

RUNNING HEAD: JELLYFISH – A SUSTAINABLE FUTURE FOOD?

**Making Sustainable Foods (such as Jellyfish) Delicious**

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SUBMITTED TO: *International Journal of Gastronomy & Food Science*

DATE: NOVEMBER, 2018

WORD COUNT: 4,100 WORDS

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ABSTRACT

Given global concerns over the depleting resources of our seas and oceans, and the increasing lack of sustainable seafood options, jellyfish are emerging as a potential future food. Jellyfish currently represent a sustainable food resource, one whose availability will likely increase with global warming. While jellyfish are a popular delicacy in many parts of Asia, it is currently an unfamiliar food to the majority of Western diners. In this paper, we show how multisensory experience design can be used to introduce diners to this highly-textured, if essentially flavourless, source of food. Created by chef Jozef Youssef, and served at Kitchen Theory's Gastrophysics Chefs Table, the jellyfish dish is placed on a table that is projection mapped with an underwater scene, accompanied by a bespoke, crossmodally-congruent soundscape delivered to diners wearing headphones. The response from diners to this unusual food has so far been uniformly positive.

KEYWORDS: JELLYFISH; SUSTAINABILITY; MULTISENSORY EXPERIENCE  
DESIGN; GASTROPHYSICS; PROJECTION MAPPING; SOUNDSCAPE

## **Introduction**

Given current unsustainable patterns of food consumption in the developed world (Reisch, Eberle, & Lorek, 2013), together with the negative health consequences of consuming too much red meat (Kmietowicz, 2017), many people have been looking into the possibility of developing alternative sources of food. In this context, two oft-mentioned alternatives include entomophagy (see Deroy, Reade, & Spence, 2015; Raheem, Carrascosa, Oluwole, Nieuwland, Saraiva, Millán, & Raposo, 2018; and Evans, Flore, Bom Frøst, & Nordic Food Lab, 2017, for reviews) and lab-grown meat (e.g., see Schaefer, 2018).

However, another source of food that has started to attract the attention of a growing number of gastrophysicists recently in the west is jellyfish (see Spence, 2017). Not only are the populations of jellyfish in our seas and oceans currently plentiful (see Doyle, Houghton, Buckley, Hays, & Davenport, 2007), they are predicted to grow as global temperatures continue to rise (Delap, 2018; Mills, 2001; <https://futurism.com/videos/thanks-to-global-warming-you-can-swim-with-millions-of-jellyfish/>). In fact, over the last couple of years, jellyfish numbers have exploded in the Mediterranean. This, the result of various factors including oxygen depletion, increase of plankton by eutrophication, depleted populations of large predators such as red tuna, swordfish and sea turtles that feed on jellyfish, temperature changes, and water contamination (Mills, 2001). Pollution, too, may be fuelling the jellyfish explosion. It turns out that jellyfish succeed in all sorts of fouled conditions, including “dead zones,” where rivers have pumped fertilizer runoff and other materials into the ocean (Tucker, 2010). The growing awareness of jellyfish numbers has left some creative/innovative individuals wondering how to take advantage this plentiful foodstuff (see Horowitz, 2017). Despite their abundance in the wild, however, it is important to point out that, jellyfish can only be harvested once they have reached the medusa stage, which occurs only in the summer and hence jellyfish fishing is a seasonal activity.

Jellyfish may, in fact, be one of the few foods that we could remove from the sea that would have a net positive effect. They are an invasive species, known for invading beaches, raiding fish farms (Tucker, 2010), and have a long history of disrupting power stations out at sea. On occasion, they have even caused the power stations to shut down (Laskow, 2013). In order to deal with this issue, a number of countries have started to develop jellyfish-proofing strategies, such as the one that one finds in Busan in South Korea, where 280,000 native jelly-eating filefish were released along the coast. In Japan, meanwhile, the fishermen use barbed poles to beat the giant Nomuras. In Europe, Mediterranean beaches have jellyfish spotter boats and planes as well as a jellyfish hotline. In Cabo de Gata-Níjar, a ‘natural park’ in the south-eastern corner of Spain (also Andalusia's largest coastal protected area), indigenous loggerhead sea turtles (jellyfish predators) have been released in order to help take care of the problem.

