Seafood Nutrition Partnership
7th Annual State of the Science Symposium
Washington DC, September 21, 2023

When **blue** is **green**:

Seafood as a Driver in the Green Transition

A defense for a **flexitarian** approach based on a **scientific** understanding

The solution to sustainable eating is not a one-way street
(Schmidt & Mouritsen) *Front. Psychol.* **11**:531 (2020)
A role for macroalgae and cephalopods in sustainable eating
(Mouritsen & Schmidt) *Front. Psychol.* **11**:1402 (2020)
Design and 'umamification' of vegetables for sustainable eating
(Mouritsen & K. Styrbæk) *Int. J. Food Design* **5**, 9-42 (2020)
Umami taste as a driver for sustainable eating (Schmidt & Mouritsen) *Int. J. Food Design* **7**, 187-202 (2022)

Are our food and food systems sustainable?

NO !

Global food production is main responsible for changes in the planet's ecosystems

climate, water, use of land, biodiversity, P-, C- og N-cycles

Global changes are needed

More than half of the goals are related to food, food systems, and health.

Food in the Anthropocene: the EAT–*Lancet* Commission on healthy diets from sustainable food systems

Walter Willett, Johan Rockström, Brent Loken, Marco Springmann, Tim Lang, Sonja Vermeulen, Tara Garnett, David Tilman, Fabrice DeClerck, Amanda Wood, Malin Jonell, Michael Clark, Line J Gordon, Jessica Fanzo, Corinna Hawkes, Rami Zurayk, Juan A Rivera, Wim De Vries, Lindiwe Majele Sibanda, Ashkan Afshin, Abhishek Chaudhary, Mario Herrero, Rina Agustina, Francesco Branca, Anna Lartey, Shenggen Fan, Beatrice Crona, Elizabeth Fox, Victoria Bignet, Max Troell, Therese Lindahl, Sudhvir Singh, Sarah E Cornell, K Srinath Reddy, Sunita Narain, Sania Nishtar, Christopher J L Murray

Lancet 2019; 393: 447–92

Food production is the main reason for changes in the Earth's ecosystems (climate, water, use of land, drinking water, biodiversity, P and N cycles)

Proposed solution for a healthy and sustainable diet for an increasing population:

Diet mainly composed of
- Vegetables, fruits, whole grain, legumes, nuts and unsaturated fats
- Moderate amounts of **fish** and poultry
- Little or no red meat, processed meat, added sugar, refined cereals, and starchy vegetables

Daily recommendations, plant based
- **300g vegetables, 200g fruit**
- 230g whole grain (rice, wheat, corn); 60% of caloric intake
- 50g starchy vegetables (e.g., potatoes)

The solution is fragile

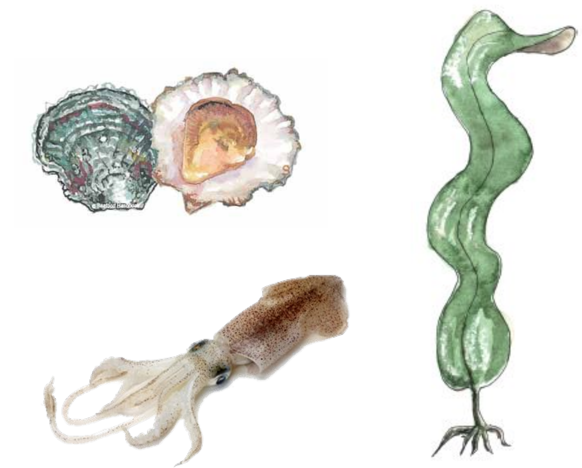
Where is TASTE ?

Where are the marine algae?
Where are the molluscs?

Can you eat that much?

Eat more greens: But how do we make all this more delicious?

Look towards the ocean



Relative sustainability:

Eat low down in the food web

The solution to sustainable eating is not a one-way street
(Schmidt & Mouritsen) *Front. Psychol.* **11**:531 (2020)

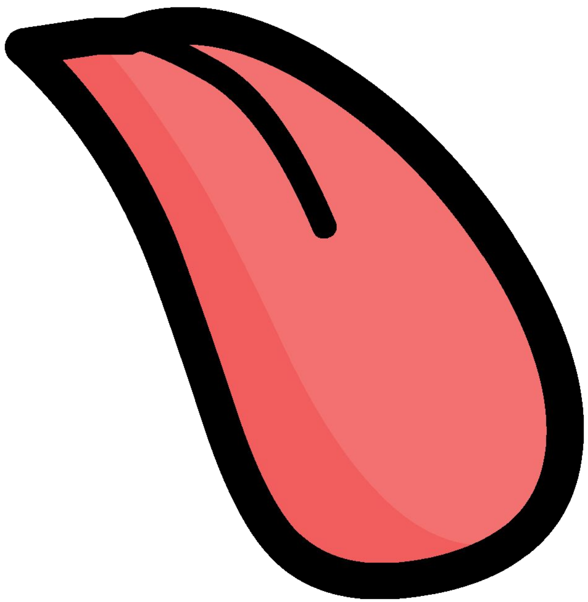
Taste comes first … then

- Health
- Calories
- Nutrition
- Sustanability
- Organic
- …

Taste - Taste preference? Deliciousness?

