



Cephalopod Gastronomy—A Promise for the Future

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Cephalopods, specifically Coleoidea (squid, octopus, and cuttlefish), have for millennia been used as marine food by humans across the world and across different food cultures. It is particularly the mantle, the arms, the ink, and part of the intestines such as the liver that have been used. In addition to being consumed in the fresh and raw states, the various world cuisines have prepared cephalopods by a wide range of culinary techniques, such as boiling and steaming, frying, grilling, marinating, smoking, drying, and fermenting. Cephalopods are generally good nutritional sources of proteins, minerals, omega-3 fatty acids, as well as micronutrients, and their fat content is low. Whereas being part of the common fare in, e.g., Southeast Asia and Southern Europe, cephalopods are seldom used in regional cuisines in, e.g., North America and Northern Europe although the local waters there often have abundant sources of specific species that are edible. There is, however, an increasing interest among chefs and gastroscintists to source local waters in a more diverse and sustainably fashion, including novel uses of cephalopods to counterbalance the dwindling fisheries of bonefish, and to identify new protein sources to replace meat from land-animal production. The focus of the chefs and gastroscintists is on texture and flavor properties of the different cephalopods being subject to a variety of culinary transformations. Combining these trends in gastronomic development with the observation that the global populations of cephalopods are on the rise holds an interesting promise for the future.

Keywords: cephalopods, food, gastronomy, gastrophysics, sustainability

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INTRODUCTION

There is archeological evidence that humans have caught cephalopods for food in the Mediterranean region for at least the last 4,000 years. The Egyptians and later the Greek and the Romans lowered ceramic amphorae tied to a string to the bottom of the sea and waited for an octopus to use it as a den. Other techniques use traps with a bait. At Hawaii octopus were caught on hooks, and squid and cuttlefish have around the world for centuries been captured by nets, e.g., using light to attract squids at night. Cephalopods have been part of the daily fare in coastal areas around the world, in particular in Southeast Asia and in Southern Europe for millennia. In ancient Greece, both octopus, cuttlefish, and squid also entered in large formal banquets.

It is probably in the Far East, in particular in China and Japan, where there are the richest traditions for consuming cephalopods. The Japanese are likely to be the people who value cephalopod food the most, not least octopus. Today Japan is the country that consumes more octopus per capita than anywhere else in the world.

For obvious reasons, there is not much information available regarding how the ancient food cultures prepared the various kinds of cephalopods for food. The famous Roman gourmet and hedonist Marcus Gavius Apicius (25 BCE–37 CE) is credited for a cookbook *De re coquinaria* that is the oldest known and existing cookbook from the Antique. In Apicius' book there is a recipe for octopus with pepper, lovage, ginger, and the Roman fish sauce *garum* (Grocock and Grainger, 2006). There are only few surviving manuscripts with recipes from the Middle Ages. In a handwritten manuscript from the Fourteenth century (Schweid, 2014) an anonymous writer from the kingdom Aragon presents a Catalan recipe for octopus filled with its own arms together with spices, parsley, garlic, raisins, and onions, and prepared over open fire or in an oven.

Upon the invention of printing, more cookbooks were seeing the light of day and often recipes with cephalopods appear, mostly with octopus; e.g., from the Sixteenth century a Catalan recipe for baked octopus and an Italian one using boiled, roasted, and marinated octopus (Schweid, 2014). A well-known example is the famous *pulpo à la Gallega*, a national dish of Galicia, where there is an abundance of octopus in the waters. Dried octopus has also there for centuries been used as a commodity for trading with people inland.

Today the annual catch of cephalopods around the world amounts to about 4.8 million tons (FAO, 2014) and protein from cephalopods covers about 2% of humans' global consumption of protein. In this light, it is striking that compared to the dramatic flow of cookbooks, more than 25,000 every year, there are extremely few cookbooks devoted to cephalopods (Cronin, 1981; Schultz and Regardz, 1987; Mouritsen and Styrbæk, 2018). Similarly, although cephalopods are a traditional component of the cuisine in many parts of the world, few top chefs or gastronomic entrepreneurs have until recently taking an interest in elevating cephalopods to the Michelin-stars. Examples of cephalopod dishes are illustrated in **Figures 1–5**.

There are signs that this is about to change on two counts. On the one side, chefs in food cultures where there is no tradition for either fishing or consuming cephalopods are starting to explore and define a local cephalopod cuisine; on the other side chefs in countries where there is a long tradition for eating cephalopods are gaining an interest in re-inventing the use of these, e.g., by considering new types of preparations or using body parts that were rendered worthless in the traditional cuisine.