Researchers found that jellyfish, among other marine species, excrete organic compounds as bodily waste. The excretions of other species are consumed by bacteria that form important parts of oceanic food webs. By contrast jellyfish excretions nourish gammaproteobacteria, a class of microbes that little else in the ocean likes to eat, and that produces little of further biological use (see Condon, Steinberg, del Giorgio, Bouvier, Bronk, Graham, & Ducklow, 2011; Keim, 2011).

### **Edible Jellyfish**

Edible jellyfish fisheries are currently a multimillion dollar business in Asia (Omori & Nakano, 2001), due to the ingredient's popularity in China, Japan, Korea, and Thailand (e.g., Horowitz, 2017; Kapoor, 2018). Pedersen, Christensen, Duelund, Hansen, Brewer, and Clausen (2018) note that jellyfish is “*a food material mostly uncommon to the Western palate, but a delicacy in traditional Asian cuisine having a gastronomic history of more than a thousand years. It is*

88 *eaten mainly for its interesting crunchy mouthfeel resulting from a month-long salt*  
 89 *preservation using sodium chloride and alum. This preservation drastically changes the texture*  
 90 *of the jellyfish from being gel-like to resembling that of pickled cucumbers.”* (see also Hsieh  
 91 Leong, & Rudloe, 2001). This fits with the Eastern fascination with texture, as highlighted by  
 92 the work/writing of Fuchsia Dunlop (Muston, 2012). As the food writer puts it: “*In China,*  
 93 *texture is part of the pleasure of food and people praise the feel as much as flavour”*. Indeed,  
 94 “*According to one study, Americans use just 78 words to describe the texture of food. By*  
 95 *contrast, there are more than 400 such terms in Japanese.*” Cool, translucent strips of jellyfish  
 96 have been memorably described by one author as feeling “*like a cross between a cucumber*  
 97 *and a condom, rubbery but with a tendency to break apart with each bite.*” (all quotes from  
 98 Delap, 2018).

99 About a dozen jellyfish varieties with firm bells are considered edible, mostly from the  
 100 scyphozoa order Rhizostomeae (see Brotz, 2016; see **Table 1**). Stripped of their tentacles and  
 101 mucous membranes, jellyfish are typically soaked in brine for several days and then dried.  
 102 Lately, in an apparent effort to bring this ingredient to a broader audience, the Japanese  
 103 government has encouraged the development of haute jellyfish cuisine—jellyfish caramels, ice  
 104 cream, and cocktails. Scientists in Italy have discovered the chemical composition of jellyfish  
 105 in the Mediterranean are similar to those eaten in the Far East and are now on a mission to  
 106 demonstrate that the ideal location for jellyfish is on our dinner tables (Duggins, 2017).  
 107 Meanwhile, Danish chef Klavs Styrbæk has also been experimenting with jellyfish in a number  
 108 of innovative dishes (see Mouritsen & Styrbæk, 2017; Overgaard, 2017). However, on a global  
 109 scale, it is not clear exactly how many of the identified species of jellyfish are edible (e.g.,  
 110 Armani et al., 2013; Hsieh & Rudloe, 1994; Omori, 1981; Omori & Nakano, 2001; Sloan,  
 111 1986). The good news, though, is that researchers have found that those patients with seafood

allergies do not appear to exhibit an allergic reaction to jellyfish (Raposo, Coimbra, Amaral, Gonçalves, & Morais, 2018).

INSERT TABLE 1 ABOUT HERE

### **Jellyfish Nutrition & Flavour**

Regardless of their description, jellyfish have many advantages as a source of food, being low in fat, and currently highly sustainable. That said, jellyfish is more jelly than fish. In fact, they are 95% water (Lowndes, 1942). According to Zimmer (2017), this means that a cup of live jellyfish provide no more than 5 calories (or 1/3 of the number of calories in a cup of celery). Put another way: *“Bite for bite, fish provide around thirty times more calories than jellyfish.”* (Zimmer, 2017). Many animals eat jellyfish (Hays, Doyle, & Houghton, 2018), though often they will bite off the nutritious parts such as the reproductive tissues that contain calories and protein, while leaving the bell of the jellyfish which is mostly just water (Zimmer, 2017). The collagen can give rise to a gelatinous texture (see Gambini, Abou, Ponton, & Cornelissen, 2012, on the rheology of jellyfish), creating the impression when eaten that a jellyfish is more texture than anything else.