The basic (physiological) tastes

Sweet and umami are special



Sour

Sweet

Salty

Bitter

Umami

- and so are *koku*-attributes

Umami

Salivation, appetite, satiety & healthy eating

Konbu tsukudani

Umami flavour as a means to regulate food intake and to improve nutrition and health (O. G. Mouritsen) *Nutr. Health* **21**, 56-75 (2012)

‘Problems’ with vegetables

- Vegetables are not ‘meant’ to be eaten
- Vegetables lack **sweet** and **umami**
- Vegetables can be **bitter**

- *Homo sapiens* craves basic tastes **sweet** and **umami** (by evolution) and stay away from **bitter**

☞ Therefore: there is a need for *culinary sciences* to help promoting the green transition

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There are two routes, and both go through **taste**

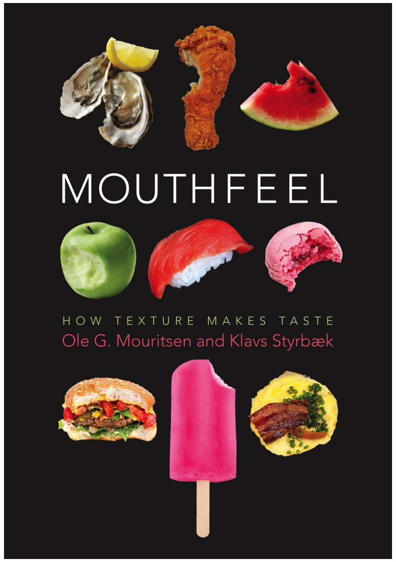
1. route

Add sweetness and umami to vegetables

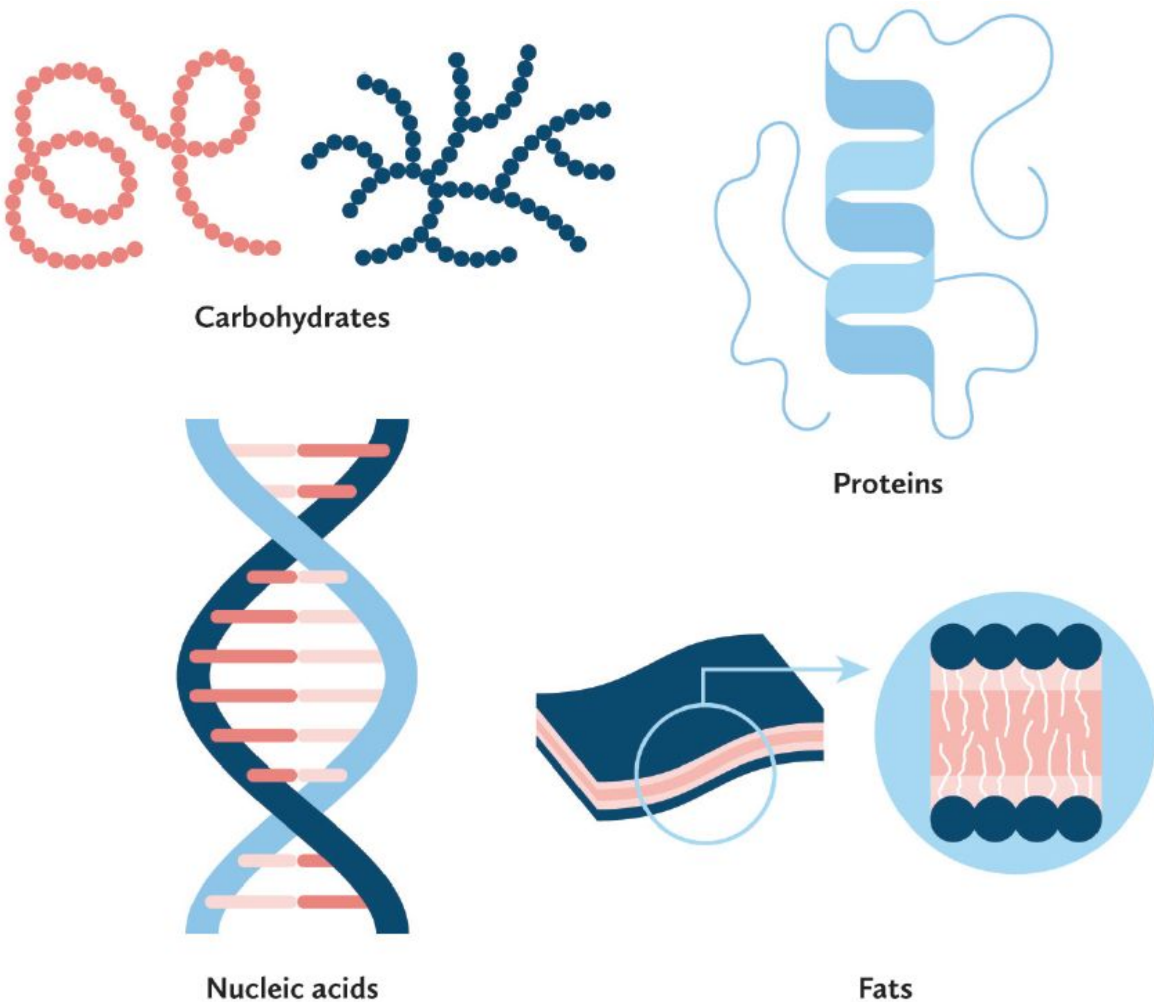
2. route

Release of the vegetables' own potential to yield sweetness and umami

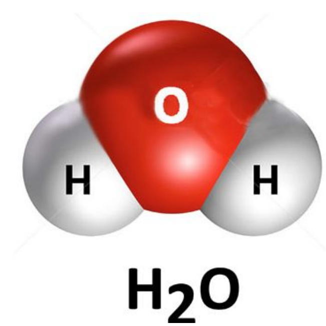
+ a focus on texture/mouthfeel



The molecules we eat and their taste

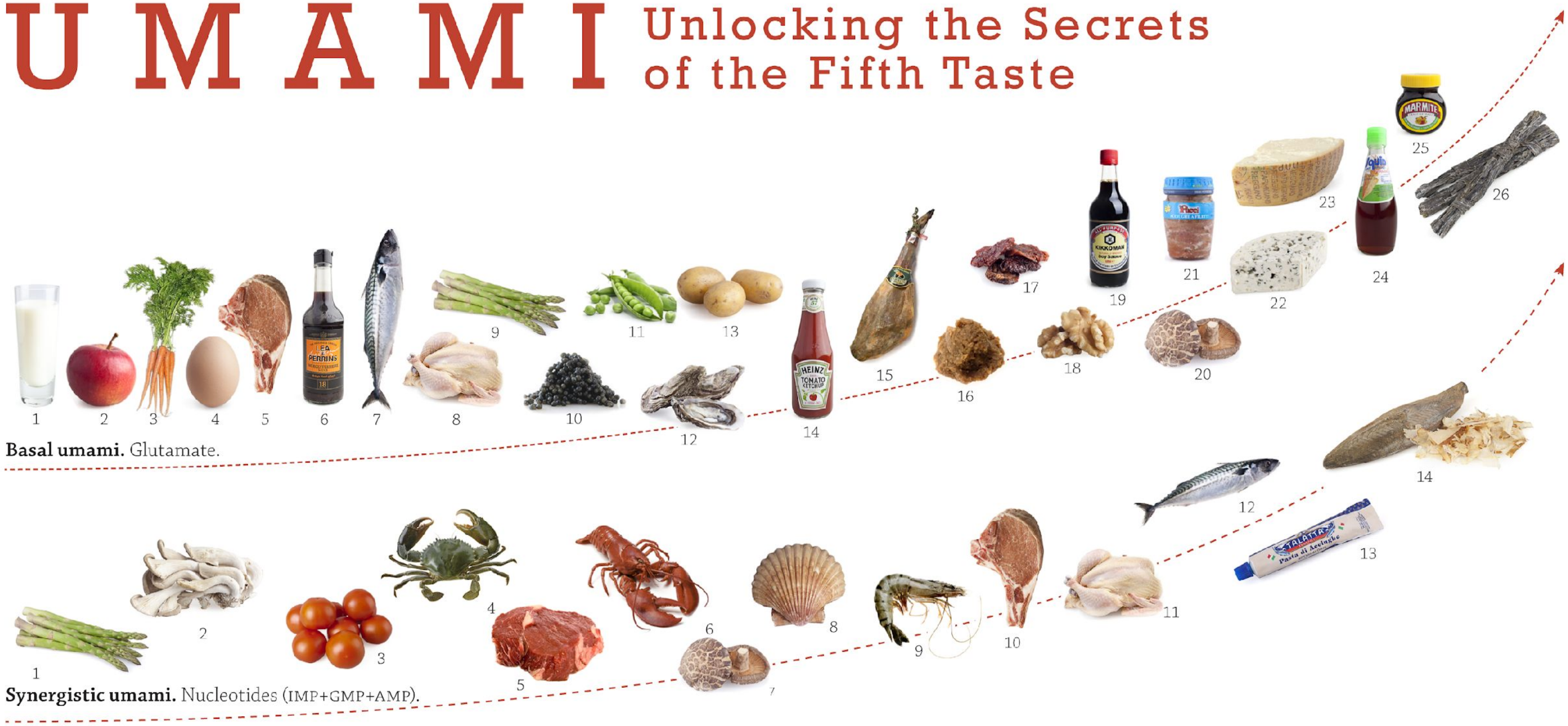


+ lots of water



Umami taste synergy

UMAMI Unlocking the Secrets of the Fifth Taste



A representative selection of raw ingredients and processed food products that contain umami taste substances, ranging from very small quantities (on the left) to an abundance (on the right). The products on the top have basal umami (from glutamate), while those on the bottom have synergistic umami (from the nucleotides IMP, GMP, and AMP). Note that the horizontal axes are not linear and the position of a given product on the axis does not correspond to its absolute content of umami substances. However, the individual products on each axis are placed in the correct relationship to each other.

Basal umami
1: cow's milk, 2: apple, 3: carrots, 4: egg, 5: pork, 6: Worcestershire sauce, 7: mackerel, 8: chicken, 9: green asparagus, 10: caviar, 11: green peas, 12: oysters, 13:potatoes, 14: ketchup, 15: air-dried ham, 16: miso paste, 17: sun-dried tomatoes, 18: walnuts, 19: soy sauce, 20: dried shiitake mushrooms, 21: anchovies in brine, 22: blue cheese, 23: Parmesan cheese, 24: fish sauce, 25: Marmite, 26: dried seaweeds (konbu).