These changes hold a promise for an emerging, new cephalopod gastronomy. As this gastronomy evolves we may not only see more interesting and delicious food for the curious gastronomist and the foodies, but possibly also novel industrial products that will be appreciated by a larger part of the population around the world. To grasp the full implications of this possible development we shall in this paper put the gastronomic potentials of cephalopods in the perspective of marine food supplies to a growing world population, sustainability, and global climate changes. An important piece of information in this context is that whereas world fisheries of bonefish are under great pressure and many fish populations are dwindling (FAO, 2014), it appears that the global populations of



FIGURE 1 | Octopus salad, a classical South European dish made of boiled octopus arms (*Octopus vulgaris*), carrots, celeriac, garlic, and Italian parsley with olive oil, lemon juice, and oregano. Photo: permission by and courtesy of Kristoff Styrbæk.

all squid, cuttlefish, and octopus species important for human consumption are on the rise and have been so consistently for the last sixty years (Doubleday et al., 2016).

WORLD CATCH AND CONSUMPTION OF CEPHALOPODS

Cephalopods are caught for human consumption around the world both on large industrial scale and by small, artisanal fishing communities. Since there are very few and mostly small experimental activities with aquaculture of cephalopods (Vaz-Pries et al., 2004; Iglesias et al., 2007), the catch is dominated by wild sources. Cephalopods are together with tuna, shrimp, and lobster considered to be the most valuable marine fisheries. FAO (2014) has estimated the total global catch to be 4.8 million tons annually but the figure may be unreliable since not all countries report their catch and it is mostly the large industrial fisheries that contribute to the report. Although some of the catch is used for bait in other fisheries, by far the largest part is used for human consumption.

Catch of species from the Teuthida order constitutes the most important products accounting for 3.6 million tons, followed by octopus and *Sepia*-like species. The commercially most important species are from the family of the flying squids (Ommastrephidae), in particular *Illex argentinus*, *Dosidicus gigas* and *Todarodes pacificus*. *Todarodes pacificus* alone accounts for half of the world's catch of cephalopods, and it has been estimated that this species is possibly the only one of the wild species that has enough potential to contribute significantly to the world supplies of protein. This would however require the development of more effective and sustainable fishing methods with less bycatch and waste. Japan is one of the major consumers of *Todarodes pacificus*, and most of it is used for sashimi.

Every year, 350,000 tons wild octopus are caught with a trade value of around 1.5 billion dollars. Most of it is caught in Asia, in particular in Chinese waters. There is also catch of octopus



FIGURE 2 | Semi-dried squid (*ika no ichiya-boshi*), a classical Japanese dish, made of *Loligo forbesii* with ponzu mayo and *shichimi*. Photo: permission by and courtesy of Jonas Drotner Mouritsen.

(*Octopus maya*) at the off Yucotán coast in Mexico, and the catch is mostly exported to Europe and Asia. The European catch of octopus is traditionally made in Portugal and Spain but is now down to 40,000 tons a year and it has halved over the last thirty years. The fishing of Atlantic octopus has moved to the waters near the coasts of Morocco and Mauretania.

A substantial part of the catch of cephalopods consists of unspecified species, and because of an active trading pattern of imports and exports, traceability and quality control is complicated. As an example, octopus products aimed for the sushi market may come from third parties via Japan. Concerning the catch of *Sepia*-like species, China and Thailand are the main producers. Thailand, Spain, China, Argentina, and Peru are the world's largest exporter of *Teuthis* and *Sepia*-like species. The largest producers and exporters of octopus are Morocco, Mauretania, and China. Spain, Italy, and Japan are major world consumers of cephalopods, and the demand is increasing.

NUTRIENT COMPOSITION AND TASTE OF CEPHALOPODS

Nutrients in Cephalopods

The available data for nutrient composition of cephalopods suffer from a variation over the different data bases, reflecting that it is often not the same species that are reported about and that the actual cephalopods are derived from different locations and in different states of their life cycles. Still, there are some general trends which we shall briefly review here in order to better access the nutritional value of the different cephalopods (Ozogul et al., 2008). We compare the values for octopus, squid, and cuttlefish with corresponding values for one other simpler mollusk (blue mussel), one lean fish (cod), one fat fish (salmon), and one land animal (beef), cf. **Table 1**.

Cephalopods have a water content of about 80% and are high in protein, about 16%, which is similar to bonefish and



FIGURE 3 | A semi-classical Cambodian-inspired dish of marinated and grilled siphon and retractor muscles of *Loligo forbesii* on lemon grass. Photo: permission by and courtesy of Jonas Drotner Mouritsen.

beef and a little higher than mussel. In contrast, cephalopods are low in fat (0.7–1.4%, squid being the most fatty), about the same as cod (0.7%), less than mussel (2.2%), and much less than salmon (13%) and beef (13%). Except for octopus, cephalopods have an overweight of unsaturated fatty acids, in particular super-unsaturated omega-3 DHA and EPA (Ozogul et al., 2008). Cholesterol is singled out by high levels in squid and in cuttlefish compared to octopus whose cholesterol levels compare with those of bonefish but are less than in beef.

The caloric energy content (about 80–90 cal/100 g) in all mollusks including cephalopods is much less than in fish and beef. Cephalopods are in contrast higher in carbohydrates than the other species, but none of the mentioned species contain any sugars or dietary fibers.