According to Khong, Yusoff, Jamilah, Basri, Maznah, Chan, and Nishikawa (2016), all jellyfish tend to have low calorific values (1.0-4.9 kcal/g D.W.) combined with negligible fat contents (0.4-1.8 g/100 g D.W.), while protein (20.0-53.9 g/100 g D.W.) and minerals (15.9-57.2g/100g D.W.) are the richest components. Total collagen content of edible jellyfish varies from 123 to 694 mg/g D.W., accounting for approximately half its total protein content. The dominant amino acids in both bell and oral arms of all jellyfish studied includes glycine, glutamate, threonine, proline, aspartate and arginine, while the major elements were sodium, potassium, chlorine, magnesium, sulphur, zinc and silicon.

Given that western palate's lack of education towards the mindful appreciation of texture in food, coupled with preconceptions regarding what jellyfish will feel like in the mouth and the general negative association with their sometimes dangerous sting, texture will most probably be one of the biggest obstacles to getting this highly sustainable ingredient to gain widespread acceptance. According to Del Bello (2018), jellyfish are primarily protein and "*are rich in nutrients, including vitamin B12, magnesium, and iron, and low in calories.*" (see **Table 2**). In terms of flavour, jellyfish provides just the faintest hint of the taste of the sea (Scharping, 2018).

INSERT TABLE 2 ABOUT HERE

#### *Jellyfish crisps and other gastrophysics delicacies*

One of the ways in which gastrophysicists have recently been attempting to make jellyfish appealing to consumers is by turning them into crisps (this, a creative way to overcome the typical western diner's textural preconceptions). According to Pedersen and her colleagues, the best method for doing this involves soaking the jellyfish in 96% ethanol (i.e., alcohol) for a few days and then drying (Pedersen, Brewer, Duelund, & Hansen, 2017; Pedersen et al., 2018; Scharping, 2018; Spyrou, 2017). The media interest in edible jellyfish crisps has been phenomenal (see Del Bello, 2018; Overgaard, 2017; Scharping, 2018), perhaps hinting at the public interest in potentially desirable new sources of food. That said, Harold McGee (1984/2004, p. 231) only gives jellyfish the very briefest of mentions (a few words, and no more) in his compendious volume *On Food and Cooking*.

#### **Ryujins's Servant**

##### *Preparation*

As edible forms of jellyfish are not currently widely available in the UK (and European) market,<sup>1</sup> the ingredient currently has to be sourced in frozen form via a Japanese restaurant supply group based in London (see <http://www.skyeul.co.uk/>). The jellyfish had undergone the traditional processing required to render it ready for use in cooking, this involves a multi-phase procedure using a mixture of salt (NaCl) and alum (AlK[SO<sub>4</sub>]<sub>2</sub>·12 H<sub>2</sub>O) to reduce the water content, decrease the pH, and firm the texture (Hsieh et al., 2001). It is important to note that guidelines by The Joint Food and Agriculture / World Health Organisation Expert Committee on Food Additives (Revised November, 2016; [https://www.cfs.gov.hk/english/programme/programme\\_rafs/files/Guidelines\\_on\\_the\\_use\\_of\\_Al\\_additives\\_e.pdf](https://www.cfs.gov.hk/english/programme/programme_rafs/files/Guidelines_on_the_use_of_Al_additives_e.pdf)) have resulted in commercial food manufacturers reducing the alum content in foods such as jellyfish due to adverse health effects. In recent years researchers have been working on alternative solutions to eliminate the use of alum by using various tanning salts (see Pedersen, Brewer, Duelund, & Hansen, 2017). The processed jellyfish is then cut into ‘ribbons’ or flat noodle strands approximately 1cm wide, and marinated. Marinating the jellyfish is an effective way of infusing a wide variety of desirable flavours in to this otherwise rather bland-tasting ingredient.

As jellyfish is considered a Japanese delicacy (it is also a delicacy in Korea and China), and given the growing global popularity of Japanese cuisine and its associated flavours and textures (many of which are not familiar to traditional western palates), we wanted to design this dish to exploit these characteristics, and so the dish was given a Japanese theme. The title of the dish is “Ryujins’s Servant”. Ryujin was the ancient Japanese God of the sea, whose servants were depicted as turtles, jellyfish and other such sea creatures (see Smith & Brown, 2007). In keeping with the Japanese theme, the jellyfish is marinated in a traditional so-called Chuka

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<sup>1</sup> Though prepared jellyfish is available, both shredded and whole, in certain Chinese grocery stores (e.g., in London’s Soho).