Synergistic umami
1: green asparagus, 2: oyster mushrooms, 3: sun-ripened tomatoes, 4: crab, 5: beef, 6: lobster, 7: dried shiitake mushrooms, 8: scallop, 9: shrimp, 10: pork, 11: chicken, 12: mackerel, 13: anchovy paste, 14: *katsuobushi*

Umami: Unlocking the Secrets of the Fifth Taste
Ole G. Mouritsen & Klavs Styrbæk

旨味

cup.columbia.edu
umamibook.net

COLUMBIA UNIVERSITY PRESS

1. route

Add umami and kokumi by means of other ingredients (than green)

Marinades, stocks, sauces, dressings:
deliciousness *without* (much) fat

- typical of **animal**, **algal** or **fungal** origin

A flexitarian approach

Design and 'umamification' of vegetables for sustainable eating (O. G. Mouritsen and K. Styrbæk)
Int. J. Food Design **5**, 9-42 (2020)

2. route

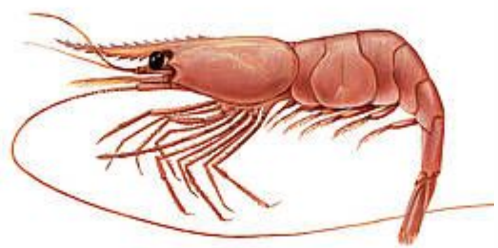
Release of the vegetables’ own potential to yield sweetness and umami

- Fermentation by microorganisms
- Fermentation by enzymes

Carbohydrates, proteins, fats □ taste compounds
Conservation/reinforcement of crispy texture

- Examples: miso/soy sauce (*Aspergillus*), tempeh (*Rhizopus*), lacto-fermentation, tsukemono, …

A lot of help from the sea



- ☛ Umami: glutamate and nucleotides - synergy
- ☛ Kokumi: certain tri-peptides

A role for macroalgae and cephalopods in sustainable eating
(O. G. Mouritsen and C. V. Schmidt) *Front. Psychol.* **11**:1402 (2020)
Umami synergy as the scientific principle behind taste-pairing champagne and oysters
(C. Vinther Schmidt, K. Olsen, and O. G. Mouritsen) *Nature Sci. Rep.* **10**, 20077 (2020)

The ω-3/ω-6 ratio

- Seaweeds: 1-10
- Cephalopods: 4-40
- Marine roe: 5-30

Fermented sauces with umami and kokumi







Flavor of fermented fish, insect, game, and pea sauces: *garum* revisited
(Mouritsen, Duelund, Calleja, Frøst) *Int. J. Gastronomy Food Sci*. **9**, 16-28 (2017)

Cephalopods as food

Global populations of octopus, squid & cuttlefish are increasing

- 800 species in all salty waters. >30 species exploited as human food.
- 5% of total global fisheries and increasing rapidly. Only wild catch.
- Global annual production 4.8 mio. metric tonnes; value ~8 billion $US.

- Highly unexploited seafood.
- Need for **gastronomy** and gastrosciences to enhance broader use in households and food industry as well as to increase market value. Focus on **taste** and **texture**.
- High in protein (16%); future source of **animal protein**.
- High in minerals Ca, Na, Fe and trace elements Cu, Zn, Se, Cr. Octopus high in vit B_{12}.

- Short life cycle (2-3 yr). Rapid reproduction and proliferation.
- Low environmental toxic load
- Quick adaptation to environmental changes. Tipping competition with bonefish?

2016 World Congress on Cephalopods: *Overview on Supplies*. Vigo, Spain
Conclusion: **" … all populations have grown over the past 50 years"**

Doubleday *et al*., Global proliferation of cephalopods. *Cur. Biol.* **26**, R406-R407 (2016).
Cephalopod gastronomy - a promise for the future (O. G. Mouritsen and K. Styrbæk) *Front. Comm. Sci. Environ. Comm*. **3**:38 (2018).

Cephalopod gastronomy

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Squids of the North: gastronomy and gastrophysics of Danish squid (Faxholm, Schmidt, Brønnum, Sun, Clausen, Flore, Olsen, and Mouritsen) *Int. J. Gast. Food. Sci*. *14*, 66-76 (2018).

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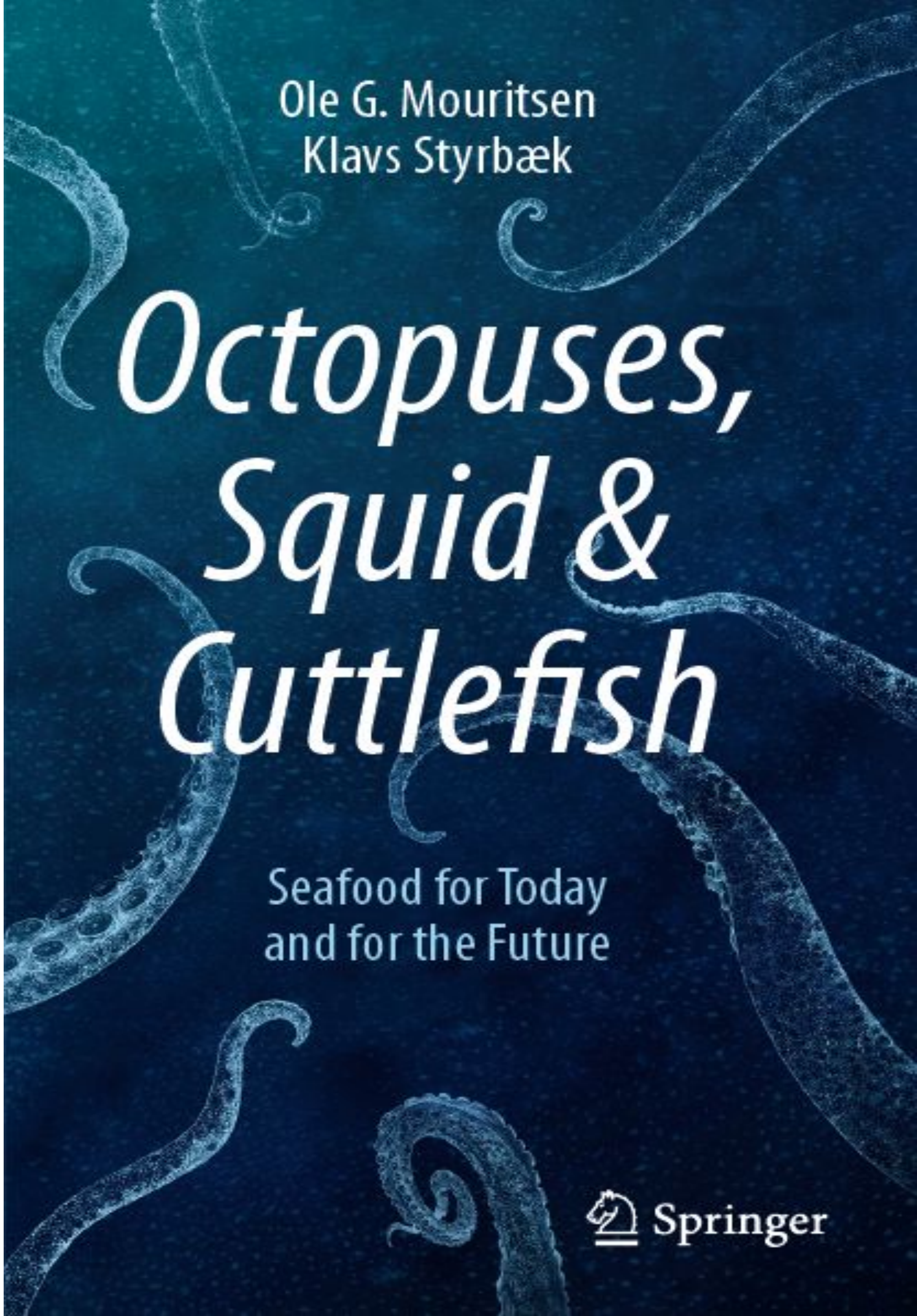
Cephs & Chefs Recipe Book (2021).