All cephalopods are good sources of calcium. Iron and sodium levels are high in octopus and cuttlefish compared to fish and beef. Concerning micronutrients (trace elements) recent studies (Storelli et al., 2010) have shown for species caught in the Mediterranean that the essential elements copper, zinc, selenium, and chromium are heterogeneously distributed in the different cephalopod species, with more selenium in squid and more copper and zinc in octopus. Chromium is equally distributed in the different species. Based on these studies it was concluded that consumption of cephalopods could make a significant

TABLE 1 | Contents of water, calories, macro and micro nutrients, fibers, and vitamins in three groups of cephalopods compared with the composition of blue mussel, salmon, and beef (grass-fed; ground, raw) (Ozogul et al., 2008; USDA, 2018).

Content/100 g	Octopus	Squid	Cuttlefish	Blue mussel	Cod	Salmon	Beef
Water (g)	82	78	81	81	73	65	67
Energy (kcal)	82	92	79	86	143	208	198
Protein (g)	15	16	16	12	17	20	19
Carbohydrate (g)	2	3	0.8	3.7	0	0	0
Fiber (g)	0	0	0	0	0	0	0
Sugar (g)	0	0	0	0	0	0	0
Fat (total) (g)	1.0	1.4	0.7	2.2	0.7	13	13
Fatty acids							
Saturated (g)	0.2	0.4	0.1	0.4	0.1	3	5.3
Mono-unsaturated (g)	0.2	0.1	0.08	0.5	0.1	4	4.0
Poly-unsaturated (g)	0.2	0.5	0.13	0.6	0.2	4	0.5
Cholesterol (mg)	48	233	112	28	43	55	63
Ca (μ g)	53	32	90	26	16	9	12
Fe (μ g)	5	0.7	6	4	0.4	0.3	2
Mg (μ g)	30	33	30	34	32	27	19
P (μ g)	186	221	387	197	203	240	175
K (μ g)	350	246	354	320	413	363	289
Na (μ g)	230	44	372	286	54	59	68
Zn (μ g)	1.7	1.5	1.5	1.6	0.5	0.4	4.6
Vitamin C (mg)	5	5	5	8	1	4	0
Folate (μ g)	16	5	16	42	7	26	6
Vitamin B ₁₂ (μ g)	20	1.3	3	12	0.9	3	2
Vitamin A (IU)	150	33	375	160	40	193	0
Vitamin D (IU)	–	–	–	0	36	441	6
Vitamin E (mg)	1.2	1.2	–	0.6	0.64	3.5	0.35

contribution to the necessary daily intake of selenium, copper, and zinc.

When it comes to vitamins, it holds for all mollusks that they contain no vitamin D and very little vitamin K, in contrast to large amounts of vitamin D in fish, in particular fatty fish. It is noteworthy, that octopus has a high level of vitamin B₁₂.

Taste of Cephalopods

All seafood, including cephalopods, have different tastes depending on the species, where they have lived, and which part of the animal you eat. In particular, the texture-component of the taste experience varies vastly with a marked difference in mouthfeel between, e.g., octopus and mussels, and squid and bonefish. This variation is due to the fundamental difference in the muscular collagen structure in the different organisms. So even if the protein content are basically the same, the texture reflects dramatic differences in the motional behavior of the different species. Still, cephalopods have tastes that are similar to those of other mollusks and partly also bonefish when it comes to umami (Mouritsen and Styrbaek, 2014).

Cephalopods have as other organisms from salty waters, like bonefish, shellfish, and seaweeds, many different tastes and flavors, but they share a component of umami taste due to their high content of nucleic acids, like ATP, that enzymatically can be turned into free nucleotides such as inosinate and adenylate

under the proper conditions after the animal has been killed under not too stressed conditions. In particular squid can contain high levels of adenylate, up to 184 mg/100 g (Yamaguchi and Ninomiya, 2000), which is about as much as scallops and six times as much as a sun-ripe tomato. Moreover cephalopods can also contain large amounts of free glutamate, up to 146 mg/100 g, that is comparable to scallops and corn. The simultaneous presence of both free nucleotides and free glutamate is the precondition for the very potent umami-synergy mechanism coming into play (Mouritsen and Khandelia, 2012).

Animals that live in salty water, including cephalopods, need in their cells to accumulate osmolytes that can counterbalance the osmotic pressure across the cell walls. Such substances include free amino acids and trimethylaminoxid (TMAO). Cephalopods use TMAO as osmolyte to a larger extent and sweet-tasting amino acids (e.g., glycine, alanine) to a lesser extent than, e.g., mussels. TMAO is tasteless and cephalopods therefore have a less sweet taste than other mollusks. When an organism dies its content of TMAO is by the organism's own active enzymes turned into trimethylamine (TMA) that has the unpleasant "fish odor." Cephalopods therefore more easily develop unpleasant flavors than fish if not kept at very low temperatures that render the enzymes less active.

The preferred taste of prepared cephalopods is very dependent on the food culture. Japanese prefer a mild flavor as close to the



FIGURE 4 | A novel dish of tartare made of *Sepia officinalis* with pistachio, lime, and avocado. Photo: permission by and courtesy of Jonas Drotner Mouritsen.