Kurage seasoning. This is paired with the flavours of fermented cucumber ‘nuka-zuke’, a traditional Japanese form of pickling in which ingredients are buried in a seasoned rice bran overnight (note that it is generally prepared not overnight, but rather for varying times, up to many months), imparting strong umami, yeasty, and salty characteristics. Other flavour pairings include shredded ‘Gari’ Japanese pickled ginger and hijiki seaweed.

#### *Chuka Kurage seasoning recipe*

500g Jellyfish, 50g sugar, 25g soy sauce, 20g mirin, 50g rice vinegar, 50g sesame oil, 10g chili oil, 50g chili sauce (gochuyan), and 7g sesame seeds. With the exception of the jellyfish, place all of the ingredients in a bowl and mix together and keep aside. In a separate bowl, place the jellyfish and add the marinade one spoon at a time, massaging it in by hand. Once all the mix has been incorporated, leave the jellyfish to marinate for an hour, at which point it is ready to serve.

#### *Nukezuke cucumber gazpacho*

1000g rice bran, 100g sea salt (or kosher salt), 125g beer, 50g water, 1 small whole dried chilli, 20g Konbu (Saccharing Japonica), 1 clove garlic, 4 large cucumbers (sliced lengthwise into quarters), and 200g fresh cucumber juice. Toast the rice bran over a low heat (use a dry pan). Once toasted and cooled, add the sea salt, beer, and mix by hand or using a wooden spoon. Add the water a little at a time until the bran has the texture of ‘wet sand’. Add the chilli (large slices), kelp (cut in to strips) and garlic (large slices). This mixture is called a ‘Nukadoko’, to prepare it for pickling it must first be left for a week with a few ‘test’ piece of cucumber (or other similar vegetables). Each day the nukadoko must be agitated by hand in order to grow both lactic bacteria and wild yeast in good balance. After a week, the cucumber is removed and

the nukadoko base is now ready to ferment. Take three large cucumbers (quartered lengthwise) and rub with coarse salt (to increase their surface area) then quickly rinse and bury in the nukadoko. Leave overnight, then remove the cucumber and rinse any excess bran mix off with cold water. Juice the pickled cucumbers. This juice may be excessively sour (as a result of pickling) and salty, there may be a need to balance out the taste/flavour with fresh cucumber juice. It is served as a cold cucumber gazpacho.

### *Presentation*

Visual and auditory cues are key elements in the multisensory presentation of Ryujins's Servant. The jellyfish is served on a projection-mapped table showing an underwater scene as diners listen to a crossmodally congruent soundscape that blends crunching sounds with underwater ambience (see **Figure 1**).<sup>2</sup> The use of crunching sounds builds on earlier research showing that crunchiness and freshness of potato chips could be enhanced simply by boosting the sound of the crunch (Zampini & Spence, 2004). Note also that crunchiness/crispiness are amongst the most desirable of food attributes (see Spence, 2015, for a review). Perhaps also relevant here, the latest research shows that we tend to adapt more slowly to the flavour of noisy foods than to silent foods (see Elder & Mohr, 2016; Luckett, Meullenet, & Seo, 2016).

When considering the use of sound as part of a multisensory dining experience, the experience designer has a choice as to whether to present the soundscape via external loudspeakers or via headphones. While autonomous sensory meridian response (ASMR)-like responses tend to be much more effective when presented over headphones (see Spence, in press, for a review), no such extraordinary responses were expected with the sounds presented with this dish, since the

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<sup>2</sup> We know from recent research that the ambient soundscape playing in a restaurant setting (at least if carefully designed) can exert a significant influence over what diners think about the dish that they are eating (see Wang, Keller, & Spence, 2017; see also Spence, Shankar, & Blumenthal, 2011).

soundscape presumably did not have sufficient specific sensory qualities that have been shown to elicit such auditory responses – e.g., such as whispering and close-up sounds, and repetitive purposeful action sounds like wrinkling or rattling paper (see Barratt, Spence, & Davis, 2017). That said, it did include crunching sounds and the sound texture of walking on snow that one might have thought would have been effective ASMR inducers. That said, as diners consume the jellyfish, their mastication sometimes coincides with the crunch presented in the soundscape. The periodic crunching sounds are presumably more likely to be interpreted as coming from the diner’s own mouth when presented over headphones (and so localized as coming from inside the diner’s head), rather than from external loudspeakers (and hence localized externally). Additionally, persuading the diners to wear headphones, at least for one course, seems to make them more mindful of the food that they are eating (see Spence, 2017, for a review). Conversation at the table tends to cease, as the diner’s brain tries to make sense of the binding vs. segregation of their own crunching actions with the crunching sounds that can be heard approximately every six seconds as the soundscape plays through the headphones (Chen & Spence, 2017). The research shows that the multisensory integration of auditory and tactile cues tends to be maximal when the sensory inputs are synchronous, and drops off as the interval between auditory and tactile stimuli increases (see Guest, Catmur, Lloyd, & Spence, 2002).