Umami synergy in some seafood

$$\boxed{EUC = \sum_i u_i + \left(\sum_i u_i\right) \times \sum_i \sum_N \gamma(N) v_{i,N}}$$

Food item (raw)	Glu	IMP	AMP	GMP	EUC
Squid (*Loligo forbesii*)					
- Mantle	109	5.3	48	3	2,900
- Arms	101	5.4	15	3	1,900
- Fins	72	6.2	38	3	1,800
- Liver	462	10	5	6	14,000
European oyster (*Ostrea edulis*)	257	30	94	18	28,000
Pacific oyster (*Crassostrea gigas*)	160	15	42	9	8,600
Scallop	140		172		5,400
Chicken	22	202	13		5,400
Salmon roe (*Oncorhynchas keta*)	3-19	6-18	4	12-18	~500 (Hayashi et al., 1990)
Sturgeon roe (*Acipenser transmontanus*)	25	-	15	-	1,055
Sea urchin (*Paracentrotus lividus*)	209	70	70	19	60,000 (Camacho et al., 2023)

Umami potential of Nordic squid (*Loligo forbesii*)
(C. V. Schmidt, M. M. Poojary, O. G. Mouritsen, and K. Olsen) *Int. J. Gast. Food Sci*. **22**, 100275 (2020)
Umami synergy as the scientific principle behind taste-pairing champagne and oysters
(C. V. Schmidt, K. Olsen, and O. G. Mouritsen) *Nature Sci. Rep*. **10**, 20077 (2020)
Octopuses, Squid & Cuttlefish: Seafood for Today and for the Future (O. G. Mouritsen and K. Styrbæk) Springer Nature Switzerland AG (2021)
Umami taste as a driver for sustainable eating (Schmidt and Mouritsen) *Int. J. Food Design* **7**, 187-202 (2022)
Roe gastronomy (Mouritsen) Int. *J. Gastronom. Food Sci*. ***32***:100712 (2023)

Algae as food

Eat more and better seafood from the bottom of the food web

Macroalgae (seaweeds)

- 12,000 species in all climatic belts. About 500 species exploited as food.
- Global annual production 29 mio. metric tonnes; value 6.5 billion $US.
  >95% in aquaculture; >80% for direct human consumption.
- Future scenario: multi-trophic eco-aquacultures including seaweed, fish, filter feeders.

- Highly unexploited and generally sustainable crop.
- Need for **gastronomy** and gastrosciences to enhance broader use in households and food industry as well as to increase market value.
- Important **nutrients** in seaweeds: high levels of micro- and macronutrients, vitamins, poly-unsaturated fatty acids. K-salts > Na-salts.
- Various uses as **food**: Whole foods; hydrogels; salt substitute; condiments; in bread, meat- and dairy products.
- **Taste** comes first: Rich source of free glutamate **umami**. Enhances flavor and deliciousness of other foodstuff, e.g., vegetables.

Microalgae

Will become important supplies for poly-unsaturated fatty acids as fisheries are dwindling.