FIGURE 5 | Squid "fettuccine:" a novel dish made with squid (*Loligo forbesii*), lobster, cherry tomatoes, lime juice, ponzu, salmon roe, lemon spheres, and black dried lime. Photo: permission by and courtesy of Jonas Drotner Mouritsen.

cephalopods natural flavor as possible and they will therefore only add very subdued and subtle flavors, e.g., from marinating liquids. In other places in Southeast Asia such as Vietnam,

Thailand, and China, eaters prefer cephalopods with more spicy, powerful, and fishy flavors.

It is generally true that the taste and flavor of fresh cephalopods are reasonably mild and quite easily blend in with other flavors. Therefore, in gastronomic uses of cephalopods one needs to be aware of the danger of suppressing the subtle flavors of the cephalopods by stronger tasting ingredients, such that one is left with the texture as the only surviving characteristics of the cephalopod used.

Safety Issues

Sharing the same water and often the same feed the cephalopods can suffer from the same bacterial and parasitic diseases as bonefish, e.g., anisakis (Abollo et al., 2001), and the same measures must be taken when dealing with cephalopods a food as with other types of seafood. The formation of biogenic amines, e.g., histamin from the amino acid histidin, is a serious concern in seafood, particularly during storage (Kim et al., 2009; Hu et al., 2012). It turns out, that cephalopods are low in histidin and are therefore less prone to bacterial production of histamin.

Pollution by heavy metals and other toxins is an increasing problem in the marine environment and the different species are affected to different degrees. A major problem is accumulation of mercury and arsenic in fish and shellfish, and cadmium in squid. In principle, all cephalopods will accumulate heavy metals in their tissues, particularly the innards. However, since all cephalopods have very short life spans, typically less than three years, the problem of accumulation is much less than with longer-lived predators higher up in the food web, such as tuna and whales.

Recent measurements of non-essential, toxic elements (mercury, cadmium, lead, and arsenic) in the most commonly consumed species octopus, squid, and cuttlefish caught in the Mediterranean have shown (Storelli et al., 2006, 2010) that octopus are the most loaded and squid the least. Hepatopancreas contains the largest amounts of the toxins, except of mercury and arsenic that are equally distributed between innards and muscles. Regarding arsenic, cuttlefish accumulate the most. However, since arsenic is mostly found in organic form it is not considered to of any health concern. The combined evaluation of the health risk based on recommendations for the maximal weekly intake is that only cadmium can be a potential health hazard. e.g., a portion of 70 g octopus can contain 36% of the recommended weekly load of cadmium. In contrast, the contents of mercury and lead found in all three type of species is so low that is not considered a danger to health. The authors of the study conclude that in general there is no reason to discourage consumers from eating cephalopod meat (Storelli et al., 2006).

GASTROPHYSICS APPLIED TO CEPHALOPODS

Gastrophysics is a new and emerging, interdisciplinary field of science that can be defined as qualitative reflections and quantitative studies of all gastronomic aspects pertaining to food, including culinary precisions and transformations, preparation

techniques, texture, and taste with focus on physical effects and physico-chemical characterization (Mouritsen and Risbo, 2013). The empirical basis of gastrophysics is gastronomy itself as well as food and food preparations of specific gastronomical value and potential. It is possible that gastrophysics in combination with neurogastronomy (Shepherd, 2012) can furnish the scientific underpinnings of gastronomy at large.

The usual starting point for a gastrophysical approach is a gastronomically-inspired question. In the context of cephalopod gastronomy, several obvious questions pose themselves pertaining to texture and taste. The most prominent question would be: how does one treat the muscular tissues of cephalopods, specifically the mantle and arms, and for squid also the tentacles and retractor muscles, to obtain a particular structure that leads to a desired texture and mouthfeel (Mouritsen and Styrbæk, 2017).

Cephalopod Muscular Structure: The Principle of a Muscular Hydrostat

The special construction of muscular structures in cephalopods has imparted them with a unique freedom in their motional patterns that compensates for their lack of skeletal structures. Octopus has lost shells completely, and cuttlefish and squid only have rudimentary inner shells in the form of a cuttlebone and a gladius, respectively, neither of which provide much skeletal support for muscular movements.

In the absence of any supportive internal or external skeletal support, cephalopods have solved the problem with mobility by building muscular tissues that work according to the principle of a muscular hydrostat (Kier and Smith, 1985; Hanlon and Messenger, 1996), that is a deformable system subject to constant pressure and volume. In order to exploit this principle the muscle fibers are strongly cross-bound and organized in three dimensions in contrast to unidirectional muscles in, e.g., bonefish and mammals.

Gastrophysics Applied to Cephalopod Muscular Structure

There is typically four times as much collagen in cephalopods compared to bonefish and it is much more cross-bound and hence much stronger. The level of cross-binding is a determining factor for the toughness of the tissues. The muscle fibers in cephalopods are longer and typically ten times thinner than in bonefish. This implies that the muscular structure appears more smooth than in bonefish. These facts together with the three-dimensional organization of the cephalopod muscles is the main reason why these organisms can use the principle of a muscular hydrostat to exhibit an artistic degree of mobility in all directions. If the muscle mass was a structure-less fluid hydrostat, this would not be possible.