#### INSERT FIGURE 1 ABOUT HERE

The use of sounds associated with the sea reference another famous seafood dish where a soundscape is a primary part of the dining experience: The “Sound of the Sea” dish served at Heston Blumenthal’s The Fat Duck restaurant in Bray (see Blumenthal, 2007, 2008; Spence, Shankar, & Blumenthal, 2011). However, this superficial similarity underlies an important difference. The soundscape associated with Sound of the Sea was, in a certain sense, designed to trigger nostalgic memories of being by the seaside as a child (see Leonor, Lake, & Guerra,

2018). By contrast, the underwater soundscape served with Ryujins's Servant (<https://soundcloud.com/ivaudiobranding/jellyfish>) is, by contrast, much less familiar (much like the jellyfish itself which, as has already been noted, is likely unfamiliar to most diners). The soundscape is intended to enhance the textural properties of the dish using an almost overlooked sense in the common perception of flavour: audio stimulation.

## **Conclusions**

Our hope, in presenting Ryujins's Servant at Kitchen Theory's Gastrophysics Chef's Table (<https://gastrophysics.co.uk/>), is that if we can create an enjoyable initial experience for the diner (at least for the majority of those diners in the West who are likely unfamiliar with it), then they will be more likely to subsequently try eating jellyfish again (see Spence, 2017). As such, this gastronomic intervention will hopefully help, in some small way, to 'nudge' diners toward this highly sustainable source of food (Mathis & Tor, 2016), one that a number of researchers have been suggesting ought to be promoted in the west (Hsieh et al., 2001; Hsieh & Rudloe, 1994).

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398



Table 1. Identified species of edible jellyfish in the world. Modified from Omori and Nakano (2001; <http://nordicfoodlab.org/blog/2015/8/11/jellyfish>).

Cepheidae	<i>Cephea cephea</i>
Catostylidae	<i>Catostylus mosaicus</i>
	<i>Crambione mastigophora</i>
	<i>Crambionella orsisi</i>
Lobonematidae	<i>Lobonema smithii</i>
	<i>Lobonemoides gracilis</i>
Rhizostomatidae	<i>Rhizostoma pulmo</i>
	<i>Rhopilema esculentum</i>
	<i>Rhopilema hispidum</i>
	<i>Neopilema nomurai</i>
Stomolophidae	<i>Stomolophus meleagris</i>

405

406 Table 2. Nutritional information concerning jellyfish (from  
 407 <http://www.thecaloriecounter.com/Foods/1500/43497/Food.aspx>). See also Raposo, Coimbra,  
 408 Amaral, Gonçalves, and Morais, (2018, Table 2),

Nutrition Facts			
Serving Size 1 cup (58g)			
Amount Per Serving			
Calories 21		Calories from Fat 7	
% Daily Value*			
Total Fat	0.8g		1%
Saturated Fat	0.2g		1%
Polyunsaturated Fat	0.3g		
Monounsaturated Fat	0.1g		
Cholesterol	2.9mg		1%
Sodium	5620.2mg		234%
Potassium	1.7mg		0%
Total Carbohydrate	0g		0%
Dietary Fiber	0g		0%
Sugars	0g		0%
Protein	3.2g		6%
Vitamin A 0%		Vitamin C 0%	
Calcium 0%		Iron 7%	
* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:			
	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

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## FIGURE LEGENDS

413

414 Figure 1. Jellyfish shown wrapped around the tweezers as presented to the diners at Kitchen  
415 Theory's Gastrophysics Chef's Table multisensory dining experience. The cucumber gazpacho  
416 is poured over the dish at the table (Panels A and B).

417

418 Figure 2. The projection mapped undersea scene that diners see at the Gastrophysics Chef's  
419 Table when eating chef Jozef Youssef's jellyfish dish. Notice also the over-ear headphones that  
420 the diners are encouraged to put on before starting the dish (Panels A and B).