FAO. The State of World Fisheries and Aquaculture, Rome (2018)

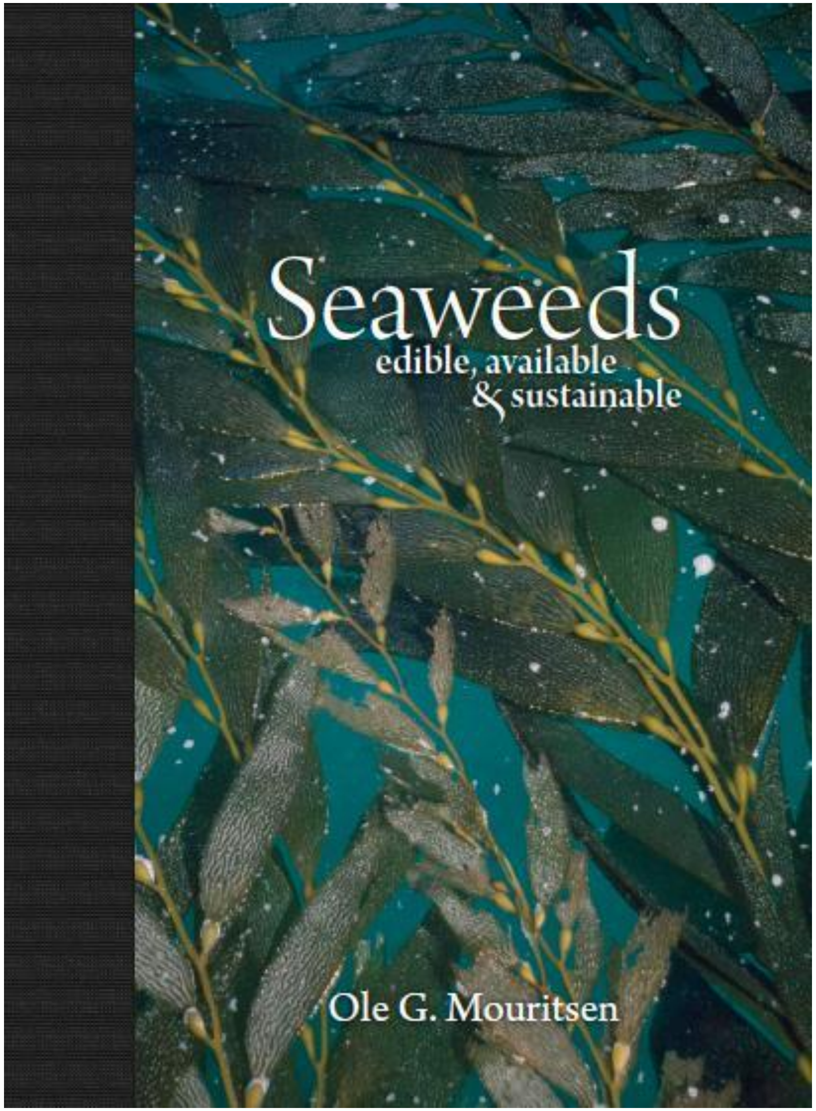
Seaweeds: Edible, Available & Sustainable (O. G. Mouritsen) Chicago University Press, Chicago (2013)

Phycogastronomy

Seaweeds. Edible, Available & Sustainable
(O. G. Mouritsen) Chicago University Press, Chicago (2013). 300pp.

World cuisine of seaweeds: science meets gastronomy
(O. G. Mouritsen, J. L. Pérez Lloréns, and P. Rhatigan) *Int. J. Gast. Food. Sci.* **14**, 55-65 (2018).

The rise of seaweed gastronomy: phycogastronomy
(O. G. Mouritsen, J. L. Pérez Lloréns, and P. Rhatigan) *Bot. Mar.* **62***,* 195-209 (2019).



Seaweeds in the context of **human evolution & health**

A role for dietary macroalgae in the amelioration of certain risk factors associated with cardiovascular disease

(Cornish, Critchley & Mouritsen)

Phycologia **54**, 649-666 (2015)

Consumption of seaweeds and the human brain

(Cornish, Critchley & Mouritsen)

J. Appl. Phycol. **29**, 2377-2398 (2017)

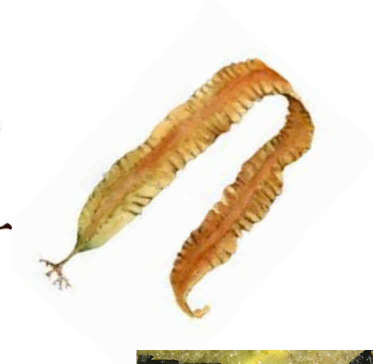
Minireview on the microbial continuum: consideration of a link between judicious consumption of a varied diet of macroalgae and human health and nutrition

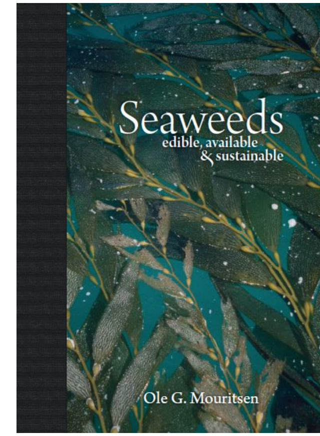
(Cornish, Mouritsen & Critchley)

J. Ocean. Limnol. **37**, 790-805 (2019)

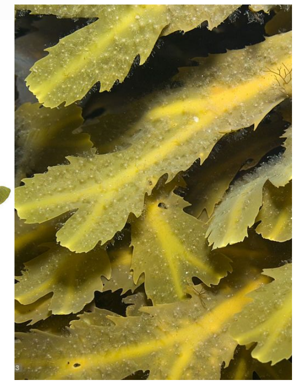
Umami from seaweeds ?