The details of the organization of the muscular fibers in different cephalopods and in different parts of the cephalopods, i.e., arms, tentacles, and mantle, are different (Mizuta et al., 2003; Kier and Stella, 2007; Kier, 2016) and this difference is of uttermost importance for the use of the meat as food and how tender it will be. As an example, decapods like squid, because

of their special ability to perform jet-repulsion swimming, do not have parallel muscles in the long direction of the mantle, but particularly strong muscles circularly organized around the mantle. This implies for fried squid dishes that cutting the conventional rings across the mantle is in fact the worst possible way regarding tenderization. Cutting along the long direction of the mantles cut more muscle fibers and lead to a more tender product. Knowledge about the physical structure of the muscles in cephalopods can therefore be a useful guide for gastronomy.

Tenderizing Cephalopod for Optimizing Texture

Many cephalopods, in particular octopus, are notoriously known to be challenging to prepare and have a reputation for becoming chewy and rubberlike, rather than tender, creamy, succulent, or crisp. The cure is to tenderize the cephalopods. Tenderization can involve heating, freezing, pressurizing, mechanical massaging, fermenting, and curing with salt, acids, and enzymes, as well as combinations of these approaches (Katsanidis, 2004, 2008; Mouritsen and Styrbæk, 2018).

It is generally recommended to freeze cephalopods before further preparation as food because it will do away with possible parasites. Some chefs also claim that it will tenderize the meat because ice-crystal formation will break-up the muscle fibers. This is possibly true in the case of octopus but less so in the case of mantles from decapods where there is only little effect of freezing on texture. The drawback of freezing cephalopod meat is that it will invariably lose some water.

Heat treatment is the most used procedure to tenderize cephalopods, e.g., by boiling in water or sous vide, baking, frying, and grilling. Since both temperature and duration of the treatment are in play at the same time it can be quite complicated because the collagen and the muscular protein in the tissue have different ways of responding to heat. Salt and acid will also affect the result of cooking octopus and how quickly the proteins in the meat denature. Acid, e.g., vinegar, tends on the one hand to stiffen the muscular proteins but will on the other hand promote the break-down of the collagen and lead to seeping out of gelatin into the cooking water, rendering the result drier. Salt is supposed to have the opposite effect but may not do anything good for the taste (McGee, 2008).

The mantle from decapods, like *Sepia officinalis* and *Loligo forbesii*, need very brief heating at low temperatures (50–60°C) to become more tender and succulent, and in many cases you are better off eating the mantle raw and only heat-treat the arms and tentacles very lightly.

Concerning tenderization by mechanical means, traditional Greek chefs recommend taking an octopus by one arm and bash it repeatedly against rocks, and Japanese chefs suggest to massage the octopus arms by your hands, adding grated *daikon* and salt. More modern techniques involve tumbling the raw octopus in saltwater for hours in tumbler. Other techniques imply scoring the outer surface of decapod mantles possibly in a crisscross pattern or simply to puree the meat in a blender or in a Paco-jet machine. The latter type of tenderization is used, e.g., to produce *surimi* of squid meat.

Similarly to meat from fish and land animals, the meat from cephalopods can be tenderized by the action of specific enzymes. A traditional approach proceeds using squid intestinal enzymes from the hepatopancreas that contains some very aggressive enzymes. The hepatopancreas of squid (e.g., *Todarodes pacificus*) is therefore employed to start fermentation in traditional Asian fish sauces. A fermentation medium with 10–30% salt and squid hepatopancreas is used to form a special marinade *shiokara* in Japanese or *chokkaru* in Korean. The Korean *chokkaru* often enters *kimchi*, and *shiokara* is used in Japan to prepare the traditional squid dish *ika no shiokara* that is shredded squid mantle fermented in its own intestinal enzymes. During the fermentation process a lot of free amino acids and peptides are formed that lead to strong umami and *kokumi* tastes. The high levels of salt prevent putrefaction over the very long fermentation periods that can last for months. Fresh and non-pasteurized ink from cuttlefish also contain enzymes that can facilitate some tenderization.

Enzymes from fruits, such as bromelain from pineapple juice, are also known to be able to tenderize squid muscles by loosening the collagen network (Ketnawa and Rawdkuen, 2011).

SOME USES OF CEPHALOPODS IN THE WORLD CUISINE

It is hardly surprising that different countries have different traditions with respect to using a given food commodity and ingredient in their cuisine, which is amply reflected in recipes and the general food culture. But it may be surprising, e.g., that whereas the Japanese cuisine to a large extent uses cephalopods as raw or very lightly treated food there is in Spain hardly any tradition for eating raw cephalopods or raw seafood of any kind for that matter. Italy places herself somewhere in between, both with a tradition of regional dishes of raw or lightly marinated seafood (*pesce crudo*), including cephalopods, and a tradition like the Spanish of frying and grilling cephalopods.

