi* to Korea in 2002 (Kitamura et al. 2010). Both countries export *S. clava, H. roretzi,* and *H. aurantium* to Europe and North America (Lambert 2005). Tunicate aquaculture operations in Jinhae Bay in Korea are large enough to be of concern for their environmental impacts (Lee et al. 2012).

Tunicates are cultivated on long line systems in both Korea and Japan (Figure 4A). Seed *Styela* are traditionally collected from the wild on nylon net collectors in shallow subtidal areas and then transplanted for grow-out on longlines where they grow to market size in about a year (Kang et al. 2011). Oyster shells, sometimes used for settlement of *H. roretzi* larvae in the sea, are entwined in vertically hanging pieces of rope secured about every 0.5 m to a horizontal, anchored, floated long line. *H. roretzi* are also spawned in hatcheries; the larvae attach to ropes which are then placed out in the sea, hanging from long horizontal lines. Recruits grow to harvestable size of about 22 cm in height in 2 years in Korea and in over 3 years in Japan (Azumi et al. 2007b). Water temperature range for *H. roretzi* is 2–26° C with optimum growth in water temperatures from 8–13° C. In Chile there is some effort to restock *Pyura chilensis* in rocky areas that were overcollected (Haye and Muñoz-Herrera 2013). There is no specific aquaculture yet for this species, but they are an important fouler on farmed scallop lines, where they are sometimes harvested (Lopez-Rivera et al. 2009).

Soft tunic syndrome in *Halocynthia roretzi* aquaculture

Diseases causing mortality in ascidians have rarely been reported (Monniot 1990). However, mass mortality of cultured *H. roretzi* has been occurring at an increasing rate. In Korea the disease soft tunic syndrome in cultured *H. roretzi* began causing economic losses in 1985; production decreased to 4,500 tons in 2004, and by 2007, 70% of cultured *H. roretzi* were lost. In 2008, the disease spread to Japanese *H. roretzi* aquaculture (Azumi et al. 2007a,b; Kitamura et al. 2010). Possible contributing causes for the mass mortality are changes in environmental factors such as water temperature, salinity or dietary plankton (Azumi et al. 2007b). The effects of prolonged intensive culture in a given area may be contributing to the problem. Symptoms of the disease include thinner and separated siphonal spines, thinning of the tunic cuticle, and lowered density of tunic fibers (Kitamura et al. 2010), which eventually result in rupturing of the tunic and death. The causative agent for soft tunic syndrome is the kinetoplastid protist parasite *Azumiobodo hoyamushi* Hirose et al. 2012 (Kumagai et al. 2013; Hirose et al. 2014; Park et al. 2014).

New sources of edible tunicates

There are about 481 species of solitary tunicates in the Styelidae and Pyuridae (Shenkar and Swalla 2011, Table S1). Undoubtedly other species than those already harvested are edible. Various native and non-native solitary styelids and pyurids occur worldwide and often abundantly in coastal areas. With proper monitoring and preparation, certain edible tunicate species that are currently an underutilized but highly nutritive food in many parts of the world could be easily harvested or cultivated. For example, in addition to the wild *Halocynthia aurantium* harvested through the ice in the Provideniya region of northern Russia using special rakes (Figure 3C, D), occasionally *Boltenia ovifera* (Linnaeus, 1767) are also collected for consumption (I. Zagrebin, pers. comm.). While *B. ovifera* are rare in this region, they are abundant elsewhere such as in New England and eastern Canada (Francis et al. 2014) and inhabit pilings and floating docks in parts of Maine (L. Harris, pers. comm.).

Abundant, widespread invasive species could be new products for seafood markets and resources for aquaculture development. Outside its native range, *S. clava* is considered a nuisance, biofouling invasive especially problematic for shellfish aquaculturists (Figure 4B). Brunetti and Cuomo (2014) report that *S. clava* "has fully invaded" Long Island Sound, and preliminary studies suggest it can tolerate 30^{o} C and may soon invade areas further south on the US East Coast. Karney and Rhee (2009) proposed harvesting *S. clava* and marketing them as a fresh, raw product to Asian communities in the US who consider it a delicacy and presently only have access to frozen processed imported product. The country of origin for *S. plicata* is unknown (Pineda et al. 2011) but it too is a cosmopolitan species that occurs in huge numbers in the Mediterranean, southeast and southwest US, India, Korea and elsewhere. Non-native *Microcosmus* species other than the native Mediterranean species that are currently consumed are most likely similar in taste and nutrients, such as *M. exasperatus* and *M. squamiger*.

Over exploitation of conventional fishery resources has created a need to identify and promote alternative and cost effective nutritious foods from non-conventional sources. Ascidians constitute an important marine renewable resource (Tamilselvi et al. 2010). The increasing need for protein-rich food has made it necessary to explore other protein sources in areas such as India, where tunicates are not traditionally consumed (Meenakshi 2009). *Herdmania pallida* is high in protein, lipid and carbohydrates and could be developed into a food product in India and other regions where it is a very abundant invader, at least in pickled form which dissolves the spicules (Tamilselvi et al. 2010). In an increasingly connected world, non-native tunicates have spread beyond their original ranges and successfully populated new areas to such a degree as to be considered nuisance invasives. With suitable safeguards, their value as an underutilized source of seafood should be recognized.

Other uses for abundant tunicates include fish food and biofuel. A team of researchers at the University of Bergen in Norway has proposed the aquaculture of tunicates for the production of food for farmed fish because of the nutritional content of the ascidians. Waste cellulose remaining after the extraction of the nutritional components could be used for biofuel production (Beciri 2013). The productive use of invasive tunicates will aid in reducing the impact of these species. Further research should be conducted to develop other possible uses for abundant invasive tunicates.

See Appendix 1 for a description of various methods of preparation and a few recipes and photos.

Preparation

Tunicates are sold fresh in local markets in many countries (Figure 1); the internal organs are sometimes removed, sometimes left in. Bodies removed from the tunic and sometimes the whole animals are frozen, canned or dried and exported for sale worldwide (Figure 2). The tunic is thick and tough on all the commonly consumed species and is usually removed before preparation, though Nanri et al. (1992) reported that the tunic of *Microcosmus hartmeyeri* is consumed in some locations in Japan.

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The following supplementary material is available for this article:

Appendix 1. Preparation of tunicates and recipes.

Figure S1. Prepared edible tunicates.

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