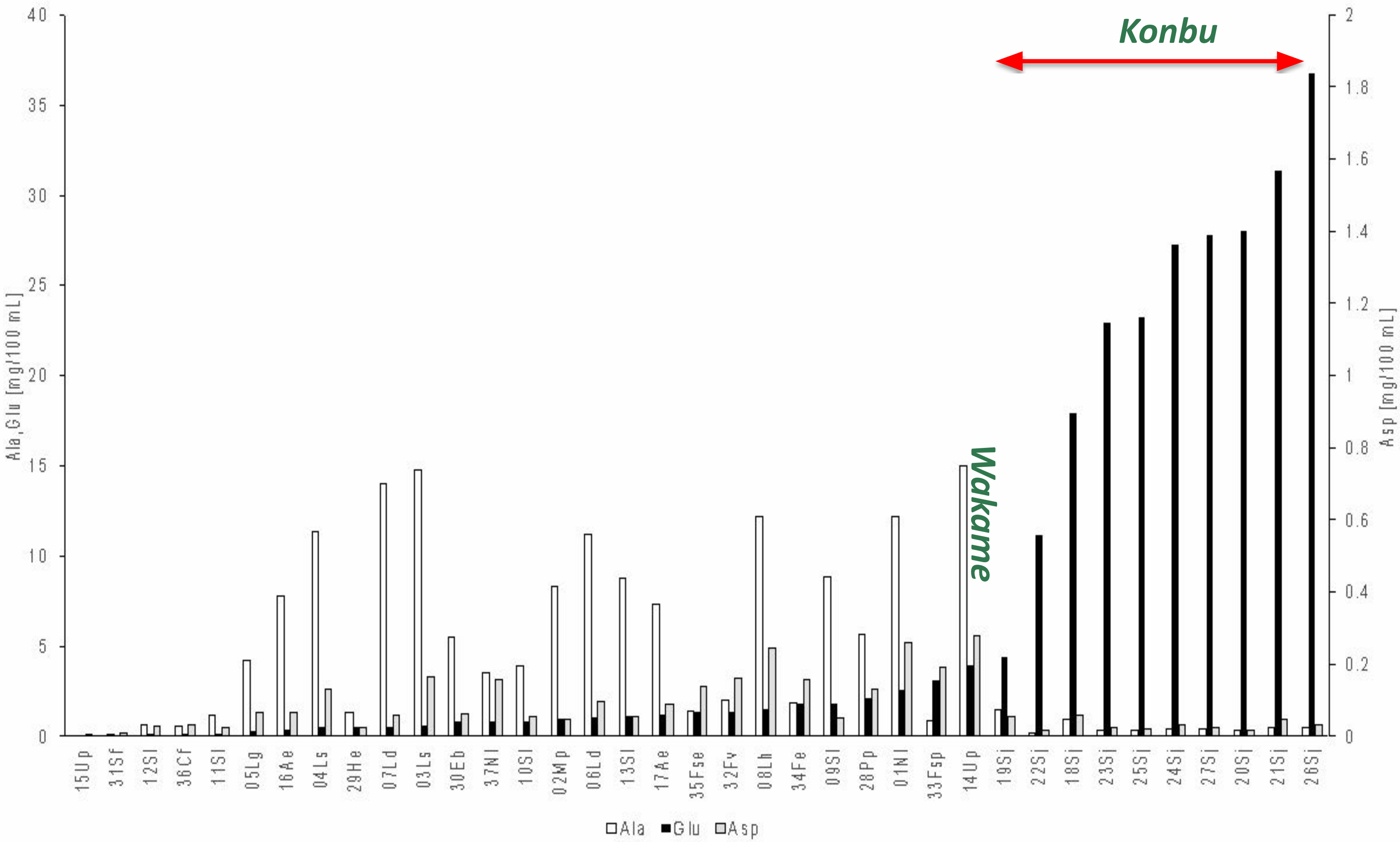


Umami taste, free amino acid composition, and volatile compounds of brown seaweeds (O. G. Mouritsen, L. Duelund, M. A. Petersen, A. L. Hartmann, and M. B. Frøst) *J. Appl. Phycol*. **31**, 1213-1232 (2019).

20 different brown seaweeds of 12 genera

Nereocystis, Macrocystis, Laminaria, Saccharina, Undaria, Alaria, Postelsia, Himanthalia, Ecklonia (former *Eisenia*), *Sargassum, Fucus,* and *Corda*

Dulse (*Palmaria palmata*): 10-40mg/100g (*dashi*)