Raw or Almost Raw

Many types of decapods can be eaten in raw or nearly raw form provided they are completely fresh and do not contain nematodes in which case they need to have been frozen first to at least -20°C in 24 h and preferably 72 h. Octopus are seldom eaten raw because it is generally too tough (Schweid, 2014). As a curiosity, it can be mentioned that there is an Apulian specialty dish from around Bari called *vurp arrazzat*, meaning “curly octopus,” made from small octopus that are eaten raw after an elaborate tenderization procedure. This procedure, that is applied only to small specimens of *Octopus vulgaris* (less than a kilo) or other small octopus species (e.g., *Eledone moschata*) involves first beating of the octopus against rocks, then beating it with a wooden ladle, then agitated washing in seawater, and finally cradling or rolling it so it curls up. During this procedure, the animals are first unnerved and the fibers become disrupted and extended, rendering the flesh soft, after which the texture contracts again and the meat turns extremely crunchy. They are eaten completely fresh with a squeeze of lemon.

An extreme case of eating raw octopus is the Korean dish *sannakji* that is raw and live tips of octopus arms cut off a live octopus. Needless to say, this is a brutal way of treating an animal and in addition, taking pieces of living and moving octopus arms into the mouth, can be dangerous since the suckers will attach to the mucus membranes and can lead to suffocation.

The Japanese cuisine is rich in seafood that is eaten raw, typically as sashimi and sushi, it be of fish, shellfish, and cephalopods. The best-known kind of sushi is hand-pressed *nigiri-zushi* that often is topped with a piece of raw *ika* made of the mantle of cuttlefish or squid (Mouritsen, 2009). Octopus (*tako*) for sushi are prepared as thin slices cut across cooked arms.

In Marinade and Sauce

There is only a short way from raw cephalopods to lightly marinated preparations, such as South American *ceviche* or Italian *pesce crudo* where pieces of cephalopod mantles and arms are marinated in salt, acid (vinegar or citrus-fruit juice), or sauces like soy sauce, *ponzu*, or *sanbaizu* that contains *dashi* with lots of umami taste. Other interesting marinades can be made of miso or sake lees (*sake kasu*) that serve both to tenderize the meat and to impart umami taste. When marinating in acidic media one should be aware of the fact that acids make the muscle proteins contract and can lead to a firmer texture in the short run and only tenderizing over longer times.

Squid and cuttlefish mantles cut in fine strips along the long direction of the mantle are particularly suited for marinating. These strips, called *ika-somen* in Japan, look like a kind of fettuccine pasta and are often served on top of a bowl of rice (*chirashi-zushi*) or in a soup broth.

Dried

A traditional way of preparing octopus in Greece and at other coasts around the Mediterranean, e.g., Southern Spain, proceeds by air-drying the whole octopus outside so it loses about half its weight. They are then grilled. This procedure renders the meat very crisp but also somewhat chewy. A similar technique is used in Japan for both octopus and squid, *saki-ika*, i.e., dried *ika* from *Todarodes pacificus*. Fully dried cephalopods can be shredded and are often used like a kind of snack similar to jerky, in which case they typically are flavored by soy sauce, *yuzu*, or various spices.

Part of the traditional Japanese breakfast consist of grilled dried fish or squid. Often the squid is only semi-dried (*ichiyaboshi*) over night. The drying implies that the squid retains some of its firmness and its taste compounds do not seep out during grilling.

According to more modern recipes, octopus can be made rather tender by drying the raw arms a couple of hours at 65°C , possibly first rolled in spices like curry, after which they can be grilled or smoked and used as a snack (Mouritsen and Styrbæk, 2018).

Grilled

Some of the most genuine culinary experiences one can have by visiting the coastal areas in Portugal and Spain is to enjoy a simple meal of freshly caught grilled squid, *calamares à la plancha* in Spain and *calamares grelhados* or *lulas grelhados* in Portugal.

The serving is complete with a few boiled potatoes, a little green lettuce, and a wedge of lemon.

It is mostly decapods that are grilled this way, and the grilling is done quickly and involves both mantle including fins, arms, and tentacles. For the smaller species and specimens the whole cephalopod are put on the grill, and for the small *Sepia* species (e.g., *Sepia elegans*) this can be an interesting challenge for the diner due to the ink. A traditional way of grilling and presenting a grilled whole squid is by first cutting it half way through and across the mantle so it during grilling opens like an accordion.

Fried

Frying breaded or battered squid and cuttlefish in oil is a very fast and common way to prepare cephalopods, but it is not without dangers since the meat can become tough if cooked too much, and the crumble can become too greasy if it is not sufficiently dry and crunchy. A dry crumble can be obtained by using *panko* that is a special kind of Japanese bread crumbs with a lot of small airy pores that repel the oil. Ill-prepared fried squid rings are probably the best way of scaring people from eating cephalopods.

Andalusia in the Southern part of Spain has a cuisine with a rich tradition for fried seafood, *pescaito frito*, not least cephalopods which are often served as a kind of *tapas*. Local specialties include *puntillitas* (*calamares chiquititos*) and *calamaritos* (*chipirones*). *Puntillitas* are made from *Alloteuthis subulata*, and *calamaritos* are small squid of the species *Loligo vulgaris*. *Chocos fritos* is the popular name for the mantle of small *Sepia officinalis*. An Andalusian specialty is *huevos de choco* that is made of the nidamental glands from large *Sepia officinalis*. These glands produce gelation materials that harden the roe in the female *Sepia* and is considered a valued delicacy that require little preparation. They are lightly grilled or served in a marinade of olive oil, garlic, and parsley.

Deep-frying of raw squid and cuttlefish is a classical approach in the Chinese cuisine and it has the advantage that high heat can be applied for a very short time when one uses a wok. In the Cantonese cuisine one of the most classical dishes is salt and pepper squid (*jiāoyán yóuyú*); another one is deep-fried squid with sugar peas (*zajin chao xianyou*). When using the squid or cuttlefish mantles for these dishes they are usually cut out in squares and then scored which make them curl up in a characteristic coniferous cone-like shape that contributes aesthetically to the presentation of the dish.

Steamed and Boiled

World cuisines have a great many different recipes for preparing steamed and cooked-in-water octopus and there are almost as many recipes as there are chefs. The trouble is related to the difference in response to heat by muscle protein and collagen which in turn raises the question regarding the best combination of temperature and cooking time, as well as the effect of salt and acid. The complexity of the problem is possibly best reflected in the great variety in traditional recipes for preparing octopus. Some Spanish chefs say that octopus should be boiled in a copper vessel and Italian chefs may say that it is instrumental to place two corks on the boiling water. More scientific approaches to cooking octopus in water can be facilitated by a pressure cooker and the cooking time can then be at least halved in many cases.

A systematic approach to this problem may proceed by using sous-vide techniques (Myhrvold, 2010).

Cooked octopus arms are used in a variety of warm and cold preparations and dishes. A classical dish in Southern Europe is cold octopus salad with slices or chunks of octopus arms together with various vegetables, beans, and herbs.

In Japan, octopus caught around the Awaji island in the Strait of Akashi between Honshu and Shikoku in the Easter part of Japan is considered to be the most flavorful. It is particularly highly valued in the summertime when the water contains large supplies of shrimp and crabs which are octopus' favorite food. There is a rich food culture around Awaji octopus (*tako*). The most famous preparation is *tako-yaki* that is a kind of dumplings with a dough wrapped around minced meat from octopus arms, possibly supplemented by the remains from *tempura* preparations. The dough contains ginger and spring onions and is baked in special molds. The dumplings are dipped in different sauces, and the traditional *Akashi-yaki* is pure *tako-yaki* dipped in *dashi*. *Akashi-yaki* is served all around the Osaka area where it is a popular kind of streetfood. Octopus is so popular there that July 2 is designated as a special *tako*-day.

The cooking water from boiling an *Octopus vulgaris* can be very flavorful and umami-rich and upon reduction lead to a sauce that is viscous due to gelatin released from in particular the gelatinous skin of the arms. This sauce can be used to glaze octopus arms or enter in a very delicious emulsion or cream that has a strong meaty flavor. One of the most classical preparations in Spain is the Galician dish *pulpo à la Gallega* that consist of slices of boiled octopus arms with paprika and olive oil. It is by tradition served warm on a wooden plate with boiled potatoes. In this dish the octopus arms have cooked and simmered for a long time so they are extremely tender and creamy and when done right they are not too dry.

Although less often than octopus, decapods are also in some cuisines cooked or steamed, e.g., using sous-vide techniques. Cooking is more important for the texture of the arms and tentacles than the mantle.

With Ink

Ink from squid and in particular from cuttlefish are used in several food cultures to color various dishes as well as pre-prepared foodstuff such as rice, pasta, bread, and cakes. It is also possible to prepare interesting looking snacks by coloring with *Sepia* ink. Fresh ink does not only color a dish but can also help to tenderize meat because of its content of active enzymes. A classical Spanish dish is squid prepared in its own ink, *calamar in su tinta*.

CONCLUSIONS AND OUTLOOK: FOOD FOR THE FUTURE

Projections for the world population predicts that in 2050 there will be 10 billion people in the world. This rapid growth in population will imply a dramatic increase in the competition about the natural resources and hence put focus on the sustainability of our food supplies in the context of economy as well as social, environmental, and political factors. It is becoming

clear that we live in the Anthropocene era where humans are making a significant and possibly irreversibly footprint on the earth, its ecosystems, and its climate. This raises questions as how to distribute and exploit our available resources in a more sustainable fashion.

This is not least the case when it comes to the world's food supplies. Production of meat, in particular beef, takes a heavy toll on the consumption of water and energy leading to large effects on carbon dioxide emissions and climate. The production of protein from beef is approximately twenty times as costly as production of protein from insects and farmed chicken and salmon. It is at this point it becomes relevant to look for other, more sustainable protein sources, and the cephalopods bring themselves into focus.