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Chef
Klavs Styrbæk

Carrots with *konbu tsukudani*

Wild cabbage with bladderwrack and blue mussels in dashi

Chef
Klavs Styrbæk

Thank you

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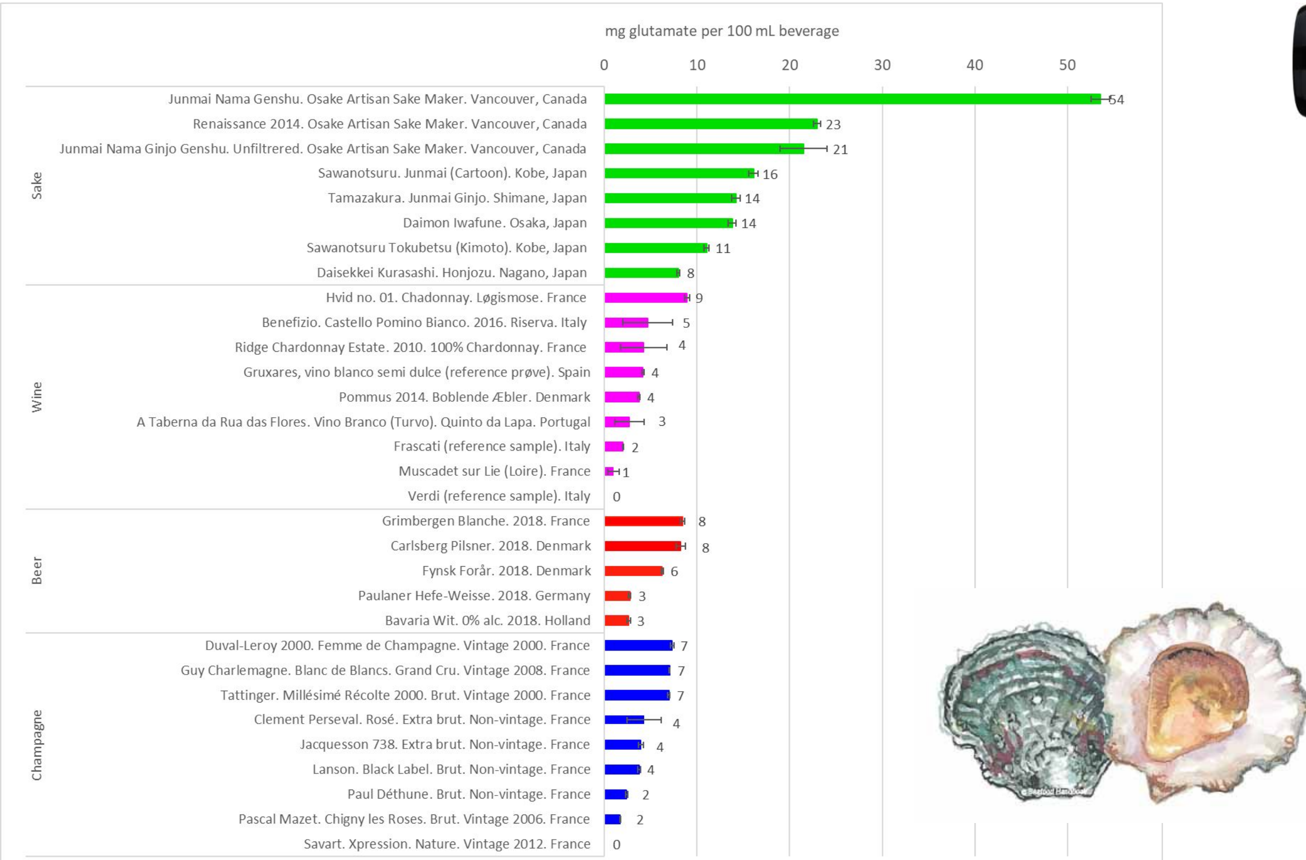
Fatty acid profiles of selected roe (cf. chicken eggs)

Fatty acid	Fatty fish Salmon (Vasconi et al., 2020)	Lean fish Cod (Vasconi et al., 2020)	Crustacean Norway lobster (Rosa et al., 2003)	Echinoderm Sea urchin (Cruz-García et al., 2000)	Cephalopod Sepia (Sykes et al., 2009)	Chicken egg (Frida, 2023)
C 12:0	-	-	0.15	-	-	0.0
C 14:0	3.44	1.47	1.8	11	2.8	0.31
C 15:0	0.54	0.30	0.69	-	-	0.0
C 15:1	-	-	-	-	-	-
C 16:0	10.63	17.59	18	20	25	24.2
C 16:1 n-5/7/9	4.83	4.89	8.3	3.2	2.3	2.28
C 16:2 n-4	0.14	-	-	-	-	-
C 16:3 n-3	-	-	-	-	0.45	-
C 16:3 n-4	0.85	0.08	-	-	-	-
C 16:4 n-3	-	-	0.074	-	-	-
C 17:0	0.51	0.25	0.63	0.18	1.7	-
C 17:1 n-8	--	-	1.0	-	-	-
C 18:0	4.76	2.83	3.4	3.3	9.2	9.0
C 18:1 n-9	18.25	12.50	27	2.0	3.1	42.5
C 18:1 n-7	2.85	4.25	5.7	3.0	2.2	1.89
C 18:1 n-5	-	-	-	-	0.51	-
C 18:2 n-7	-	-	-	-	-	-
C 18:2 n-6 (LA)	1.32	0.53	1.1	0.95	0.81	13.8
C 18:3 n-3 (ALA)	1.22	-	0.49	1.9	0.61	0.84
C 18:3 n-6	-	-	0.074	0.28	-	-
C 18:4 n-3	1.07	0.46	0.35	3.6	-	0.0
C 18:4 n-1	0.34	-	-	-	-	-
C 19:0	-	-	0.29	-	-	-
C 20:0	-	-	0.27	0.98	0.85	0.0
C 20:1 n-9/11	1.28	4.48	-	8.5	2.7	0.46
C 20:1 n-7	0.32	0.34	0.70	-	-	-
C 20:2 n-6	0.32	-	0.52	1.5	0.15	0.033
C 20:3 n-6	0.12	-	0.29	0.43	-	0.025
C 20:3 n-3	-	-	0.25	15	0.23	0.96
C 20:4 n-6 (AA)	1.42	3.07	2.0	2.7	3.5	2.1
C 20:4 n-3	2.51	0.12	0.59	-	-	0.0
C 20:5 n-3 (EPA)	15.41	17.80	7.7	16	15	0.013
C 21:5 n-3	-	-	-	-	0.07	-
C 22:0	-	-	0.09	-	-	0.086
C 22:1 n-11	-	-	0.63	-	0.0	0.0
C 22:1 n-9	0.19	-	0.28	3.7	0.0	0.0
C 22:4 n-6	-	-	0.14	-	0.11	2.05
C 22:5 n-3	5.56	1.90	1.3	-	1.4	0.042
C 22:5 n-6	-	-	0.38	-	0.62	-
C 22:6 n-3 (DHA)	22.04	27.14	15	2.5	27	0.16
n-3/n-6	15.14	13.20	5.6	6.7	8.6	0.13

Spices anyone?

Food-drink pairing



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