The oceans are in some sense a poorly exploited and poorly managed natural food resource when it comes to fisheries. Several species are endangered and overfished, and at the same time environmental factors put limits to expansions of agriculture of fish and shellfish (Boyle and Rodhouse, 2005; SAPEA, 2017). If we are to use the marine food resources in a better and more sustainable fashion to feed a growing population with healthy and safe food we need to learn to consume marine food in a more diverse and insightful manner, including eating from lower trophic levels and limiting bycatch and waste. We must come to term with eating more seafood directly rather than piping it through land animals as feed, thereby losing typically 90% of the nutrients in each trophic level.

This is where the cephalopods come in. Cephalopods are extremely effective to turn their food into musculature, they grow quickly, and they have fast generational shifts. The global volume of fisheries of cephalopods has increased in recent years (Jereb and Roper, 2005, 2010; Payne et al., 2006; Anderson et al., 2011; Pauly et al., 2013; Jereb et al., 2016). One challenge in this context is that they are notoriously difficult to put into aquaculture (Vaz-Pries et al., 2004) and no real successful commercial cultures have yet been established.

In 2015 the UN passed an act "Agenda for Sustainable Development" toward 2030 (UN, 2015), which also considers distribution and administration of fisheries and aquaculture with a focus on safety and human nutrition. The cephalopods are part of this agenda. However, it is difficult to make plans and control the catch of cephalopods because a major part of the fisheries take place in international waters, but also because our knowledge about cephalopod behavior in the wild is rather limited. The limited data makes predictions cumbersome and uncertain. One circumstance that adds to the complexity is the short life span of most cephalopods.

An important finding in recent years has put this whole complex into a new and very interesting light (Doubleday et al., 2016): research has shown the surprising result that there is a global rise in the cephalopod populations. By analyzing data for the populations of 35 different species from six different families (31% Octopoda, 52% Teuthida, and 17% Sepioidea) over a period of 6 years (1953–2013), the researchers have in all cases found clear signs of growing populations. The unique aspect about these observations is that this observation holds true for both species that are fished and species that are not fished and

the survey moreover included cephalopods from all levels of the water column. The similarity in the growth pattern for the different species suggests that the growth does not simply reflect an increase in the catch due to improved and more intensified fishing methods. Moreover, the different species included in the survey both encompass species that move over thousands of kilometers in the oceans and species that move around only locally. The reason for the universal and global growth pattern must consequently be related to some other mechanism.

The interpretation of this striking observation has been (Doubleday et al., 2016) that the cephalopods have profited from the anthropogenic climate changes. It is known that cephalopods react and adjust quickly to environmental changes, in particular water temperature (Rodhouse et al., 2014). Increasing water temperatures could have caused migration of some species toward more northern and colder waters. What that eventually will imply for the fish and cephalopods native to those waters is still too early to say.

It is also possible that the decrease in the populations of some bonefish that prey on cephalopods on the one side have given cephalopods an advantage. On the other side certain fish are also prey for the cephalopods. In any case, it is possible that the changing climate has pushed to the million-year old competition and ecological balance between cephalopods and bonefish (O'Dor and Webber, 1986). In Perm (299–252 million years ago) the bonefish teemed and entered a fierce competition with the then ruling cephalopods, leading to the occurrence of the Coleoidea, the cephalopods without outer shells, and the bonefish got the upper hand with now 30,000 different species against the only 800 remaining cephalopods. Maybe the balance is now tipping and their enormous reproductive power and their ability to adapt to environmental changes now give the cephalopods a renewed chance to rule the oceans.

Hence, there is a good reason to look to the cephalopods as an important food resource which we should pay more attention to. This raises several questions. One is related to using the wild populations in a more sustainable fashion. Another one is related to as how we can possibly design systems for cephalopod aquaculture (Iglesias et al., 2007). The answers to both these questions require more research and biotechnological development (Vidal, 2014). A third question pertains to ethical issues regarding the treatment and killing of cephalopods (Fiorito et al., 2015), not least octopus that clearly, although an invertebrate, is imparted with faculties that may render it both intelligent and possibly having consciousness (Fiorito and Scotto, 1992; Mather, 2008; Montgomery, 2015a,b; Godfrey-Smith, 2016) as now manifested in the Cambridge Declaration on Consciousness¹.

The last question and the answer to this question has been the topic of the present paper. The question can be simply rephrased as: do we want to eat cephalopods? In many food cultures around the world this is obviously a silly question since they have a rich tradition for using cephalopods in their food and cooking. It is less obvious in other cultures in which cephalopods may be as

¹Cambridge Declaration on Consciousness. Available online at: <http://fmcconference.org/img/CambridgeDeclarationOnConsciousness.pdf>

weird a foodstuff as insects for those who are not accustomed to eating insects. Even though arguments can be presented that cephalopods are certainly very edible, nutritious, healthy, and can even be prepared as tasty food, it is not easy to change people's food preferences. It is well known from public campaigns that even if a certain diet is known to be healthy, nutritious, and sustainable, people are not going to eat it unless it is delicious. Therefore, a focus on cephalopod gastronomy is required to stimulate a motion in the direction of more people eating more cephalopod-based food.

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